MINISTRY OF FINANCE, EGYPT.

SURVEY OF EGYPT.

NOTE ON THE AGE OF THE GREAT TEMPLE OF AMMON AT KARNAK

AS DETERMINED BY THE ORIENTATION OF ITS AXIS,

BY

F. S. RICHARDS, M.A., M.C.,

DIRECTOR, COMPUTATION OFFICE.

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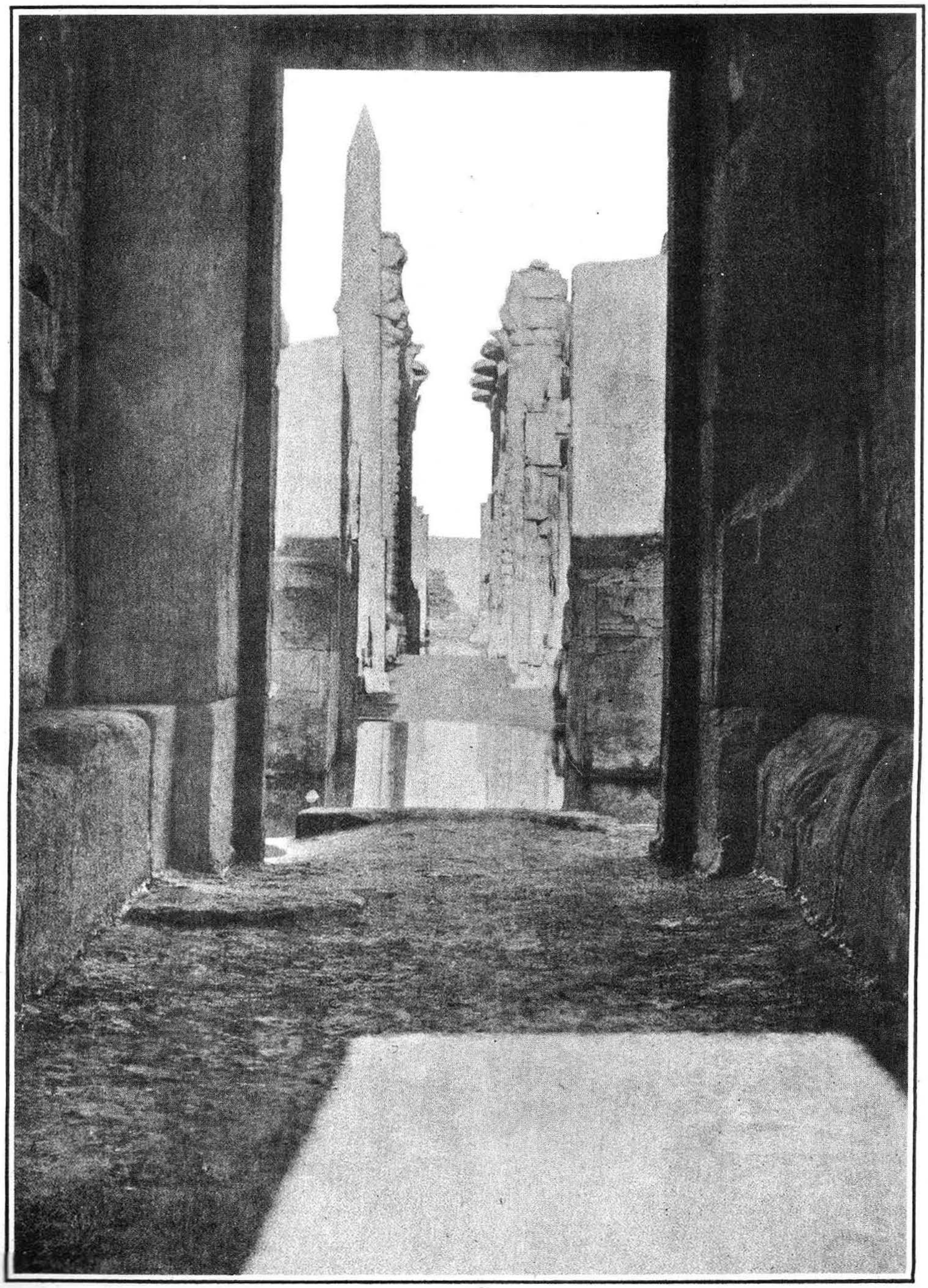
Plate V.

KARNAK TEMPLE.

The Axis looking West.

View from the Altar in the Sanctuary.



PREFACE.

The survey work upon which this report is based was undertaken in the early part of 1914 and the complete discussion and publication of the results were delayed by the war. The general map of the temple has been compiled from the survey of the Karnak site made by the late Mr. H. Skill in 1913 and 1914 and which has not hitherto been published. The names were kindly supplied by Mr. R. Engelbach, Chief Inspector of Antiquities, Upper Egypt, who also very kindly provided the photograph (Plate V).

L. B. WELDON,
Surveyor-General of Egypt.

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I.—NOTE ON THE AGE OF KARNAK TEMPLE.

In his book entitled "The Dawn of Astronomy" Sir J. Norman Lockyer suggests that the great temple of Ammon (or the temple of Amen-Ra) at Karnak was so laid out on the ground that the sun at the instant of setting at the time of summer solstice shone right down the axis of the temple and illuminated the sacred images reposing on the altar in the sanctuary of the temple. He says: "The whole object of the builder of the great temple at Karnak—one of the most soul stirring temples which has ever been conceived or built by man—was to preserve that axis absolutely open; and all the wonderful halls of columns and the like, as seen on one side or other of the axis, are merely details; the point being that the axis should be absolutely open, straight, and true.

"From one end of the temple to the other we find the axis marked out by narrow apertures in the various pylons, and many walls with doors crossing the axis.

"In the temple of Amen-Ra there are seventeen or eighteen of these apertures, limiting the light which falls into the Holy of Holies or the sanctuary. This construction gives one a very definite impression that every part of the temple was built to subserve a special object, *viz.* to limit the light which falls on its front into a narrow beam, and to carry it to the other extremity of the temple, into the sanctuary, so that once a year when the sun set at the solstice the light passed without interruption along the whole length of the temple, finally illuminating the sanctuary in most resplendent fashion and striking the sanctuary wall.

"These apertures in the pylons and separating walls of Egyptian temples exactly represent the diaphragms in the modern telescope."

He goes on to say: "Whatever view may be entertained with regard to their worship, these temples were constructed among other reasons for the purpose of obtaining an exact observation of the precise time of the solstice.

" The temples were the astronomical observatories. and the first observatories that we know of in the world."

Now the reason the sun does not rise and set in the same places every day is because the axis of the earth's rotation is not perpendicular to the plane of the earth's path round the sun. In fact the earth's axis is inclined at an angle of some $23\frac{1}{2}^{\circ}$ away from the perpendicular. It is this fact which accounts for the seasons of the year, the alterations in the lengths of day and night, and the different positions occupied by the sun at the times of rising and setting. This angle between the earth's rotational axis and the perpendicular to the earth's path round the sun is, of course, the same as the angle between the plane of the earth's equator and the plane of the ecliptic (or the earth's path) and is called " the obliquity of the ecliptic."

The mutual attractions between the other planetary bodies of the solar system and the earth have the effect of moving the plane of the ecliptic in space. This alters the obliquity of the ecliptic. This change in the obliquity is very gradual and has only amounted to half a degree (that is, the diameter of the sun) in the last four thousand years.

If then the sun at sunset at the summer solstice shone down the axis of the Karnak temple at the time the temple was built, it does not do so now because of the slow change in the obliquity of the ecliptic. Also, if we measure the direction in which the axis of the temple now points, and if we know what the obliquity of the ecliptic was during the past ages, we can then calculate the age of the temple by noticing the date at which the obliquity of the ecliptic was such that the sun would shine down the axis of the temple at the time of summer solstice. Further, since the sanctuary is the oldest part of the temple and the pylons on the west are of a considerably later date, the dates when these pylons were built can also be determined if we assume that they were centred slightly away from the original axis as laid down on the foundation of the temple so as to allow for the slight change that had taken place in the obliquity of the ecliptic between the date of the foundation of the temple and the building of the pylons. Sir J. Norman Lockyer noticed this change in the axis towards the west end, but he made no attempt to assign dates to the later parts of the temple: he confined himself to the date of the foundation of the temple.

From observations he had taken Sir J. Norman Lockyer determined the date of the foundation of the temple as 3700 B.C. These observations were taken in 1891, and the centre line of the temple could not be determined with the desired accuracy because of the débris, etc., which had accumulated along the axis.

The task of digging out the temple was, however, being undertaken by the Department of Antiquities, and in 1911 Mr. Howard Payn made further observations on behalf of Sir J. Norman Lockyer.

These observations were taken under considerable difficulties, and the axis of the temple was not completely cleared. In a letter dated October 11 and published in "Nature" of October 19, 1911, Mr. Howard Payn says: " The result of the survey in general quite confirms the data used by Sir N. Lockyer in fixing the date at which the original axis was laid down, *viz.* about 3700 B.C. "

When considering the effect of the altitude of the hills across the Nile Valley behind which the sun set, Mr. Howard Payn said his observations would " make the date of the foundation a little earlier, possibly . . . 4000 B.C."

In order to clear this matter up the Surveyor-General of Egypt agreed to have the necessary measurements made as soon as the axis of the temple had been cleared. Accordingly in April 1913 Mr. T. D. Scott observed the astronomical azimuth of the centre line of the sanctuary and measured the distances the centres of other doorways, pylons, etc., on the axis, deviate from this line.

The result of this survey showed widely discrepant values from those used by Sir N. Lockyer and gave an impossible date for the foundation of the temple.

So as to make quite sure of the facts it was consequently decided to make a complete survey of the axis of the temple from end to end. This was undertaken early in 1914 by Mr. P. G. Windsor, and the method adopted was as follows :—

Two intervisible points were taken, roughly in the axis of the temple, one on the old quay wall outside the temple to the west and the other on the window sill of the eastern wall of the sanctuary. By means of the theodolite, points were accurately lined in at all important points on the axis along this line, which was also extended right through the temple to its eastern extremity. A very accurate survey of the axis was then made off this line and plotted on scale

1 : 200, the actual dimension to the nearest half-centimetre being recorded on the plan. (Plate II.)

The azimuth of this line was then measured by Mr. D. R. Meldrum in March 1914.

Before discussing the conclusions that can be deduced from this survey it might be advisable to examine the accuracy of the work as far as is possible with the data at our disposal.

Referring to the general map (Plate I) the various doorways, etc., are numbered (1) to (18). Mr. Legrain pointed out to Mr. Scott the line (8) to (12) which defines the centre line of the sanctuary. Mr. Scott measured the deviations of the centres of the other doorways, etc., from this line. The table (p. 11) shows a comparison between Mr. Scott's survey and Mr. Windsor's survey. It will be seen that the greatest difference found between these two surveys is 33 millimetres, or just over an inch, so there can be no doubt as to the accuracy of the work.

As to the azimuth—

Mr. Scott's observed azimuth was 296° 53′ 57″ clockwise from south for the line (8) to (12).

Mr. Meldrum's observed azimuth for the line of Mr. Windsor's survey was 297° 4′ 31″ clockwise from south.

Referring to Mr. Windsor's plan the difference between these two lines is 108 millimetres in 35·46 metres.

The angle whose tangent is 108/35460 is 10′ 28″, so referring Mr. Meldrum's azimuth to the line (8) to (12), we get its value 296° 54′ 3″ which is exactly confirmed by Mr. Scott's observed value because it must be remembered that a difference of one millimetre in the identification of the centre of one of the doorways would make a difference of 6″ in the azimuth.

Being quite sure that the survey and the observed azimuths are correct, we can now proceed to discuss the conclusions to be deduced from them.

The vertical angle to the hills on the west of the Nile along the axis of the temple was observed by Mr. Skill in June 1913. The observed value was found to be 2° 36′ 38″. The instrument was placed 1·10 metres west from the altar in the granite chapel in the axis of the temple and the height of the axis of the instrument was 1·52 metres. The instrument was placed so as to be about the same height as the sacred images placed on the altar. No correction for height of instrument is thus needed. This value also agrees very closely with the vertical angle adopted by Sir N. Lockyer.

The problem of finding the age of the temple can now be tackled. Firstly we must find what the declination of the sun must be so as to shine straight down the temple axis at the instant of sunset at the time of summer solstice. This is a simple matter of computation when the azimuth of the axis and the angular height of the hills behind which the sun sets are known. The formula is:—

$$\sin \delta = \sin h \sin \varphi + \cos h \cos \varphi \cos A$$

where h is the angular height of the hills,
φ is the latitude,
A is the azimuth of the temple axis measured from north, and
δ is the declination of the sun it is required to find.

There is no reason to suppose that the *latitude* of Karnak has altered since the foundation of the temple, so it is taken as 25° 43′ 5″ N. which is scaled from the Survey of Egypt 1 : 50,000 map. For the *azimuth*, as it is the date of the oldest part of the temple we require, we take Mr. Scott's observed azimuth of 63° 6′ 3″ W. of N. For the *vertical angle* of the hills behind which the sun set, the vertical angle observed was 2° 36′ 38″ elevation. The observations were taken at 11 a.m. on May 27, 1913, with an observed temperature of 89° F. and a pressure of 752 millimetres deduced from neighbouring stations. The distance to the hills is about eight kilometres. From experiments conducted at Helwân Observatory in 1909, the value of the terrestrial refraction on a line fourteen and a half kilometres long across the Nile Valley was found not to change by more than 15″ between 11 a.m. and sunset. Since the terrestrial refraction varies as the square of the distance, the change in the refraction between 11 a.m. and sunset in a line eight kilometres long would not be as much as 5″. Thus no correction is made for instrumental and refraction errors, and the value 2° 36′ 38″ for the vertical angles to the hills at sunset at the time of the summer solstice is adopted.

The Director, Meteorological Service, Ministry of Public Works, deduces the pressure and temperature at Luxor at sunset at the time of the summer solstice to be 749 millimetres pressure and 33° C.

temperature. These values differ from those observed at the time when Mr. Skill's vertical angle was taken by an amount which would only alter the astronomical refraction by 5″. Consequently it is thought best to take Mr. Skill's value for pressure and temperature when computing the astronomical refraction. These also are the most logical values to take, as any error in the refraction is more likely to be eliminated than not by using these values.

The following values for the astronomical refraction for an altitude 2° 36′ 38″, with pressure 752 millimetres = 29·6 inches and temperature 89° F. = 31·7° C., are obtained.

Jordan	14′	10″
Chauvenet	14′	30″
Hints to travellers	14′	42″
Close	13′	58″

A mean value of 14′ 20″ is accordingly taken. If we assume hat the time the sun shone down the axis was the exact instant its centre touched the horizon the vertical angle need not be corrected for semi-diameter but only for parallax.

The following corrections are therefore applied to the vertical angle :—

Vertical angle observed		2°	36′	38″
Correction for refraction	−		14′	20″
		2°	22′	18″
Correction for parallax of sun ...			+	9″
Vertical angle for computation ...		2°	22′	27″

The computation is as follows :—

		Natural.
Log sin h =	$\bar{2}$·6172643	
Log sin φ =	$\bar{1}$·6374327	
Sum ...	$\bar{2}$·2546970	0·0179762
Log cos h =	$\bar{1}$·9996271	
Log cos φ =	$\bar{1}$·9546960	
Log cos A =	$\bar{1}$·6555435	
Sum ...	$\bar{1}$·6098666	0·4072552
	Sum ...	0·4252314

$\therefore \delta = 25^\circ\ 9'\ 55''$

This then is the necessary declination of the sun or what is the same thing the obliquity of the ecliptic for the sun to shine down the temple axis. From this we are to determine the age of the temple.

Simon Newcomb gives this formula for the obliquity of the ecliptic ($=\omega$) :—

$$\omega = 23^\circ\ 27'\ 8''\cdot 26 - 46''\cdot 845\ T - 0''\cdot 0059\ T^2 + 0''\cdot 00181\ T^3$$

where T is the time measured from 1900·0 in solar centuries.

This also is the formula given in the Nautical Almanac, 1918, page 591.

A similar formula is given in the Encyclopædia Britannica for the epoch 1850, which reduces to this one when T is put equal to 0·5.

From this formula the following table is given by Newcomb :—

Year.		Mean Obliquity of Ecliptic.		
B.C.	2500...	23°	58′	44″·00.
	2000...	—	55′	38″·99.
	1500...	—	52′	23″·10.
	1000...	—	48′	57″·70.
	500...	—	45′	24″·14.
	0...	—	41′	43″·78.
A.D.	500...	—	37′	57″·97.
	1000...	—	34′	08″·07.
	1500...	—	30′	15″·43.
	2000...	—	26′	21″·41.
	2500...	—	22′	27″·37.

These values are plotted in Figure 1.

It is also stated in the Encyclopædia Britannica that "for dates more than three or four centuries before or after 1850 the result is necessarily uncertain by one or more tenths of a minute."

Substituting in the formula we get the obliquity of the ecliptic for the year 4000 B.C. to be :—

$$\omega = 24^\circ\ 6'\ 39''\cdot 6.$$

This we see differs by more than a degree from the required obliquity to make the sun shine down the axis at 4000 B.C., which is about the time of the supposed foundation of the temple. We also see that since 4000 B.C. up to the present day the obliquity of the ecliptic has only decreased by some 40′.

Also, if the sun shone down the axis of the temple at the date of its foundation it has since decreased by more than 100′, which would give a ridiculous date for the foundation of the temple.

The true to scale Figure 2 showing the different pylons at Karnak as seen from the inner wall of the sanctuary and the position of the setting sun at different epochs illustrates the impossibility of dating the foundation of the temple from astronomical methods better than mere words.

In order to test this theory and to detect any possible error in the survey and deductions, Mr. Skill went to Karnak at the time of summer solstice in 1913 and observed the sunset from the sanctuary. He found that the sun was not visible at all along the axis, being completely hidden by the southern half of the first pylon. He measured the opening of the pylon, which is $1^\circ\ 37'$ as seen from the sanctuary. Consequently the centre of the sun as it set was at least $64'$, that is $48'$ (half the angle of the opening) $+ 16'$ (the semi-diameter of the sun) south of the centre of the doorway of the first pylon as seen from the sanctuary. This entirely confirms the fact that never since the great temple of Karnak was built has the sun ever shone straight down its axis.

With regard to the possibility of dating the later pylons of the temple to the west of the sanctuary from their deviations from the original axis of the sanctuary it is seen at once from the table (p. 11) that points (1) and (2) are the only two that deviate seriously from the axis of the sanctuary and that these deviate to the north of the line. By the gradual change in the obliquity of the ecliptic the sun has been moving south since the original foundation of the temple, so we should expect the later parts of the temple to deviate south of the line of the original axis. Pylon I is known to be of later date, and it actually deviates to the north, so there is little doubt that the deviation was not deliberately made to correct for the change in the obliquity of the ecliptic since the original foundation of the temple.

There is thus no reason to suppose that the temple of Amen-Ra at Karnak was originally laid down to have any relation whatever with the position of the setting sun at the time of summer solstice.

II.—NOTE ON THE ACCURACY OF THE DATE OF FOUNDATION OF THE TEMPLE AS DETERMINED BY THE POSITION OF THE SUN IN THE HEAVENS AT THE TIME OF ITS FOUNDATION.

The formula is :—

$$\sin \delta = \sin h \sin \varphi + \cos h \cos \varphi \cos A.$$

The latitude φ can be accurately determined to $1''$ of arc and will therefore be taken as errorless.

The altitude h can be measured to about $5''$ of vertical angle. but the astronomical refraction cannot be determined nearer than to about $20''$. Assuming that the mean atmospheric pressure and temperature have not seriously altered in six thousand years and so can be determined within very close limits, there are still differences up to $40''$ in the astronomical refraction as given by various authorities, so the vertical angle h as taken is liable to an error of $20''$.

The azimuth A can be measured to $5''$ and we are quite sure we have got it correct, but the centres of the various doorways cannot be determined to nearer than to one centimetre on account of weathering. The line (8) to (12) is some 35·5 metres long and one centimetre on this distance gives $58''$. The azimuth of the axis of the sanctuary is thus liable to an error of $1'$ on account of weathering of the doorways.

Differentiating the formula we get :—

$$\cos \delta \frac{d\,\delta}{d\,h} = \cos h \sin \varphi - \sin h \cos \varphi \cos A,$$

assuming A to be constant,

$$\text{or } \cos \delta \frac{d\,\delta}{d\,A} = - \cos h \cos \varphi \sin A,$$

assuming h to be constant.

In this case $\dfrac{d\,\delta}{d\,h} = 0{\cdot}46$

and $\dfrac{d\,\delta}{d\,A} = - 0{\cdot}89.$

So that an error of 20″ in the vertical angle makes an error of 9″ in the declination and an error of 60″ in the azimuth makes an error of 53″ in the declination.

Referring to the formula we see that in 4000 B.C. the declination of the sun was changing at a rate something like 140″ in five hundred years.

Thus an error of 20″ in the vertical angle would alter the date of the foundation of the temple by thirty-three years and an error of 1′ in the azimuth would alter it by a hundred and ninety years.

We thus see that it is impossible to determine the date of the foundation of the temple to nearer than a hundred years by these means and that I believe is not as accurate as the date is already known by purely archæological methods.

Besides it must not be forgotten that precise astronomical observations have not been taken for more than two hundred years, and even with the aid of recorded eclipses in ancient records, the obliquity of the ecliptic six thousand years ago is not known within an amount which would give greater accuracy to the date of the foundation of the temple than purely archæological methods.

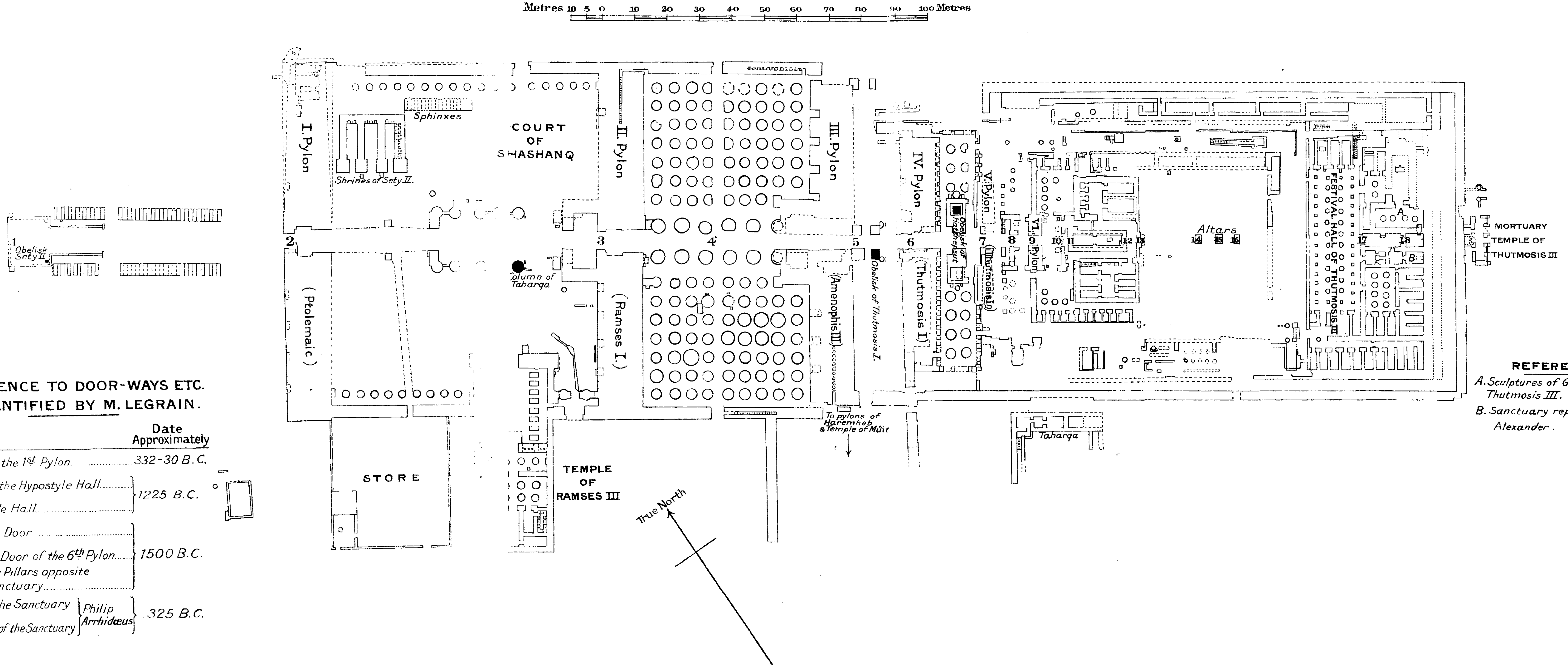
III.—A COMPARISON BETWEEN THE SURVEYS OF Mr. SCOTT AND Mr. WINDSOR.

Point.	Mr. Windsor's Survey.					Mr. Scott's Survey.	
	Distance along the Axis West to East.	Distance Perpendicular to the Line		Distance Perpendicular to the Line 8-12.		Distance Perpendicular to the Line 8-12.	
		North.	South.	North.	South.	North.	South.
	Metres.	Metres.	Metres.	Metres.	Metres.	Metres.	Metres.
(1)	0	0·325	—	1·375	—	1·400	—
(2)	85·27	—	0·018	0·772	—	0·690	—
	97·00	—	0·100	0·656	—		
(3)	182 30	—	0·350	0·145	—	0·127	—
* (4)	218·00	—	0·270	0·116	—	0·118	—
* (6)	277·00	—	0·210	—	0·004	—	010
* (7)	300·00	—	0·070	0·066	—	0·075	—
(8)	307 99	—	0·112	0·0	—	0·0	—
* (9)	316·00	—	0·700	0·018	—	0·027	—
(10)	322 69	—	0·100	—	0·033	0·0	—
(11)	325·83	—	0·015	0·043	—	0·043	—
(12)	343·45	—	0·004	0·0	—	0·0	—
(13)	346 70	0·020	—	0 014	—	—	0·015
(14)	364·80	0·105	—	0·044	—	0·030	—
(16)	376·93	0·175	—	0·077	—	0·080	—
(17)	415·48	0·0	—	—	0·215	—	190
(18)	428 50	0·020	—	—	0·235	—	255

* These points do not depend on a single measurement but are the means of two or more accordant measurements.

THE GREAT TEMPLE OF AMMON AT KARNAK

Scale 1:1,000



REFERENCE TO DOOR-WAYS ETC.
AS IDENTIFIED BY M. LEGRAIN.

Nº		Date Approximately
2 Door of the 1st Pylon		332-30 B.C.
3 Door of the Hypostyle Hall		1225 B.C.
4 Hypostyle Hall		
8 Granite Door		1500 B.C.
9 Granite Door of the 6th Pylon		
10 Granite Pillars opposite the Sanctuary		
11 Door of the Sanctuary	Philip Arrhidæus	325 B.C.
12 Window of the Sanctuary		

REFERENCE

A. Sculptures of Garden of Thutmosis III.

B. Sanctuary repaired by Alexander.

Reproduced by the Survey of Egypt (20/855). 1932, (32/362).

THE AXIS OF THE GREAT TEMPLE OF AMMON AT KARNAK

SCALE 1:500

Metres 10 0 10 20 30 40 50 Metres

REFERENCE

Points on chain line (Small round irons fixed in cement .... D

Granite ....

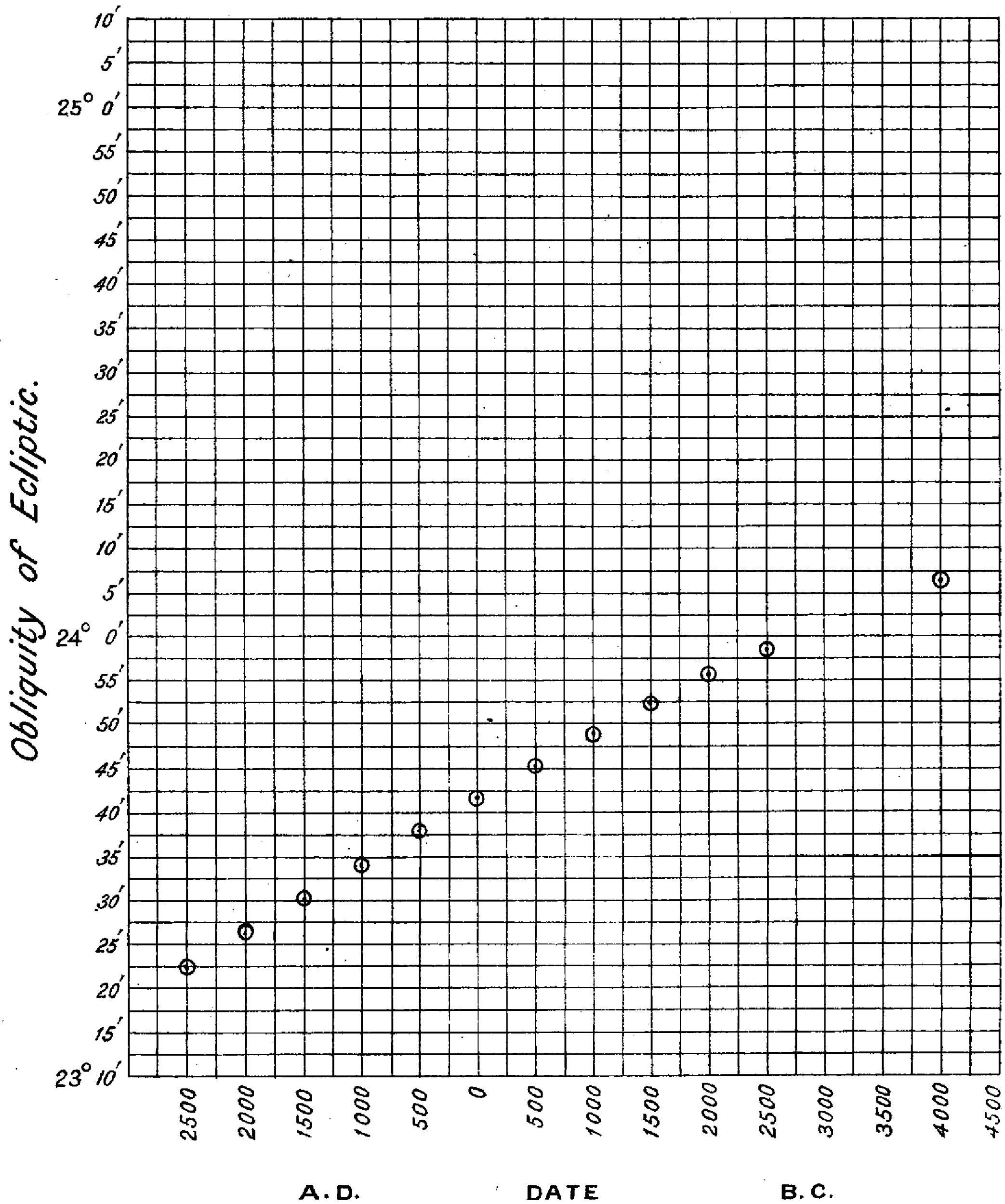
Points corresponding to those on Plate I. .... ②

Ill-defined detail ....

Reproduced by the Survey of Egypt 20/865. 1932, (32/362).

Fig. 1

Showing the obliquity of the ecliptic at various dates as given by Simon Newcomb



Printed by the Survey of Egypt, 1920. (20/865). 1932, (32/362).

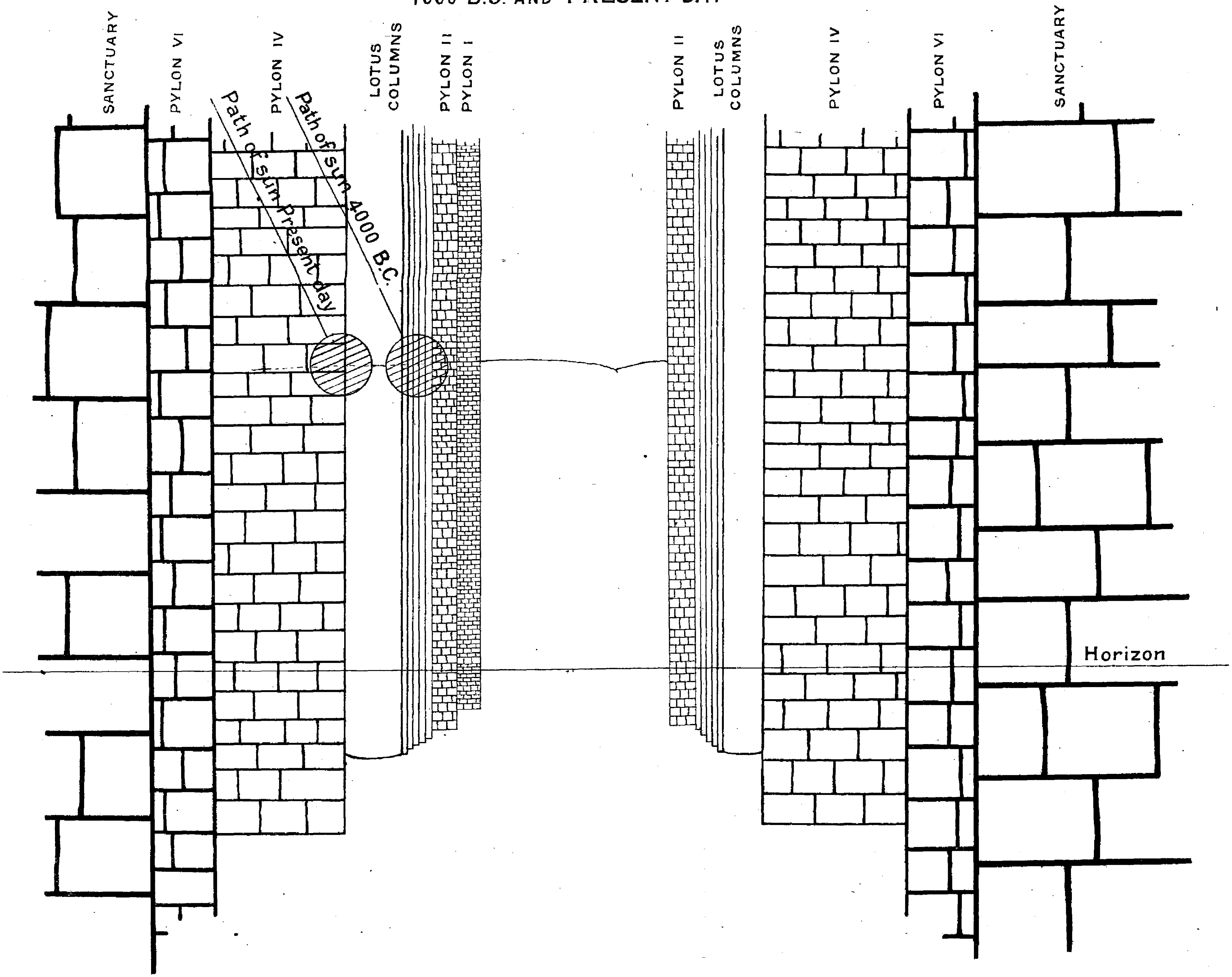
Figure II

DIAGRAM OF KARNAK TEMPLE

As viewed from the eastern end of the Sanctuary

Showing the position of the setting sun at the summer solstice

4000 B.C. AND PRESENT DAY



S. of E. 20/865. 1932.(32/362)