

Piedras Negras Preliminary Papers~~✓~~

No.

STONE VAULTING AT PIEDRAS NEGRAS

with an Appendix on

A Cross Section in Court 1 of the Acropolis. 3

by  
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STONE VAULTING AT PIEDRAS NEGRAS

With and Appendix on a Cross Section in Court 1 of the Acropolis.

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1559	July 18 -	
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	155	

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Table 1

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Mar 1, 1592 = full moon (do. New Year.)

Mar 1 : Feb 14, = new moon.

11.16.2.6.7 = Feb 24  
+ 9

11.16.2.6.16 = Mar 1 (Moon)

360 | 94900 | 26

720  
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365 | 94900 | 260

730  
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2190  
3

2290 681

2283 481

7200

2.7.2

18  
28  
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Feb 13, 1520

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May 30  
Jun 31  
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Oct 31

260

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Stephanos, 1539

Murby Oct 31, 1539

13 days diff.

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## STONE VAULTING AT PIEDRAS NEGRAS

The distribution of stone vaulting for roof construction in the New World is so contiguous, and so commonly associated with Maya glyphic writing, that it has received the specific appellation "Maya Vault". There are, however, a great many other traits of fundamental importance in Maya culture which, at the time of the Conquest, were or had been in use outside of the Maya area. Within the realm of architecture, the use of lime mortar and plaster, of stone walls, of terraced pyramidal substructures, of grouping about courts and plazas, and of painted and sculptured decoration may be mentioned, to illustrate the accepted fact that a common base underlies both the Maya and non-Maya high cultures of Middle America, or that one partially derives from the other. Why the vault is limited to Maya buildings and apparently absent in the others which have fundamentally so much in common is an important problem, and definite facts regarding vaults at Key Sites should help to elucidate it.

The Three Eldridge R. Johnson Expeditions to Piedras Negras, the first two under the direction of Dr. J. Alden Mason, the third of the writer have accumulated considerable data on vaulted and non-vaulted buildings at that side. Some of this information appears to have a bearing on the uses, development and chronology of vaulting at this city and forms the subject of this report. Its value in the general study of the vault can be made more certain by future work at Piedras Negras, but will be especially enhanced when detailed comparisons with other cities are made. To some extent these are possible with existing publications, but are not attempted here.<sup>1</sup>

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<sup>1</sup> Vaillant discusses vaults at Holmul and publishes a plate of vault

sections from a number of sites in Merwin and Vaillant "The Ruins of Holmul", Peabody Memoirs, Vol 3 No 2, Cambridge, 1932;

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The study of Usumacinta architecture at Piedras Negras is severely limited by the badly ruined condition of its surface buildings. In only a few cases can we say anything about the upper zones and roofs, and even the medial cornice is missing on most. On the other hand the exceptionally long series of known hotun markers at the city, the earliest 9.4.0.0.0 and the latest 9.18.5.0.0 or later, make what is left of great chronological value, if we are able, in the end, to correlate buildings with monuments.

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Readings of dates are from an unpublished list kindly supplied by Dr. Sylvanus G. Morley of the Carnegie Institution of Washington.  
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The reduction of buildings to mounds has its minor advantages. We should be able to learn what types of mounds are left by what types of fallen buildings, and to use this information for comparative studies at unexcavated site. And we are more free to make incisions in what remains of the buildings, and in substructures, in order to obtain data on methods of construction, building sequences, Etc., with a minimum of labor and expense. But it has thus far been impossible to take full advantage of these circumstances for lack of funds sufficient to move large quantities of debris.

In response to the various factors enumerated above, especially the last, our plan in general (still far from completion) is to excavate completely one or two samples of each type of building which can be determined as a type from surface observation; and to trench transversely and so obtain cross-sections all or at least a considerable number of the balance of each type.

The latter expedient has been applied to substructures to a limited extent, with gratifying stratigraphical results. We have not as yet been able to clear the surfaces of substructures sufficiently to justify complete theoretical restorations, except in one instance. (Structure R-3) This must, of course, be done before our picture can be anything like complete, but involves a larger laboring force than we have as yet had at our command. Needless to say, bush clearing and surveying followed by the drawing of a map of the city, with ground plans of all building walls above the surface, is the basis for classifying the mounds.

The map as it stood in 1932 has been issued with our Preliminary Paper No. 1, and on it are located all the surface structures referred to in this paper, with ground plans of many of them. The map has since been greatly extended in all directions, and it is now quite certain that the three principal ceremonial groups - South, West, and East - are surrounded by low-mound areas, probably for the most part domiciliary in function.

With few exceptions duly noted, we believe we have reliable cross-section data on all the surface buildings of the city which were stone vaulted, and on a lesser number which were not. The information is collected in a number of tables at the end of the paper, ready for use in comparisons with other sites.

This information is arranged from the point of view of convenience in analysis at this site. Within each unit of the tables, buildings are arranged according to the ratio of wall thickness to room width, the heaviest buildings first, the lightest last. This is an arbitrary arrangement except in the group of Table 1-A, where we will try to show that the arrangement has historical significance.

Thirty-three separate building operations are represented, though in a few cases one building became part of a later one.

From an analysis of the information respecting these buildings, we offer four tentative hypotheses respecting stone vaults at the city; as follows:

1. Stone-vaulted roofs were here confined to buildings of ceremonial use, and to so called palaces which, if residential buildings, were of very special and uncommon design.

2. Buildings of major and minor ceremonial importance (pyramid temples and platform "Shrines") and so-called palaces were also constructed with roofs on perishable supports, presumably flat beam and mortar or peaked thatched roofs.

3. The Palace Group shows difference in skill or engineering knowledge in vault building, or both, with chronological implications. The advance resulted in lighter walls and wider chambers.

4. The stone vault did not here appear until a considerable time after the founding of the city, and was introduced from without.

These hypotheses rest to a large extent on the assumption that we are correct in calling large numbers of mounds non-vaulted from surface examination only. A discussion of our criteria for recognizing completely fallen vaults forms the first part of the paper. Next we take up our four main points. Finally, since none of our deep cuts into substructures has been reported upon, we append an abbreviated account of one of these which provides us with a stratification of vaulted buildings over a certain non-vaulted one and several others which may have been non-vaulted.

Data given in the tables from the buildings of Structures K-5-1st, K-5-3d, O-12, O-13 and P-7 is supplied by Dr. Mason, who excavated them personally, while the writer is responsible for the others.

Criteria for Recognizing Completely Fallen Stone Vaults

In Table 1 at the end of the paper are listed, with two exceptions, all of the known "double-range" vaulted buildings of the city and two non-vaulted examples of the same fundamental type. By double -range we simply mean that there are a front and a rear room, or front and rear ranges of rooms, the rooms of each range being placed end to end if vaulted. The vaults run from side to side of the building, that is end to end of the rooms, the inner halves of each vault being one continuous mass balanced on the single medial wall which separates the rooms or ranges of rooms. A cross section through this type is shown in Plate 1, Structure J-9, where parts of the vaults are still standing. Structure U-3, in the same plate, is double ranged, but without vaults. All of the buildings of this type are "free-standing", that is, rear as well as front walls rise directly from the basal plinth, and, like the front, must themselves resist any side thrust from the roof. "Double-range" does not imply anything as to relative length of the building, though most, but not all, are quite long; nor anything about the ground plan other than the presence of two rooms or two lines of rooms, one behind the other, with parallel longitudinal axes, separated by a medial wall. There may be (and generally are) additional transverse rooms at the ends, which we have disregarded in this discussion.

The only double ranged structures that we have investigated which are not included in Table 1 are the outer chambers of Structure P-7, and the two rear rooms of Structure O-13, which will be found in Table 5. These will be discussed separately, later on.

In Table 2 are listed supposedly vaulted free-standing single-range buildings, and five supposedly non-vaulted free-standing single-range buildings. Single range simply means that there is no rear room

and therefore no midial wall. "Free-standing" again means that the rear wall stands free of surrounding constructions, like the front wall. Nothing is implied as to size. We have not encountered any free-standing single-range buildings of more than one room, but there might be such under our definition, so long as the rooms were placed end to end.

The distinction we have in mind between "single-range" and "double-range" is a structural one. In the first case the roof is supported on two parallel walls, in the second on three.

Table 2 includes all known or suspected free-standing single-range vaulted buildings with the following qualifications: Structure J-29 on the Northeast Section side of the Acropolis is a false pyramid and the debris indicates one or possibly two vaulted buildings on it, neither of which have been investigated; we suspect that Structures O-4 and R-13 in the South Group, S-2 and S-4 in the Southeast Section, and a mound about 100 meters northeast of Structure E-1 in the Northeast Section were vaulted. All are very small.

Table 3 includes eight vaulted single-range buildings which are not "free-standing". Structure J-6, Room 3, is an example of this, and is illustrated in cross-section in Plate 1. The rear wall of the room is also the retaining wall of a great mass of fill behind it, marked 1 on the plan. This peculiarity which we style "build-on" is apparently an adaptation to topographical necessities - it results from the position of the building - but it has structural influence, and affects the character of the mound resulting from its collapse, therefore the type must be considered separately.

Since we know of no "built-on" non-vaulted buildings we will use only the buildings of Tables 1 and 2 in looking for differences in the debris of vaulted as opposed to non-vaulted buildings. First we

should say that specially cut boot shaped stones, which absolutely prove the presence of a fallen vault in many buildings of northern Yucatan, were not used here and so will not help us. Also, the exposed sides of the facing stones were practically never beveled to conform to the slope, so that this assistance is likewise denied us. There are, however, four classes of evidence to look for.

### CAP STONES

Cap Stones in the debris of the two completely cleared palaces (Structures J-2 and Room 3 of J-6) showed plainly that there at least these were specialized and recognizable. They are recognizable in photographs of J-9 and K-5. They are long and often narrow, fairly heavy slabs. They can be recognized by their length (70cms to 1m) plus the artificial straightening of both edges by hammering off small bits at a time, obviously in order to get a fairly straight edge and a fairly good fit with the stone against which it was placed. Plaster marks indicating the exposed portion have not been found preserved. We have miserably neglected our opportunity to definitely establish this criterion by recording it wherever found. Most cap stones are broken in falling so that size alone will not distinguish them, and the chipped edges must be looked for, especially in those cases where we depend on a mere test trench. There is little doubt that these specialized stones occurred in all the vaulted buildings, but before we say they must be present in all vaulted debris, we must check up our supposition which, in most cases, is still possible. It is quite certain that they were not found in any of the buildings listed in our tables as non-vaulted.

### Vault Slabs

By "slab" we mean a stone which is long and wide in relation

to its thickness. It is a piece split off from thin strata of the limestone. Fortunately for our present problem, slabs are universal in vault construction and quite scarce in most vertical walls. These are the equivalent of the boot-shaped stones of Yucatan. Every vault of which we know anything at Piedras Negras is faced with the edges of relatively thin slabs, laid horizontally in mortar, one above another but each slab extending a little beyond the one below it to give the vault slope. Where examined, the vault hearting consists of slabs and slab-like blocks more carelessly laid, with a great deal of mortar. Portions of this type of vaulting have been observed in position on all the vaulted buildings noted in Table 1, and a fragment of such a vault was found on the floor of Str. R-5, in Table 2. We have absolute proof, then noted in Column P, that all the buildings given in Table 1, and which we list as vaulted, really were so, and that the vaulting facing was in each case of the slab variety. This is the general Usumacinta type referred to by Pollock as characteristic also of the Old Empire buildings at Coba.

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In a collapse the cap-stones and vault facings, which are made up of slabs, must of necessity fall directly to the floor. The debris of a fallen vaulted building must, at the bottom, consist very largely of fallen slabs, many of which are in direct contact with the floor.

Reference to Column O of Tables 1-A, 2-A and 3-A will show that a profusion of stone slabs was noted in the debris of every building known by other positive criteria (usually standing remnants of vaults) to have been vaulted. The only exception is Structure J-6-2nd, where the debris was removed in aboriginal times. Further, such a profusion was

X

absent in all the cases listed as non-vaulted. This test is usually conclusive in itself. But if there <sup>are</sup> only a few slabs, a border line case may be presented, because slabs in some quantity enter into the construction of some vertical walls. We have encountered only two cases which we considered doubtful on this account. Both structures I-17 and R-3 are considered non-vaulted when this criterion is considered with the others.

#### Quantity of Debris

The third factor is the quantity of debris as measured by its depth on the floor of the building. Maler applied this test to a Yaxchilan building, remarking that, "a broken-down stone roof always leaves a large heap of ruins." Maler, Teobert, Researches in the Central Portion of the Usumatsintla Valley, Peabody Museum Memoirs, Vol 2 No. 2, p. 120, Cambridge, 1903.

Columns L and M of Tables 1 and 2 give respectively the maximum and minimum depths of debris on the floors of all buildings now under consideration, while Column N gives the average of these two measurements, the latter gives an index of relative quantity of debris on the floor. For a given figure in this column the obsolete quantity will vary directly with the width of the room. We do not take the obsolete quantity into consideration, nor do we think it would effect our conclusions.

#### -Preliminary Considerations-

Debris and standing walls tend to be higher near the ends of buildings, and accordingly all sections are cut a sufficient distance from the ends to avoid this confusing circumstance. In each case they are cut near an outer doorway, but not through it. All depth measurements are made within the room - never between the jambs of a doorway.

In double-range buildings we use measurements from only one of the rooms. In all cases reflected in our tables with the single exception of J-9, the outer wall or pier is badly fallen at the point measured. In all double-ranged vaulted buildings, the quantity of debris in the room not measured is about the same in the

room given, except for J-9 and J-11. In both of these cases the difference is caused by absence of doorways in the room not measured at the point of our section, and consequent higher standing walls. At other points on both buildings, where outer doorways occur in the other rooms, approximately identical results would have been obtained. The rear room of Stv. U-3, which is non-vaulted, contains more debris than the front, which we give in the table. This again probably results from the presence of two wide outer doorways in the front room, and none in the rear. This difference confirms the advisability of selecting sections near doorways for purposes of comparison.

These measurements must not be taken too literally, of course. They are taken where our trenches happened to be placed, and would vary slightly at other points. And in a few cases we failed to measure and had to estimate from photographs and known heights of standing walls. Such approximate dimensions are marked with an asterisk, and we believe the probable errors of all are within the actual variations of debris depths themselves.

Two or three cautions are to be observed in using these tables comparatively. A free-standing double-ranged vaulted building - that is, one consisting of two parallel vaults through which the cross-section passes - is expected to have a deeper deposit of debris than a single-ranged building, other things being equal. This is because, in the first case, in falling, the medial wall is protected on both sides by the debris. Equal side thrusts from the vaults meet and neutralize themselves and the center, causing an equilibrium of forces which tends to preserve the medial wall to a height greater than the outer walls. See the cross-section in Plate 1, structures J-2 and J-11. Stated in another way, when standing, each vault exerts a certain front and rear force. At the center, one thrust neutralizes the other, and the inner half of each vault may be expected to drop more or less vertically to the floor. On the other hand, the outer halves may be expected to fall at an angle, much of the debris landing outside, rather on the ruin of the building, a relatively large part of outer walls being knocked off in the process. At points where the vaults are completely fallen, this condition has been observed on every one of the vaulted buildings in table 1, at points where the outer walls were weakened by the presence of

outer doorways.

The medial wall is preserved to a height greater than the outer walls or piers, irrespective of the presence of medial wall doorways; the maximum depth of debris is at the medial wall, the minimum at the outer walls, and much vault and wall material is found outside of the outer walls.

In the case of a single-ranged vaulted building, there is no opposition of forces at the center. Both walls are outer walls and both are subjected to outward thrust. They are therefore preserved only to heights comparable with those of the outer walls of double-range buildings, which are distinctly lower than preserved heights of medial walls. See Sections of Structures R-5 and J-4, Plate 1. And considerable parts of both halves of the single vault fall outside the building. The minimum height of debris would therefore be expected to approximate the same measurements on double ranged buildings, but the minimum (and therefore the average,) should be less. Figures for vaulted buildings in Tables 1 and 2 reflect this conditions (column L, M and N.)

To sum up, a greater proportion of the vaulting, of the roof it supported and also of standing wall material, should remain on the floors of a double-range vaulted building as compared with a single range vaulted building/ and with the latter, maximum and minimum depths should be more nearly equal.

Therefore, from the point of view of depth of debris, in checking supposed non-vaulted buildings against known vaulted ones, double-ranged buildings are to be compared with each other, and single-ranged buildings with each other, but not a single-ranged building with one of double range.

The above remarks are based on "other things being equal." This ~~is~~ of course may not always be the case, and should be allowed for if possible.

Former roof-combs would of course add to the depth of debris. This does not affect comparisons for determining non-vaulted structures however. The added depth confirms the presence of a vault, rather than the reverse, and we are surely safe in assuming that stone roof combs were not erected on wooden-supported roofs.

With very great variations in actual room width might make a difference

Fortunately, an analysis of Table 1 which covers strictly comparable buildings, indicates that the wider the room, the greater is the maximum debris depth, and to a lesser extent, the greater the average. Use Columns L, M, and N. Compare the last three with the first four buildings in that table, probably a wide room means a high vault, and therefore more material in the vault.

In the case of single-ranged free-standing vaulted buildings, if one wall is thicker than the other, or has fewer or narrower doorways, it may be expected to stand to a greater height than the other, though both are outer walls, and thus retaining and protecte the debris on that side. The wall with most wall space has less actual material in it, and is weakest and will permit a greater amount of debris to fall outside the building in response to the outward thrust of the vault. This is the case with three of the four single-room temples in Table 2. In the cases of Structures, K-5 and R-5, the front thickness is less than the rear, and doorways cut the front wall into mere piers. K-5 has no rear doorway, ~~in these cases, the maximum debris depth, and maximum standing wall height, are at the rear, and R-5 only a single narrow one~~ and R-5 only a single narrow one, in these cases, the maximum debris depth, and maximum standing wall height, as at the rear. Str. J-5 has a thinner front wall than rear which contains a narrow doorway, but the front doorway (probably only one) is much wider. As a result of three opposing factors, the maximum depth is at the front. The depths on Str. Q-12 were not recorded in the field, approximations being given, based on recorded heights of walls.

These are all vaulted pyramid temples, and it appears that in most such buildings, a predponderance of doorways at the front, either in number or size (usually both) combined with thicker rear walls, has resulted in a slope of the debris surface towards the front. But a comparison of maximum and minimum depths of this type with those of double-range buildings indicates that the amount of the slope up from front to rear in the single-range vaulted type is less than the slope from outer side to center in the double-range type. Compare Columns L and M of Table 1 with same columns of Table 2. The same factors, if present in a non-vaulted

but stoned walled of a building, shoved produce the same result, though perhaps to a certain degree. The front room of St 1 U-3 (Table 1) our only example of multiple doorways at the front only a now vaulted room, show the slaps to the front. In single ranged structures then, a slap of debris probably indicates which side was the front, whether vaulted or not.

Of the two vaulted groups just mentioned the double one comprises palaces around courts, the single size, the other small temples on pyramids. It must be admitted, that more debris probably get entirely away from a pyramid temple and fall down the slopes than from buildings on low platforms. But this is the material outside the ruins of the walls, which does not figure in our tables. And several of the palaces, lie at the crest of similar steep slopes without materially affecting the result on that side.

Collapse of supporting terraces may of course change everything. This has almost certainly occurred on all the pyramids covered in Table 4. See the section of structure R-16, Plate 1. It is because no rear walls were encountered in our cross-sections that we call these "stone-walled temples," but with a question mark. In most, however, the floor was intact from the front to the probable middle of the room, and the low debris depths there are almost certainly significant. Fortunately, the absence of slabs was in these cases so marked that this observation also proves that they had no vaults. What we cannot be sure of is whether they actually had stone walls all around or not. At the least, all were provided with stone piers, though of uncertain height. Fortunately, foundation collapse such as this does not figure in any of the cross-sections of our other tables.

-Comparisons of Debris of Vaulted and Non-vaulted Buildings-

Table 1 includes only free-standing double-ranged buildings all of which are positively known to have been stone-vaulted, because, in each case, parts of the vaults may still be seen in position. Table 2 includes double-ranged non-vaulted buildings known to have had stone walls and piers at least close to doorway height. Part of the walls of Str. U-3 were found preserved to a height of 1.10, and of J-12 to a height of 1.70. Both are double-ranged buildings, the first with a ground plan ✓

identical with most of those of the vaulted buildings given in Table 1. (See plan of the city.) Each was characterized by such an absence of slabs in the debris as to amount alone to proof that neither was vaulted. The two groups give us an excellent test case on differences in debris depth.

The maximum depths in the known non-vaulted buildings of this class are .50 and 1.00 m, while in the vaulted buildings, they range from 1.40 to 2.25 m (Column L, Table 1). The average depths vary from .33 to .68 m for the non-vaulted buildings, as opposed to a range of from 1.20 to .063 m for the vaulted buildings (Column N.) The difference, illustrated in Plate 1, is quite striking and serves to establish the average debris depth as a valuable criterion for use in border-line cases where slabs enter into the construction of walls as well as of vaults. Great ----- is impossible with this kind of material, but we may say that at this city fallen double-ranged vaults may be expected to leave an average depth of debris on the floor of well over a meter, with the maximum considerably more; while double-ranged non-vaulted structures, if they had stone walls to doorway height, should leave debris averaging 75 cms or less with the maximum depth not very much more than that.

Next we apply the debris-depth test to single-range buildings, at first restricting ourselves to pyramid temples. Table 2 covers supposed stone-vaulted temples. Of these, K-5 was proved to have been stone-vaulted by the quantity of stone slabs, as was R-5. The latter is the only case where we had outside proof Column P. The debris off this building included a fragment of the vault showing the surface plaster of the soffit slope in position on the edges of two vault-slabs which were still held together by the mortar between them. The angle of the finishing plaster to the plane of the slabs told the story plainly. In the cases of J-4 and O-12, unfortunately we failed to record the presence or absence of slabs in the debris, and those photographs taken do not decide the matter. These two, then, are included on the basis of depth of debris alone. The classification is confirmed to a slight degree by two circumstances; they are in the West and East Groups which contain the latest dated monuments and other vaulted pyramid temples; and the walls are as well preserved as those of known vaulted pyramid temple.

If we restrict ourselves to pyramid temples, those known to have been vaulted are much better preserved by the greater mass of covering debris than those pyramid temples (if all of them were indeed temples) known to have been non-vaulted.

Assuming that we are correct in grouping the four temples of Table 2 together as being all vaulted, the average depths of debris vary, from 1.00m to 1.40 m, the maximum from 1.00 to 1.60. The greatest average and maximum depths occur on one of our questionable temples, and the measurements in those cases are certain. The greater the depth the more certain it is a fallen vault indicator.

Comparing one of the two with non-vaulted single-range pyramid temples of Table 2-a (Str. R-3). The average depth of debris on the floor of R-3 is 75 cms, the maximum only 80 cm, both average and maximum being considerably less than in the vaulted Temples of Table 2-a. We cannot compare Str. K-5-3 a since all of the debris was cleaned out of it before it was buried by K-5-2nd. It is classified as non-vaulted because of the extreme width of its room. Though an early building, its room is 5.00 wide as compared with 2.90 m. the next widest known is the GK-5-3d, vaulted, it would have had one of the widest spans in the whole Maya area. Also, its doorways are by far the widest in the city (Column Z of tables 6 and 7). For a cross-section see Plate 1.

If we extend the comparison to the supposed pyramid temples of Table 5, we find that there the average depth varies from 35 cms to 90 cms, the maximum from 35 cms to 90 cms. None of these are stone-vaulted, on the slab test, and as expected the debris is less than in vaulted temples.

We have available data on a few non-vaulted single-range buildings on pyramids, but none on single-range vaulted buildings not on pyramids, except the built-on places of table 3, which, for reasons given below, are not comparable. But the fact that the vaulted buildings of Table 2 are on pyramids probably has not affected the depth of debris within the walls, as outlined above, and we may extend their comparison to Structure 20)1 in Table-2-b. This apparently had stone walls and piers, and certainly had no vaults, on the slab test alone. We are uncertain about the height of walls and piers. The average depths of debris is .10, the maximum 1.00. This is is

This is uncomfortably close to the lowest figures for fall single vaults, but the slab test settles the matter in this case. From the point of debris of depth this would be a border-line case.

Structur J-17 also in Table 2 is classified on the basis of both depth and quantity of slabs, though it is a border-line case in regard to the last criterion. There were a good many slabs in its debris, but the walls are made up almost entirely of slabs, which accounts for them without the vault hypothesis. Moreover they were not packed more or less closely together at floor level, as is usually the case with fallen vaults. This is a good example of the usefulness of depth of debris when the slab criterion is not clear enough to be fine. Structure V-1-2nd does not help us here, as it was cleaned out before being buried under V-1-1st. The extreme thinness of its walls in relation to room width, in this case as in structure K-5-3d, justify us, we believe, in classifying it as non-vaulted.

To sum up, we may say that in general a fallen vault at Piedras Negras usually presents such a profusion of thin stone slabs, closely packed on the floor of the building, as to leave no doubt of the debris is of assistance in deciding. In all observed cases, the average and the maximum depth of debris is less where the slab test indicated there was no vault.

In most cases the difference is marked, and the difference between maximums is even more marked than between the averages. The differences in debris depths between double-ranged vaulted and non-vaulted buildings are more convincing, to be greater than when dealing with single-ranged vaulted and non-vaulted buildings.

Considered quantitatively, and covering both single and double range buildings, in general either an average or a maximum depth of one meter of debris on the floor may be considered a border-line case. Depths of fallen vaults debris run up from this, those in non-vault debris run down from this.

We have not mentioned the single-ranged vaulted palaces covered in Tables 3. This is because they are not free-standing, the rear wall of each forming the vertical facing of great masses of fill to the rear. (See Str. J-6, Platel) This circumstances has for the most part caused the rear wall to stand to the full height of the vault-spring, even where vaults are entirely fallen.

As a result, maximum and average depths of debris are as great as those in double-range vaulted ruins, and are much greater than in any free-standing single-range vaulted structure. (Compare Columns L and N in Tables 2-A and 3) We have no non-vaulted buildings of this special type for comparison.

#### Contours of the Debris Surface.

In general, the surface of known vaulted buildings, whether single or double-ranged, indicates little as to the plan of the building excepted its approximate length and breadth. In the case of nearly all the double-ranged vaulted buildings, this was supplied by standing portions of walls and piers protruding above the surface. On the other hand, the two double-range non-vaulted buildings investigated (Structure U-3 and especially Structure J-12) showed a little or no standing walls or piers, but the debris rose and fell over them like a mantle, so that the plan could be very closely approximated without actually seeing any stones in position. (See sections of these buildings, Plate 1.) Piers were marked by humps, walls by ridges, and rooms by hollows. Both were diagnosed as non-vaulted before excavation. Excavation showed shallow debris and absence of slabs.

Contours of this type have led us to consider a number of long mounds as non-vaulted from surface examination only. We must test this feature more extensively before determining its general reliability.

The distinction presumably arises from the quantity and manner of fall debris. That from vaults fall in large masses, with an outward motion to the front and rear. As a result, piers are either snapped off or surrounded by the large quantity of debris, the surface of which tends to slide outward into an even slope.

Where the roof of thatch or beam-and mortar it may be supposed to have fallen straight down at all points before the walls or piers suffered at all, and the latter would then have risen from a very shallow deposit on the floor. Thereafter the walls themselves would go to pieces gradually, from the top down, the resultant debris falling in the first instance close to the wall or pier and building up the ridges and humps which we find. The two types of contour are illustrated in section in Plate 1.

structures J-2 (vaulted) and J-12 (non-vaulted)

The same effect was not noted in single-range buildings. This is probably because those known are all small single-room affairs. If the room is narrow enough, and the end walls are close enough, the debris from all of them may be sufficient, with the leveling effect of vegetation, to fill the center of the chamber up to the level of what remains of the walls.

#### Dimensions and wall-span proportions

It has already been noted that two buildings (K-5-3d and V-1-2nd) have been classified as non-vaulted on the basis of ratio of wall-thicknesses to room-widths alone. In both these cases there was no debris which was removed in Maya times. We believe we are fully justified in both cases. In K-5-3d the wall thicknesses are no more than in several other buildings, while the room is over two-thirds again as wide as any other known at the city, except in P-7, a special case considered below. Compared with the next widest known vault span, its width is 5.00m as opposed to 2.88 (Str. J-11). All doorways are 3.65 m wide, the next (apart from P-7) being 2.25 (Str. U-3.). In V-1-2nd, while the room is within 30 cms of the maximum room-width in other buildings, except Str. K-5-3d, just mentioned and P-7 to be considered later. The walls are only 35 cm thick, which is less than two-thirds the thickness of the thinnest other wall known, in Structure J-11. When one remembers that both Structures K-5-3d and V-1-2nd were buried by later ones, the difference is so striking as to be convincing. For all room-widths see columns F and G of Tables 1, 2, 3, 4, and 5; for doorway-widths see Column 3 Y and z in Table 6 (vaulted buildings grouped together) and table 7 (non-vaulted buildings, grouped together.) The contrast between these and the other buildings maybe seen at a glance in Plate 1.

The reverse procedure is not permissible here. That is, thick walls and narrow rooms are no certain indication of vaulted roofs. The structure in the double-range class having the highest ratio of wall-thickness to room-width observed at the city (Structure U-3), is the one which, most certainly of all, did not have a stone-vaulted roof. (Structure R-3, non-vaulted, occupies a similar position among single-ranged buildings. Therefore, no conclusions as to roofs may be drawn from ground-plans

alone, unless they show a very low ratio of wall-thickness to room-widths. If they show a high ratio, the roof may have been of either type. Compare the cross-sections of Structures U-3 and R-3, on the one hand, with J-9 and R-5 on the other, Plate 1.

Mortar Deposits underlying Stone Debris.

Wherever the roof consisted of a concrete cap supported on beams rather than vaults, a thick deposit of disintegrated mortar should be found immediately upon the floor, underlying stone debris from the walls. This follows from the presumption that such a roof should fall prior to and not contemporaneously with the walls. The action of large falling trees, or intentional destruction, might disturb this relation in spots, but probably not all over a building of any size.

There is always plenty of mortar on the floor under a fallen vault. The difference lies in the fact that with a vault there will be many slabs penetrating the mortar right down to the floor, since capstones and vault-facing had to fall ahead of the main masses of mortar which were above and behind them.

A deposit of this type, about 30 cms thick, was reported as lying on the floor and underlying the stone debris of Structure R-3, and thus confirms the non-vaulted character of that building, already diagnosed as such on the basis of paucity of slabs and fairly low depth of debris. The application of this test makes the debris depth more convincing. The depth of debris containing stones, a few of which might have served in vault construction, is reduced from 75 cms to 45 cms.

The same condition was observed in the outer chambers of Structure P-7, to be considered later, and in a pit of Structure V-2, a probably domiciliary building not included in our present study. A cross-section drawing of the debris in Structure J-17 indicates that it may also have had such a deposit underlying the slabs which, in this case, almost certainly came from the vertical walls, which are largely slab-built. It is interesting to note that in one and probably both of the cases where the debris depth of a non-vaulted ruin approaches that of vaulted ruins of the same class (J-17 and R-3) and therefore becomes of dubious value, this special type of debris accounts for part of the depth.

It seems not impossible that with extensive testing of non-vaulted ruins we will be able to add a column to our tables showing the presence or absence of this feature, and that whenever the depth figure is of doubtful use, this test will take its place. However, we have not made much use of this test, but explain it because of its value in classifying Structures R-3 and P-7, both of which are important to the discussion. Its value as indicating what type of non-vaulted roof was used is obvious.

PROBABLE TECHNICAL PROGRESS IN VAULT-BUILDING

- Preliminary Considerations -

It is axiomatic that the earliest vaults of the Mayas must have been small in span, and probably rested on relatively thick walls. Buildings with wide vaults or thin supporting walls, or a combination of both, must have been erected after a period of experimentation and experience, though not necessarily at the site where they are found. Since we know from the monuments that Piedras Negras was occupied for at least close to three centuries, and down to the general break-up of the "Old Empire", it is within the realm of probability that vault-building progress took place there, and it has been one of our objectives to look for it. Before we summarize our data on this problem it is well to outline several factors which we have taken into consideration, and which do not appear fully in the tables, and to explain the latter, which are the basis for our conclusions.

If we are to detect any ~~XXXXXXXXXX~~ technical advance in a series of Maya vaulted structures, we must ourselves understand at the fundamentals of the structural problems involved. These have been greatly clarified by Mr. Lawrence Roys, on whom we

~~LAWRENCE~~

Lawrence Roys, Engineering Knowledge of the Mayas, manuscript in course of publication by Carnegie Institution of Washington, Washington, D.C.

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draw freely. Two forces tended to cause the collapse of a completed Maya vault. The mere weight of the heavy masonry vaulting tends to crush the supporting vertical walls. The problem here is one of masonry - of building walls which can withstand the required pressure, the downward "load" or dead weight of the vault and roof.

Most Maya vaults seem to have been designed so that the walls had to stand little or nothing more than downward pressure. However, if the span become great enough in relation to the thickness of the supporting walls - especially when the outer upper zone of the building slopes back from the top of the wall - the center of gravity of each outer half-vault is no longer over its supporting wall, but over a point within the room. In such a case there is a second force to reckon with, an outward thrust which tends to force the outer walls outward - to merely push them over, rather than to crush them. The problem of meeting this thrust is one of stability, of balancing one mass of masonry against another. It must be solved in designing the building (whether consciously or not) and superior masonry will not make up for an unstable design.

In very advanced buildings where side thrusts exist it may be hard to say whether the limiting factor was strength of masonry or design for stability. But even if ~~we~~ in a given case we do not know whether progress has been made in masonry technic or in design from the point of view of stability, we may still know that progress is to be inferred. The test, in one form or another, other things being equal, must be the ratio of wall thicknesses to vault spans.

If a given wall has the correct margin of safety in the matter of resistance to crushing pressure - i.e. has the proper strength - a thinner wall must be stronger for the same size vault, and so represents progress. If side thrusts are involved, a thinner wall for a given vault also represents progress since, having a narrower base it is more easily pushed over, and represents a nicer adjustment of forces.

If the inner slopes of the vaults are made more nearly

horizontal, the total <sup>height and</sup> weight of the vault may be reduced while the tendency to side thrust becomes greater. Fortunately for our comparisons here there is no reason to suppose that the angle of soffit slopes varied materially.

Granted a constant inner vault or soffit slope, the wider the span the higher and heavier the vault and the greater the burden on the vertical walls in the matter of dead weight. Also, the wider the span the more the overhang of the half-vaults and the greater the side thrusts.

~~Therefore~~

Granted a given standard of skill in masonry construction (quality of mortar, spalling, method of bedding, selection of stone &c.) and given knowledge of the principles of stability, put to full use, the wider the span the thicker the necessary supporting walls. Two contemporary buildings under these assumptions might differ greatly in wall thicknesses and ~~with~~ vault spans. But the thicker walls will be under the wider vault, and the ratio of wall thickness to span will tend to be the same in each. The different spans may ~~be~~ have functional or other non-structural explanation. When the wall-span ratios change we have a right to suspect actual technical progress. The first step is of course to measure the buildings and determine the ratios.

The data from our vaults buildings are set out in Tables 1-A, 2-A, 3 and 5, with some additional data on the same buildings in Table 6, where they are listed in the same order. Columns C, D and E give the respective wall thicknesses, front to rear. In Columns F and G are the room widths (in vaulted buildings, as here, the vault spans), first front and the then rear. These are all main vaults, subordinate end rooms, easiest to roof, not being considered. Column H gives the total of the foregoing measurements, which is the

total width of the building, exclusive of the basal plinth. The latter varies somewhat and has no bearing on our problem, being the foundation on which the walls are ~~erected~~erected. These figures in Columns C to H inclusive are all measurements on a cross-section of the building, and are stated in meters ~~or~~ hundredths of a meter.

Column I shows the percentage of the total width occupied by the walls - the figure is the total of all wall thicknesses divided by the total width of the building. This column gives an index to the general massiveness of the structure.

The next two columns have a similar significance, but apply only to parts of the building. Column J. gives the ratio of the front wall thickness to the front room width. It is the thickness of the front wall divided by the span of the front vault. Column K gives us the same information for the rear, the rear wall being divided by the rear room-width (i.e. by the vault span).

The figures in Columns L, J and K are not measurements then, but percentages or indices. If one glances down these three columns he will notice that while the figures run in the same direction, or at least never in reverse directions, the last two are more sensitive to change, from building to building, than the first. This is because the last two (Cols. J and K) do not, ~~like~~ like the first (I) depend in part on the thickness of the medial wall, which is more constant than the outer walls.

The usefulness of these last two indices (Cols. J and K) may be questioned. If they are valid they are more useful than the more general index for several special reasons, though they should be used in conjunction with the later when possible.

First, they are more sensitive to change in outer wall thicknesses, *(in relation to contiguous room widths.)* The general figure under I, for examples, gives the same percentage

for Structures J-2 and J-13, although the outer walls have been 5  
considerably reduced in thickness. This fact is reflected in  
~~Sakura~~ Columns J and K by a drop from 62 to 54 percent.

Second, ~~the~~ in double-range buildings, the medial wall and  
superimposed inner half-vaults forms a balanced mass and does not  
therefore contribute to <sup>outward</sup> ~~side~~ thrusts. These must be allowed for  
in the design of the outer half-vaults and outer walls,, and indices  
based on them reflect more truly how close to the ~~danger~~ danger point  
in the matter of thrusts the architect allowed himself to go.

Third, these are the only indices which permit comparison with  
between double/ and single range free standing buildings, and between  
those and single range "built-on" buildings, all of which occur here  
and elsewhere. The validity of such comparisons must depend, of  
course, on the proposition that the outer half-vaults in each type  
presented about the same difficulty, whether the inner half of the  
same vault rested against a balanced medial unit (double range)  
against another outer half-vault (single range) or against a  
built-on half vault (single range built-on). The problems of actual  
erection may have differed and may have been allowed for in the  
design, but it appears to the writer that the <sup>factors necessary</sup> ~~problems~~ of/wall strength  
and stability, once the buildings <sup>were</sup> ~~was~~ up, was about the same in  
erected outer walls and half-vaults on all three building types.

It will be noted that Columns J and K are identical in principle,  
one being applied to the front, the other the the rear of the building.  
Naturally, figures appear in Column K only for double-range buildings.  
In those <sup>two</sup> ~~few~~ cases where the figures in the two columns are not  
identical, the differences are probably non-significant. We use  
the measurements made at the point investigated. Variations in these  
two cases, btween front and rear walls and rooms, probably result

from failure to line up inner and outer faces of the same wall, and carelessness in laying out the building as a whole.

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Most measurement were made at floor level, though not all.

Having noted differences in wall-span ratios between specific buildings or groups of buildings, we must allow for other factors than technical skill in masonry and vault design, and if we cannot eliminate ~~eliminate~~ or properly discount them ~~before~~ we cannot safely conclude that technical progress is the cause of the differences.

We have seen elsewhere in this paper that heavy walls and narrow room widths do not necessarily mean a vaulted roof at all (Structure U-3) and that in one instance a wide span was apparently followed by a narrower one (Str. J-6/~~2nd~~). The portion of the the earlier building of which we are sure had a high ~~ratio~~ front wall-~~front/room/width/~~ room ratio but there is another doubtful portion which seems to have had a very low ratio.

The higher the vertical portion of the wall, the less its ability to withstand a given thrust, if the vaults ~~are~~ design leaves a net thrust for the walls to withstand. The flatter the vaults, the greater the thrust. The ~~thickness~~ greater the roof thickness the greater the load, including thrust on the walls if the design has not eliminated them. Roof combs of course add enormously to the load, and ~~including~~ thrusts, if any. The introduction of piers between multiple doorways increases the load and thrust (where present) on the piers as compared with a solid wall of the same thickness.

On the other hand extraneous factors may reduce the load on walls, such as use of frequent transverse partitions, <sup>or</sup> butresses. The vaulting of a small square room, especially where vaults slope in from four sides, cannot be directly compared from the point of view of technical ability with that of long rooms. In the small room the end walls act, like transverse partition walls, as props

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The use of transverse vault beams probably ought to be considered, though their true function once the building was completely-completed and set seems not to be thoroughly understood. They certainly did not affect the total downward load on the walls but might have acted in some cases as tie-rods to counteract outward thrust, though this is doubtful. If we encountered two otherwise identical vaults, one with beams and the other without, we might be called on to explain the discrepancy before saying both buildings required the same knowledge of vault design and construction. But there is plenty of evidence that the Maya did not care particularly about eliminating this feature.

Finally, function coupled with tradition may have caused differences in wall-span ratios between contemporary buildings. It is not impossible that heavy dark-chambered structures were preferred for ceremonial buildings at the same time that lighter "palaces" were being built.

#### -The Double Range Vaulted Palaces -

Discounting all the above considerations, we have a group of vaulted buildings which we think are strictly comparable from the point of view of vault construction. These are six of the seven double range palaces of Table ~~1-A~~ 1-A. Additional ~~1-A~~ data on them is set out in Table 6, which will be referred to when used in the discussion. We will divide the six into two ~~groups~~ sub-groups, ~~1-A~~ Structures J-9, J-2 and J-13 as opposed to J-21, J-18 and J-11.

Each of these buildings six buildings is double ranged, has transverse end rooms. In all but Structure J-2 there are small inner doorways connecting the end rooms with the principal long rooms or galleries. In four of the six cases exterior doorways at the ends of the building give ~~access~~ access to the end rooms, and this is probably

the case in the other two (Structures J-13 and J-21). All but 8  
Structures J-9 and J-13 make a liberal use of piers between multiple  
doorways in the outer walls, and piers forming a triple doorway  
occur in one of those (Structure J-9). While lengths of the buildings  
vary, it is quite clear that this represents an adjustment to the  
available space. The maximum ~~total widths~~ variation of total widths,  
on the other hand, is only 1.75 m (~~see~~ Table 1-A, Col. H).

All are placed ~~around~~<sup>on</sup> the sides of one or the other of the  
three courts which cover most of the area of the Acropolis. These  
courts, though at different levels, overlook one another and form  
a homogenous group, distinct from anything else in city.

All of the medial walls are (or were originally) pierced by <sup>single</sup>  
(never double or triple)  
doorways connecting the front and rear main galleries.

It is clear from both plan and position, then, that all  
were designed for substantially the same purpose, and were <sup>built and</sup> used  
together as parts of one architectural complex. Their nearest  
affinity in plan is to the palace buildings at Palenque, with which  
they are fundamentally identical, except that all the buildings here  
stand free of each other, and all have end rooms. Although the  
vaults are almost completely fallen, there is no reason therefore  
to suppose the former presence of roof combs of any size, or, if  
there were roof-combs, they differed materially among the six  
buildings. Real roof combs are to be seen at Palenque and at  
Yaxchilan only on temples.

The height of the vault-spring (the height of the vertical walls)  
has been ascertained in only three cases, and in two of those is  
only approximate. But we have a figure for both the beginning and  
the end of the whole series, and the difference is only 44 cms (Table  
6, Col. S). There are exposed remnants of vaults in the principal  
galleries of all but Structure J-13. It is certain from observation

that vault-spring heights in no case varied greatly from the extremes given, although we failed to determine the heights accurately in those cases where a leveling instrument should have been employed.

In all cases the thickness of piers is the thickness of the walls, and so varies considerably, as expected. The widths of these piers vary only from 1.08 to 1.27 m, and the widths of outer doorways from 1.70 to 2.16 m. Variations in these factors are therefore slight and could have affected the problem of erecting vaults but slightly. All outer doorways were undoubtedly bridged by wooden lintels, and once this was done the walls presented practically identical structural problems to the vault builder, aside from their thickness and the span of the vault.

Our data on vault slopes is fragmentary. Mr. Roys in his study comes to the conclusion that Maya vaults in general slope at about 27 degrees from vertical. Our two measurements in this group are 29 and 27.5 degrees (Table 6, Col T). These ~~of~~ figures are not to be taken too literally, since vaults here are not perfectly smooth and regular. Since the two measurements are one in the ~~of~~ lighter, the other in the heavier sub-group (Structures J-11 and J-9 respectively) we assume that all the slopes were about the same.

For the two buildings where we have a positive check on the vault slopes we have calculated the vault-height, assuming that 30 cms of the cap-stones were left exposed, as we know was done on <sup>a nearby</sup> an-adjacent single-range palace. These two vault heights are probably close to correct and, because ~~fixth~~ one of them is in one of the narrowest rooms, (Structure J-9) and the other <sup>one of</sup> in/the widest (rear room of Structure J-11), they probably give a fair idea of the extreme difference in vault height. The difference in those cases is 1.22 m opposed to 2.52. The higher vault height is associated with thinner

outer walls and a wider span and so supports the theory of progress.

We have no data on the thickness of the roof-cap in this group, but have no reason to suppose it varied materially. In two single-range palaces probably varied from 40 cms in one to 60 in the other (Table 6, Col. W).

Apart from the walls of transverse end rooms, we know that all transverse partition walls running across the main galleries were erected after the main longitudinal walls. In the case of Structure J-9 it is ascertainable that the <sup>main</sup> vaults also were erected before the partitions. In that case the partitions are 50 to 75 cms thick, but are not bound to the main walls or vaults in any way, plaster on the later running without interruption across the ends of the partitions. These walls may have acted as braces to the vaults once they were erected, but the vaults were first built <sup>and plastered</sup> without their aid. The partitions probably are a much later secondary feature. Even then the nearest partitions are 11 m apart. In the rear chamber there appears to have been but one, and if we are right, there was there a 17-meter length of vault without partition support at any time. The vault problem in this structure was therefore solved in its essentials in parts of this building without the aid of partitions.

Partitions were entirely absent in Structures J-2 and J-23 (a similar but smaller building to be considered later on), both of which were completely ~~absent~~ absent. They are present in Structures J-11, J-18 and J-21, in each case with a maximum observed thickness of 50 cms, always built after the main walls and not bound to them. Surface indications are that they are few and far between and they are probably all secondary/and

There are no surface indications of the use of internal buttresses either in any of these structures, nor did they occur in any of the

Another not improbable motive in thinning walls was to offset the greater amount of labor in gathering and preparing the material for the larger vaults. The thinner the wall, the less lime to burn and carry, the less stone to quarry and transport.

The motive for wider rooms is not far to seek if, as we suspect, these buildings were living quarters, and the same applies to thinner outer walls, which meant more light and air.

The six buildings ~~of~~ under consideration are arranged in accordance with the ~~front wall-span indices~~ out-wall-span indices of Columns J and K, in a descending series in Table 1-A. The heaviest is first, the other two of the first or heavier sub-group following. Then skipping Structure J-23, which is to be considered separately, comes the lighter sub-group, the lightest, Structure J-11, last. The first sub-group is marked off sharply from the second sub-group. If we use the more sluggish index of Column I, the index drops from 47 per cent for the lightest of the heavier group (J-13) to 33 per cent for the heaviest of the lighter group. If we use the more delicate indices of Columns J and K, which leave the medial wall out of consideration, the difference is striking - 54 as opposed to 33 per cent. Within the sub-groups, if we use Columns J and K, there is a ~~stand~~ lighter building represented as we pass down the columns, though the differences are less great. Structure J-9 is a good deal heavier than J-2, and this than J-13. Structures J-21 and J-16 are almost identical in this respect, but J-11 is considerably lighter than either, and all three are much lighter than the first three.

Between the extremes of the series as a whole, the more sluggish figure of Column I falls from 51 to 28 percent. Column J shows a drop for these buildings of 75 to 18 percent, Column K from 69 to 27 percent.

It seems to the writer that such differences as these, in otherwise very similar buildings, implies with comparative certainty progress

in the art of stone masonry, or in the knowledge of what/a given masonry of standard ~~of-masonry~~ could withstand, or both. Increased knowledge of stable design may have been involved, but probably not, since a reconstruction of the vault of the lightest structure, which has the widest spans, indicates only slight outward thrusts in that building.

The writer feels that these six buildings are probably arranged in Table 1-A in their actual chronological order, but is ready to change his mind as to sequences within the two subgroups. He feels very much more certain that the first sub-group (J-9, J-2, J-13) were built before the second (J-21, J-18, J-11).

-Structure J-23 -

Structure J-23 is the seventh and last of the known double-range vaulted palaces of the city, certainly the last on the Acropolis, and indices of Columns J and K place it between the two sub-groups above discussed. The index of Column I would suggest that it belongs with the earlier rather than the later sub-groups, but there are other factors pointing the other way.

Its outer walls are thinner than any of the heavy group and as thin as ~~was~~ all but the front wall of the lightest. (Columns C and E, Table 1-A). Unlike <sup>all</sup> the other cases, thin walls are coupled with narrow rather than wide rooms. This building alone is not on one side of a court, but on the highest peak of the Acropolis hill. Its <sup>and construction</sup> plan/agrees with these of the later sub-group in certain details in which they <sup>latter</sup> differ from the earlier buildings. There is a narrow doorway between the main galleries, formed not by piercing the medial wall, but by stopping the latter short of the transverse end room walls. The inner doorways of Structure J-23 are vaulted, and vaulted inner doorways occur also in Structures J-18 and J-11. The manner of roofing inner doorways of the heavy buildings J-2 and J-13 is not

known, but the two known ones in J-9 are bridged with stone lintels.

In view of the fact that Structure J-23 occupies a unique position ~~is~~ = the most commanding in the city - these minor differences take on some weight. Though a pocket edition of Structure J-11 (the highest palace) in practically every respect, we are inclined to think it may have approached the pyramid temple <sup>may</sup> in function. The narrow rooms, even if the function was the same, have been used in order to permit the erection of a roof comb. Here <sup>f</sup> is anywhere in the city a roof comb was called for. The building ~~was visible from parts of every group and section of the city thus far investigated.~~ and commanded a view of the river both up and down stream.

Our belief is that this building belongs with the later sub-group of palaces chronologically, though we are far from sure, and much less so as to its position in that group.

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Evidence suggesting an Early Period when Stone Vaults were not used

Several incomplete lines of evidence suggest that at Piedras Negras stelae were carved and set, platforms and pyramids erected, and buildings built on them, before the stone vault was used to roof them. The evidence is here set out as posing an interesting and important problem for future solution. The hypothesis is not considered definitely established. The occurrence of all known vaulted units except P-6-2nd (part of the outer wall of which always remained visible) at the surface proves that vaults were in use at the end of the city's ceremonial history. If the vault extended back to the earliest times, buried traces of it ought to be encountered, since burial of buildings under new ones was common here as elsewhere.

1. Stratifications:

Some account of excavations under and behind Structure J-6 on the Acropolis of the West Group is given in the appendix. Here we have encountered three distinct successive buildings levels or periods under two others in which vaulted buildings occur. One of the latter is Structure J-9, the first on the list of Table 1-A. On the lowest level was a wooden-post building associated with partly demolished stone-walled buildings. The other two earlier periods yield, on our sections, no evidence of the type of building then in use. The stone buildings on the lowest level may or not have been vaulted. The excavation at least definitely proves that the most massive vaulted palace was preceded by strata of earlier structures, and therefore does not belong to the earliest period of the city. The next vaulted palace on the list reveals a floor several meters below it which is almost certainly as earlier as the earliest period under J-6. The two most massive vaulted palaces are therefore definitely moved as post-dating the foundation of the city, probably by a considerable time interval.

Among the palaces Structure O-13 has been trenched to reveal below the upper temple an earlier plastered false pyramid the top of which as shown by a section on the front-rear axis of the later pyramid was an open platform.

Structure R-3, a small free-standing pyramid of the South Group, has been trenched for a center section from top to bed rock. A proved total of three, and a highly probable total of four building periods were identified. The latest is represented by Structure R-3-1st which was a non-vaulted temple. The next level, which is quite certain involved a slightly lower pyramid which apparently supported a stone-walled temple, but with all clues as to its roof-construction removed. No remains of a building on the third level were encountered since the foundation platform appears to have been destroyed. It is barely possible that this period is really part of the second. The lowest and earliest period is represented by a low platform, with no evidence as yet as to the character of its building, if any.

In Structure V-1, a supposed domiciliary structure in the Southeast Section outside of the main ceremonial groups a non-vaulted building was superimposed on another non-vaulted building and the latter on a still earlier terrace.

Under the vaulted Structure K-5-1st was encountered a floor of ceremonial use, with complete absence of remaining building walls. But below this was found Structure K-5-3d, which as we have seen, was undoubtedly a pyramid temple with non-vaulted roof, a cross section of this building is shown in Plate I. This is a clear case of stratification of vaulted temple over non-vaulted temple. It also shows that most massive vaulted temple of simple one-room plan was preceded by two earlier building periods, and cannot be attributed to the earliest period of the city's history.

The only case where as yet we have found a known vaulted, though not quite obliterated building, dismantled in Maya times, is that of J-6-2nd. This made way for Room 1 of J-6, another vaulted structure which is fairly well dated by its throne and the niche built for it at 9.17.15.0.0., a late date at the city. Both of these buildings are on the same level, the floor and possibly the front wall of the earlier building being used for the later.

We thus have one very clear and positive stratification showing vaulted building above a non-vaulted one of the same general nature and use (both K-5-3d and K-5-1st contained "column altars," discussed below,) we have considerable negative evidence at other points. That is, five other excavations, two under palaces, two under temples and one in a house mound have failed to show any sign of vaults below the surface. Structure S-6-2sn was partly torn down to make way for a similar building at the same level, and is the sole known case of the intentional wrecking of a vaulted building.

The excavations cited but, as yet not reported, embrace both vaulted temples and palaces, and occur in each of the three main ceremonial groups of this city, that is they include the building types and positions where early vaults are most to be expected.

#### Homogeneity of Plans.

All of the pyramid temples except O-13-1st are small simple one-room affairs, the chief distinctions being in number and placement of doorways. Three of these four have the low ledge at the back of the room and the fourth (J-4) may have it.

The close correspondence in plan among the double-range palaces and among the single-built-on palaces has been already mentioned, as well as reasons for believing that the two palace types belong together chronologically.

Of the known vaulted buildings only the Pyramid temple O-13-1st and the platform structure P-7 are unique. Each of these probably represent, two phases of building and one of them O-13-1st, is well dated in its final phase as not early by Lintel 3 (Initial series 9.15.18.3.13) or Lintel 3 (9.11.15.00) which was probably here reused.

The general close correspondence of the plans of various units of the three principal types of vaulted buildings, Pyramid temples and double-range and single-palaces argues for a lesser rather than a greater time period within which all were built. The observation tends to cut down the probable length of the vault-using period, and to make it a part rather than the whole of the dated life of the city. This we know from the monuments was close to 300 years, very possible a little more.

### 3. Duplication of Vaulted types in Non-vaulted Buildings.

If points one and two tend to leave an early blank in the dated history of the city with reference to vaulted ceremonial building, non-vaulted buildings, are at hand to fill it. Structure J-12 is non-vaulted duplicate of the double-range palace type in every essential detail; and Structure R-3 duplicates the simple one-room pyramid temple. We have seen that the small shrine type of temple (P-7 in its first phase) very likely was duplicated in essentials by non-vaulted structures.

### 4. Distribution of Vaults in the City.

Examination of the map, or of Column Q of the tables, will show that out of nineteen known vaulted structures (not counting separate parts individually), only one (the pyramid temple R-5) is in the South Group, while all others are in the West and East Groups. This segregation of vaults outside the South Group is confirmed by fairly complete tests in the South Group, including all seven of its pyramids, the long platform structure R-7, and the short platform structures U-3 and R-2. The natural surface at the South Group is lower than either of the others, nearer the river, and borders the largest contiguous valley-floor and house-mound area in the city, if we exclude the Northeast Section, which is very much cut off from all the main groups by the topography.

The only one of the three main ceremonial areas, then, which is characterized by an almost complete absence of vaults, is topographically located in the region most accessible to the river, which forms the only source of water and probably was a main highway. The region has the largest flat valley bottoms, and was the most favorable part from the point of view of initial occupation.

### 5. Dated Monuments.

A few late or middle period dates, with relation to the known dated series, which is from 9.4.0.0.0. to 9.18.5.0.0 or later, are rather definitely associated with vaulted buildings. These are Throne 1 (1.17.15.0.0) for which a niche was almost certainly purposely provided in Room 1 of Structure J-6; in which room it was found; Lintel 3 (Initial Series 9.15.18.3.13, assigned by Morley to 9.16.0.0.0) from the debris on the upper terrace and in front of the temple Structure O-13-1st in its

phase; Lintel 4 (9.11.15.0.0) from debris on the upper terrace or on the front slope of the pyramid of Structure R-5; and Lintel 7 (Initial Series 9.9.8.?.?) from debris on the upper part of the front slope of Structure K-5-1st. Evidence that building operations were in progress in the West Group after 9.11.10.0.0 is furnished by miscellaneous sculptured stones No.9, probably a fragment of another throne. This was reused as a mere building stone in the West Group Ball Court (Structure K-6-a). Its calendar round date, with ending sign, is read by Morley as 11 ahau 18 chen which can only occur as a period ending within cycle nine on that date.

We have one early date associated with a non-vaulted building. This is Steal 29 (Maler's enumeration 3) which stood at the top of

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This was called Lintel 14 in Preliminary Paper No. 1, but further work has caused us to revert to the original classification and designation in conformity with Dr. Morley.

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the pyramid of Structure R-3, probably in front of the doorway. This monument seems to have stylistical affinities with the unreadable Lintel 11 from that non-vaulted temple. Its date according to Dr. Morley is 9.5.5.0.0, based on the readable Initial Series 9.5.5.?.? and the variable element in the introducing glyph for the month.

The contemporaneous date of Lintel 7 is not certain, but is probably not many years different from an Initial Series. If it was re-used in Temple K-5-1st (a theoretical possibility since on stylistic grounds Lintel 2 seems to have been re-used in O-13-1st), the temple would be later, not earlier, than the date of the lintel.

We have thus had four opportunities of striking early dates on monuments which must have been in place at the time associated vaulted buildings were in use, and the earliest is very probably no earlier than 9.9.8.0.0. One of these is in a vaulted palace, all of which are grouped together in obvious relation one to another, and the others account for three of the five known vaulted pyramid temples. Two of these are single chambers, one massive the other light, and the third is complex in plan. There exists, of course, a probable sixth pyramid temple structure J-29 as yet uninvestigated. The latter is more probably late than early, since it lies in the Northeast Section,

off from all the main groups by the topography (see plan). The chances of future work producing early dated monuments in original position and definitely associated with vaulted buildings are thus rather slim.

On the other hand, the only monument (stela 29) definitely tied to a non-vaulted building appears to be early.

It should be noted that we have not employed the evidence of stelae standing before or, more usually on basal terraces of pyramids, not of table altars, in all cases standing before and not on a substructures, until proved by excavations, there is the possibility that the stelae were erected an unknown time after the pyramid and temple in which case the temple might be much earlier than the sealae; or they may have been set before or on the basal terrace of an earlier structure, the earlier pyramid proper being late buried and hidden by the surfact structure; in which case the structure would be later than the stelae; again, the temple building alone may have been rebuilt, in which case the building may be either earlier or,----- later than the statae.

These objections do not apply with equal force to monuments founded on the tops, or on the slopes of substructures. Such must have been placed after the erection of the final substructure. If carved when erected, a reasonable presumption, the building cannot be older than the monument. If they are lintels, there is at least presumption that they were carved for use in the building proper.

There were very special circumstances connecting Throne 1 to its building. The presumption that stelae at the tops of pyramids are contemporary with the building proper is of course weaker, since the later may have been rebuilt after the stela was erected or the stela placed after the building. But in the single stela (stela 29) yielding one of the dates above considered, this was tied to a lintel in the building (unfortunately unreadable) by stylistic similarities.

Having recognized the fallibility of chronological correlations between building proper (and even substructures) and the stelae and altars at the base, it is still fair to point out that the positions of the stelae and altars at Piedras Negras, together with their dates according to

Morley's readings, are entirely consistent with our hypotheses. The earliest dated stela before a vaulted temple is Stela 33, ready by Morley as 9.10.10.0.0. This, and all stelae dated later than this (and there are thirty) stood before pyramids supporting vaulted temples, or on such pyramids, except four which stand before a pyramid without a stone-walled temple (J-3), and which was in all probability a peculiarly formed open platform 4. There is

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#### 4 Piedras Negras Preliminary Paper No. 3

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evidence that this platform preceded the stelae in time, though this was not conclusive. The five table altars all stand in the principal plazas of the West and East Groups, which are characterized by stone-vaulted buildings, and the earliest date assigned to one of these altars by Morley is 9.16.0.0.0.

The dates of stelae and altars are without exception, according to Morley's readings, period ending dates, and to a large degree, successive hotun markers are found in groups. This circumstance goes far toward proff that they have not been moved, and that they give the approximate date of actual erection or dedication. If the dates are contemporary and the monuments unmoved, a shift of interest from South to West groups after 9.12.0.0.0, so far as major sculptured monuments is concerned, is established. But stelae are here always placed with relation to pyramids, and a corresponding shift of building activity may be inferred.

#### 6. Distribution of Altars.

We have seen that the South Group differs from the East and West groups in the fact that all but one of its buildings, so far as known, are non-vaulted, and that only the earliest dates are found in original position within it. Anything which tends to be typical of the South Group at the surface and non-typical of the others helps to confirm the theory that the differences in roof structures and monument dates have chronological significance.

In the South Group are two short roughly cylindrical stones, badly eroded and possibly originally sculptured. The longest measures 1.15, the shortest .95 meters, the diameters being 45 to 50 cms. Apparently neither is part of a cylindrical

stela. These are the only stones which have been encountered in the South Group in association with Stelae which might be considered as altars. On the other hand, in the West Group are a large circular and a large rectangular table altar, and in the East Group a large circular and two large rectangular table altars. They consist of great slabs set on three legs if circular, or four in rectangular. Dates are assigned to these altars by Morley as 9.16.0.0.0 (Altar 2; 9.18.0.0.0 (Altar 4); 9.19.0.0.0. (Altar 3); and 10.0.0.0.0. (?) (Altar 1). Reading of the date of Altar 5 is not attempted. This style of altar is absent in the South Group, and is surely a late feature. Late altars then are found in West and East groups, and no altars or a very different and more simple type in the South group.

In contrast to the absence of the table altars, we have what we term "column altars" in the South group, which may be related to the two stone cylinders of that group above referred to though they are confined to the tops of pyramids. In all but one or possibly two cases, these were certainly placed within the temples. The column altar is a short plain stone cylinder, usually a little flattened on four sides; and usually tapering slightly toward the base. Wherever found in position this was set on end, in the floor, and on the front to rear axis. One, in Structure R-4, was 95 cms long and 56 cms in maximum diameter, and so compares with the columns found below in the Court. All the others are much smaller, a typical one on Structure R-16 measuring only 30 cms in length by 25 cms in maximum diameter.

These were found on all six of the pyramids of the South Group which supported non-vaulted temples, but were absent in the only vaulted temple of the Group. Outside the group they were in the vaulted pyramid temples O-12 and O-13, and failed to appear in a center-section trench in the vaulted temple J-4. They were present in K-5-3d, a third-level non-vaulted temple, and on K-5-2nd, which may have been an open platform and, which, at least, yielded no evidence of a former vaulted temple. The evidence is thus far cumulative that the South Group surface non-vaulted buildings are early. This feature, common to all of them, occurs in the West Group at two deeply buried levels.

These stones occur at the surface in the West Group in one pyramid only K-5-1st a vaulted temple here there were two column altars one in a niche in the back wall of the temple, a second in the debris just in front of the temple.

The four column altars of the three K-5 levels are alike in form and closely so in size and all but that found outside K-5-1st and relatively unprotected from the elements are fire-blackened. They serve very well to show that the non-vaulted structure K-5-3d was a temple serving the same general purpose in much the same way as the vaulted temple K-5-1st.

We do not have to rely merely on the distribution of most of these stones in the South Group, together with early monuments and a six to one preponderance of non-vaulted temples to conclude that they were an early feature. This is proved by their occurrence in the third and second levels of K-5, and, in the earliest of those cases in a definitely non-vaulted temple at that. Their occurrence in one vaulted temple merely appears to bridge the gap from non-vaulted to vaulted temples, and to show that their use persisted to vaulted times.

We have seen that the only vaulted temple in which the column altars occurs (Structure K-5-1st) is at least as likely as not to be one of the earliest vaulted buildings of this function, both from the point of view of structure and of associated monuments. The earliest stela of the west group stood on its basal terrace, apart from the possibly still earlier date of its Lintel 7. This building may easily have been one of the first vaulted structures erected at the city. It is therefore a reasonable speculation that column altars on pyramids, known to have been in vogue at an early date, went out of style after the erection of this vaulted temple, and probably before the erection of most or all of the other vaulted temples, in which it was absent. Incidentally, the change involved a change in temple ceremonial, since the stones were quite obviously used in rites involving the use of fire or incense.

Table and column altars may have little direct relation one to the other, since one occurs only on plaza floors, while the other is for the most part concerned with ceremonies within the temple. The table altars may even have been ceremonial seats or thrones. But whether one supplanted the other for a similar function, or

one went out of fashion and another came in independently, the distribution of both adds weight to the proposition that the surface temples of the South Group had their genesis in a period differing from those of the East and West Groups. If there was such a difference in period, the monuments leave no doubt as to which was earliest.

#### 7. Ball-Courts Types.

These also may be brought to bear indirectly on our problem. We have two, one in the South Group (Structures R-11-a and R-11-b) and one in the West Group (Structures K-6-a and K-6-b). The latter, we have seen, was almost certainly built some time (possibly a long time) after 9.11.10.0.0, the probably contemporaneous date of a throne fragment reused in it. We have not yet reported on this unit, which has been cleared. In function it is surely strictly comparable with the South Group Court. <sup>5</sup> The two Courts do not differ greatly in size, not in

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5 Piedras Negras Preliminary Paper No. 2.

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fundamental arrangements, but differ very greatly in probably significant detail.

The design of the South Group Court agrees with several known examples at other Old Empire cities. The inner benches of this are low (maximum height 74 cms.), but much higher (2.03 m) in the West Group Court. In the first case the face of the bench is sloping, in the latter, vertical. The face of the main mass behind the bench is sloping in the first case, vertical in the second. Three drum-shaped stone markers were present in the alley of the South Court, absent in the West. The Alley of the supposedly earlier South Court is 4.30 m wide, that of the West over 2.00 wider also the benches of the South Court are about 75 cms narrower than those of the West Court. Some of these differences must have affected the manner of playing the game, especially the high and vertically walled inner benches, fronting the alley. It is probable that courts differing in such important details were erected at different times, and this is in perfect accord with our inferences as to temples and monuments in the two groups, provided we consider the West Group Court the later. That it is not early is plainly indicated by the included throne fragment.

Suggested Explanation of the Position of the Vaulted Structure R-5  
in the South Group

The presence of one vaulted temple in the South Group does not great violence to a presumption of earlier dates for the others. Its one definitely associated monument (Lintel 4) is later than that of K-5-1st (Lintel 7) in the West Group. The seven stelae ranged before it are the latest of the South group, falling between 9.10.10.0.0 and 9.12.0.0.0. The fact that Lintel 4 (9.11.15.0.0) falls toward the end of the stelae series suggests a late rebuilding of this temple, which may have been originally non-vaulted. There is nothing inherently improbable in the thought that extensive building with vaults on the Acropolis, and in the East Group, which together contain all the latest dates, may have been the effect of a shift interest and energy to those groups, which, while it permitted a beginning to be made, prevented a complete transformation of the South Group, and only then were large plazas possible. An----- intentions to modernize the South Group, indicated by the one vaulted temple there, may have been dropped by succeeding generations who preferred to devote all their building energies to the groups where more magnificent efforts would be had.

SUMMARY

The evidence, so far as it goes, points to the introduction of stone vaults at Peidras Negras not much before and possible later 9.10.0.0.0, and class of evidence is conclusive in itself. But it gains authority by falling into so many mutually confirming categories - stratification, character of ground plans, duplications of plan in vaulted and non-vaulted buildings, distribution of vaults, definite association of dated monuments, distribution of dated steale, distribution of altar types, and distribution of ball-court types. The admittedly incomplete evidence under all these heads points always in the same direction, with the exception that one temple out of seven in the South Group is vaulted and that out of nine pyramidal structures with associated column altars, one is a vaulted temple, and these exceptions are susceptible to reasonable explanations.

Since all known vaults are sufficiently pretentious to call for more than a beginner's skill in their erection, it is probable that the idea and technic of roofing buildings with stone vaults was brought to Piedras Negras from elsewhere in the Maya area. If, as we think, this was done after most of the South Group took its final shape, it was after the city had become a typical old Empire site in all important respects except stone vaulting, when it already had carved stone stelae and carved stone Lintels (Lintel 11) pyramid temples, and probably an Acropolis (levels now buried, and the non-vaulted palace J-12.)

## APPENDIX

### A Cross-Section in Court I of the Acropolis

The stratification of building levels under the northwest end of Structure J-6, the platform on which it fronts at this end, and Structure J-7, is schematically presented in Plate 1. This section was obtained by trenching in Structures J-7 and J-9, and by tunneling under and behind J-6, on two levels. All strata of buildings are well marked by floors and terraces, much of the areas examined retaining finishing plaster in good condition. That is, there is no question but that each stratum indicated was at one time exposed and finished for use, and thereafter buried. In the case of stratum No. 3 we should state that its upper contour where buried by Levels 1 and 2, is, an approximation only, since it was there followed from beneath, the underside of its floor forming the roof of one of our lower tunnels. However, the floor was pierced in one place from beneath, and the sides of the platform were pierced from within, so that we know that it was plaster covered and we know also its height.

The strata or building periods which they represent, are numbered from the latest back. The fifty or earliest encountered may not be the earliest at this point, as we did not here reach bed rock.

#### Period V (Earliest)

On the fifth level is a small stone-walled building, 5.40 m in length, which apparently formerly faced on the present and latest floor of Court 1 of the Acropolis or possibly was raised above a lower and earlier level of that Court. Its width is unknown, as the front was destroyed in later building operations at the point examined. There is little doubt that it was small, however, unless we are dealing with the end of an almost completely demolished long building which is a possibility. The thickness of the rear wall is 75 cms. The stones at its outer rear corners are well-squared blocks, perfectly chinked and leveled, and set in mortar. These corners are by far the best masonry observed as yet at the city, from the point of view of artificially squared stone, and care in laying.

At the corner and in a distance of a meter or so, along the back and side, little reliance is placed on mortar. But beyond this the stones are much more irregular. The wall appears to be built through, however, of good blocks, on heavy slabs, split off along the bedding planes from natural formations.

There was no debris from the building on its floor, to give a clue to former presence or absence of a stone fault. The northwesterly end of this building appears in the large cross section of the plate, where it is marked x.

In our main trench, at its Southeasterly end (well to the right of the portion shown in the Plate 1) we encountered the broken-off stump of another vertical wall, running at approximately right angles to the rear of the building just described. It is only 70 cms southeast of the battered plinth which, at this end, supports that building. Its masonry seemed to be of the same character - blocks well laid horizontally in mortar - though further excavation would be necessary to reveal a corner. Its thickness seemed to be about a meter, though we could not be sure without continuing the trench farther than we did. If it rested on the usual plinth, the latter was buried by the floor at which we stopped, which is at the approximate level of the latest floor of Court 1.

About 1 meter northwesterly of the other end of our first building, was another broken-off wall, of the same character, which I think, and of the same type of masonry. To show the position of this wall, which runs parallel with rear wall of the first building (x) we have drawn it in elevation in the cross section where it is marked (y). The fill of Period 4 covers it as shown, but also descends in front of it would hide it from view if we kept laterally to the single plane on which our section drawing cuts everything else.

Between the broken end of this wall and the corner of building (x) is a small, excellently built stone drain, with vertical sides. It was covered, the covering slabs had been removed. It appears in cross-section on our drawing. Both the side of this wall which is shown, and the outside of the first building (x) were decorated with red paint, probably in a bold design.

The walls of the first building (x) had been razed to a maximum height of about 1.25 m, which was just enough to come under the floor of the next building period. The stump of the wall to the southeast not shown in the Plate had been razed so that it stood to a height of about 1.30cms, but since the wall itself is not raised on a plinth, the top as found was 95 cms below the floor of the next period. The wall (Y) at the other end stood to a height of about 90 cms only, at this point well over a meter below the floor of the platform above. Demolishing the walls of building (x) then, to the point found, was necessary to bring the Period 4 floor to its desired level, but the other walls were lowered much more than was necessary on this account. We may conclude that there was a good deal of demolition to obtain building stone for use elsewhere.

The maximum heights observed, the excellence of the masonry, and the thickness of each of the three walls makes it practically certain that all once rose at least to doorway height, and that all are parts of free-standing buildings and not of platforms. Transverse trenches prove the last observation so far as building (x) is concerned. The mere thickness of the walls has no evidential value on the question of vaulted roofs, as we have seen.

The apparent complete (certainly partial) razing of the supposed front facade of the building (x) and of the Court 1 end of the wall to the southeast, was necessary in order to place the retaining wall which rose in front of these constructions, to the latter period 4 level. There was no such obvious reason for tearing out the end of the wall (y) at the northwest, clear to its base. Perhaps this was done to obtain especially well-worked corner-stones placed there; though this interpretation is not particularly consistent with the undisturbed lower courses at the corners of building (x).

At the left in our section that is, northwest is a well plastered and well-built low stone platform of two levels, the lower being apparently a broad terrace reached by a flight of unusually wide steps. This is marked (z) in the drawing. Sunk in its surface we uncovered two post holes, one of which is shown in section in the drawing.

These indicate posts about 25 cm thick, set about 90 cm into the platform and spaced 5.80 m apart. They are set 2.50 back from the southwesterly edge of the upper level of the platform. They were quite empty when found, and their sides are formed by small uncemented broken stone which would easily fall if disturbed. Either the posts were carefully pulled out, or the stumps rotted away in place, leaving no trace because of the openness of the stone fill around them.

The steps of this platform were in use contemporaneously with the stone-walled building (y), as they appear to end against it, though they may run through it. That is, we do not know whether the steps were built after the wall, the wall after the steps, or whether both were built together. We do know at one time they were used together, as the finishing plaster on the steps turns up against the wall.

The contemporaneous use of wooden and stone-walled buildings in close proximity is thus well established. The walls of the wooden-post building were probably of wattle-work, daubed with clay and then covered with white plaster and we shall see. Apart from the possible difference in painted decoration the wooden and stone building need not have been very different in appearance.

The earliest known level then, included very well-built probably small stone-walled buildings, which may or may not have been vaulted which were apparently grouped around a court and which were associated with a well-built low plaster-covered platform supporting a wooden post building.

#### Period IV

The next level (No. 4), so far as our cut section revealed it, consisted of two low platforms. The first (to the right in the drawing) was completely bisected. It was well plastered. Immediately behind it another on this level barely covered the 5th period platform of the post-holes. It was probably plastered, but if so this had been destroyed. The body of the floor was not concrete and contained much

river sand and many pieces of burned clay, which had clearly been daubed on wattle-work. Diameters of the sticks or rees of the latter varied from        to        cms. The outer surface had been fairly well smoothed and coated with white plaster. There was no evidence of fire on the sopt, so that it is improbable that these fragments came from the building on the platform containing the post holes, but probably refuse during the next building period, and we may assume that the walls of that building were or wattle and daub. When plastered, the effect was about the same as a plastered stone wall. Buildings of this sort are still erected by the Mayas of northern Yucatan.

We can distinguish two phases of this level, represented by the platform at the right in its original form, and later as modified by a slight widening at the right, which involved a new terraced facing on that side. Again the terracing is **low and relatively wide.**

### Period III

The third building period (No.3) is represented by the exposed surface of Structure J-7 which, after it runs under the palaces of the latest periods, connects with low plastered stone platforms. These are imperfectly known even in section, as they were followed from below., the under sides of their concrete floors forming the roof of our lower tunnel. However, in turning a right-angle to find the second post-hole on Level 5, we pushed the tunnel through the stone-faced edge of the upper platform. Here we dug vertically up a little and obtained a cross-section of an outer wall of the Level 3 structure, showing it was plastered with a slight batter. The latter operation also revealed another floor 14 cms above it, which extended out beyond the edge. This might, of course, represent still another building period, but the evidence is so scanty that we will consider it only another phase the third period.

There is no question but that the floor of this building period extended about 4.50 meters southwest of the(right on the drawing)of the front of the Period 1, building (Structure J-6) which later was placed upon it, and that this part was never buried. At this point the upper limit of the pure rock supporting fill which is about 25 cms. below the fur

surface drops abruptly about 30 cms to a stratum of disintegrated mortar and small stone. The indications are that the still exposed portion of this period here dropped about 75 cms to a lower level. But if so, the stone facing of the terrace thus formed was torn out when the floor was extended to the southeast at the upper level. On this assumption, the final surface of the whole platform which we have numbered J-7 was a composite of Period 3 and Period 1 constructions. We cannot illustrate this without a larger drawing and do not insist on the idea, which requires more digging to prove.

The fill of all platforms from the three early building periods, except where the total depth of the structure is less than 30 cms. and in the region just behind terrace of side walls, is composed of pure broken rock, many of the stones quite large. The floor, laid directly on this, was of good line concrete varying between 10 and 15 cms in thickness, and surfaced with finishing plaster of apparently pure lime, well smoothed and probably polished. Terrace and other retaining walls in Periods IV and III are fairly well built of good sized stone blocks, with parallel upper and lower surfaces, the faces plastered. Stone retaining walls of Period V were not examined. All finishing plaster on floors, terraces and steps was white as found, and since color was preserved on vertical walls of buildings encountered we may conclude that the substructures never were painted.

#### Period II

With Period II we come to a very different type of substructure. When built the section examined formed one of two exposed sides of the great platform which was built out from the Acropolis hill to form Court 2 of the Acropolis group. The height to be reached was 6 m, which was divided into two terraces, the first 3.30 m high and 1.70 m broad at the top, the second 2.70 m high and running back 1 m to the basal plinth of Structure J-9, which rests upon it. The batter of the walls is about 72 degrees from horizontal, that is to say, steep, but well off from the vertical. The terrace facings are well built of good-sized blocks of the character above described laid in mortar, and were finished with white plaster. Again, no color was found, though the lower terrace and the lower part of the upper were well-buried and sealed in Maya

times.

About 45 cms behind the face of each terrace wall was the face of another, of crude construction, dry-laid without mortar and without finishing plaster, rising behind the outer shell at the same angle. We have not attempted to show details, of this sort in our plate. Between the two was a thin fill of small pure broken rock. In one sense the exposed wall is thus a veneer, but it is not bound to the inner constructional wall in any way, though through the medium of the fill between, it leans against the constructional wall. This same building practice has been observed in the two lowest of the three terraces of one and one half meters behind the face of this inner constructional terrace wall we passed through and extremely irregular and carelessly laid dry wall, which rose vertically from the old floor at our feet to the under side of the concrete floor of the terrace above. At that height the distance between the two faces was only about 70 cms. Eighty cms farther in we came to another of the same character. Both run roughly parallel with the face of the terrace, for an unknown distance northeast of the side of our tunnel. But, at the Southwest side of our tunnel they ended against a similar vertical dry wall, more carefully laid which the tunnel had been following on that side, and which runs an unknown distance into the interior. Toward the front, the latter wall runs out flush with the first mentioned inner constructional battered terrace wall, forming a corner and then turning southwest to form a continuation of the latter.

It is clear that the two vertical walls which were cut by our tunnel were erected after the last mentioned one running at right angles to them; and that the latter is joined to a unit of the battered inner terrace wall which runs southwest of our tunnel. Therefore all represent phases of one contemporaneous building operation.

It is fairly clear from this incomplete data that the fill; at least of the lower terrace was erected in sections partly bounded by extremely crude vertical dry walls which rose to the height of the terrace; it is highly probable and further that the sections were incorporated into larger units the dry-wall boundaries of which were laid with more care. A unit was probably a quadrilateral the sides laid with some care (though without mortar), vertical or nearly so except where they must follow the

slope of the intended terrace, within which unit two or more very carelessly built walls ran from side to side, marking the stages by which the hearting of the unit was built up.

The sides of the supposed unit were carefully enough laid to have structural value. Those within fell on moving a stone or two, and while they did not act as very useful bulkheads against slides of the rock fill behind them, standing to full height as our tunnel reached their outer faces, this function was probably not intended. A very slight movement of the fill behind, after removal of the fill in front, would have sent them tumbling. Neither the inner or outer faces of these transverse walls followed a given plane. On either side, one stone was as likely as not to jut ten cms or more beyond the next stones above and below.

On the other hand, the stones of the wall which we take to be one side of a main unit though also laid without mortar, are lined up to present a fairly regular face, and formed a wall which it would have quite difficult to tear out except from the top down. Both types of the walls were formed of blocks and slabs - i. e., upper and lower surfaces of the stones were parallel to each other - in sharp contrast with the shapeless broken rock which constituted the rest of the hearting.

In this respect they differ from crude walls found within the pure rock heartings of Structures J-3 and K-5-2nd, which were formed of shapeless broken rock like the rest of the fill: and to a lesser degree, from those of the constructional inner terrace facings in Structure R-3.

Apart from the absence of mortar, we seem to have here a striking analogy to the unit system by which the hearting of the warriors pyramid was erected at Chichen Itza, a New Empire building and supposedly late New Empire at that. Reasoning

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on admittedly incomplete data, we may set up the hypothesis, for future verification, that the better laid wall marks the boundary of a task assigned to an overseer, this unit very likely having structural significance, while the poorer ones represent the limits of tasks assigned to individuals or groups of individuals by the overseer.

That the bounding walls of both classes did not rise much ahead of the fill within them is quite certain, as these dry walls could not have stood free to any great height.

Vertical walls within the hearting of the upper terrace were not observed, but they may have been present. The tunnel into the first terrace was first made, and on tumbling the inner of the two crude walls such as avalanche of loose broken rock issued forth that the fill behind the inner battered wall of the second terrace was drained to our tunnel below. When we broke through the upper terrace we found a great cavity where these walls were to be expected.

This cavity extended a meter or more under the plinth and floor of Structure J-9, proving that the latter is founded on the platform and therefore no older. The building on this plinth is a double-range stone vaulted palace, and we assign it to Period II. We have not dug into the building itself, and there remains a possibility that it is later than subsidiary platform or plinth on which it rests. If such is the case, it is erected on the plinth of an earlier building which was torn down. The reason for keeping this possibility in mind is the fact that not so far back from the other exposed side of the Court 2 platform, as at present constituted, is a building of similar plan, but without stone vaulted roof. In any case, Structure J-9 is later than anything yet considered, and is probably earlier than the Period V building still to be mentioned.

If there was a development of vault technic at the city which can be measured by the progressive lessening of the proportion of wall thicknesses to room widths, this is the earliest, or one of the earliest, double-range vaulted buildings in the city.

Period I-4a

#### Period I

Period I is represented by a single-range "built-on" vaulted room, now Room 3 of the composite single-range palace J-6. Our section passes through the central of its three doorways, but is drawn as though passing through the northeasterly pier, to bring out the thickness of the latter.

The building is bedded partly on the floor level of Period III, and against the lower and part of the upper terrace of the substructure of Period II. The building,

with its roof, really replaces the lower terrace of Period II<sup>1</sup>, and formed, before it fell, a broad promenade running below and in front of the top of the earlier platform. However, at the back of this promenade a secondary terrace was raised against the upper period II terrace probably to about half the then exposed height of the latter. It is possible that this secondary terrace, now badly fallen, reached to full height, completely hiding the face of the earlier one, and broadening its top.

At the time of abandonment, this structure formed the northeasterly of three rooms of the Palace Structure J-6. Room 1 of that building is fairly well dated at 9.17.15.0.0 as mentioned elsewhere. From evidence supplied by rear walls, which cannot be elucidated here, it is fairly clear that at least the vault covering Rooms 1 and 2 was constructed at the same time. But neither the vault nor rear wall of Room 3, is continuous with the same elements of Room 2. Room 3 which is the Period I structure of our section, cannot therefore be definitely tied to the dated Room 1, in the present stage of our knowledge. On the basis of the relation of wall thickness to room width, again granting a progressive development in vault construction and using only the outer (the only free) wall (Column J in Table 3) the Period I building is clearly later than the Period II building; and with less certainty, earlier than the dated Room 1, in its final form. Of course, if Structure J-9 was the first building to be placed on the Period II platform, and is contemporaneous with it, the Period I building is certainly later.

#### Summary

Recapitulating briefly the features of the various periods may be instructive.

#### -Stone-walled Buildings-

Stone-walled buildings occur in Period V (the earliest) and Periods II and I (the latest) and there is no reason to suppose that further excavation would not reveal them in the intervening horizons. The earliest free-standing walls show much greater attention to artificially squaring corner blocks.

Red paint appears on the earliest walls, but may have weathered away from the latest.

One of the earliest finds has walls thinner than either of the later ones

on this section, and thinner than the majority of free-standing vaulted buildings of the city (see Columns C and E , Tables 1 2 and 5). None of these walls is as thick as several observed in both vaulted and non-vaulted surface buildings.

The earliest structures appear to have been a cluster of very small free-standing building, very possibly arranged around a court. The latest, one free-standing, the other "built-on", are very long, and were certainly grouped in courts.

All were finished with plaster.

The latest were roofed with the stone vault, while the evidence as to the earliest is lacking. Stone walls in themselves do not imply stone vaults, as we know from several surface examples elsewhere.

#### -Wooden-post Buildings-

One of these certainly occurred in the earliest period, and there is no reason to suppose it did not occur on the next two horizons. It occurs directly under a vaulted building, which, on the progressive development thesis, is the earliest of its type yet discovered. The wooden-post type, however, probably persisted to the end, as evidenced by many surface platforms devoid of stone vains.

#### -Substructures-

Pure broken rock hearting, surfaced with a thick sheet of lime concrete, with stone-faced sides the stones laid in mortar is the fundamental basis of construction throughout. A finishing coat of apparently pure lime plaster, unpainted, was also used at all periods.

Of the three early horizons the platforms are very low, and where a terraced side was observed, the terrace is very broad in relation to its very low height . The batter of side walls is slight. No interior constructional walls were observed within the hearting of these low platforms. On the next horizon the platform is very high, the terrace narrow in relation to its height; the terrace walls have a decided batter and are double faced, the hearting apparently was constructed in units. The Period I building has no substructure of its own (other than its basal plinth) and in effect it is an extension of the Period II substructure.

There is no reason to suppose that broad low platforms did not persist to latest times at other points.

The substructure of Period II is linked by its height, terrace proportions and complex internal construction to pyramids of the city. This high platform - pyramid concept cannot be linked exclusively with vaulted buildings, as shown in our tables, and must therefore be treated as a separate unit. In this case both high platform and vaulted buildings are superimposed over low platforms, a wooden building and stone-walled buildings which may not have been vaulted. The later buildings Periods I and II are probably very much larger and they are definitely vaulted; the later substructure is so much higher (and, from surface evidence, longer) than anything revealed by our trench in the lower three levels, and that is belongs to a radically different type.

-Estimate of Total Period of Building in Court 1-

Whether these differences between the first three and the last two periods are to be attributed to the time interval between the groups of periods, or to differing function, can be definitely proved stratigraphically only by similar investigations under other high platforms and pyramids. With this in mind, it is permissible to point out that very substantial stone buildings, though probably small, were scrapped when Period IV (next to earliest) began; that (the latter continued) long enough to call for an addition; and that there are two distinct floor levels in Period III. The erection of the Period II, platform changed the appearance of Court 1 radically, and so did the erection of the Period I building. Finally the latter is now part of a composite building and is separated from another part well dated at 9.17.15.0.0 therefore, considering structure J-6 as a whole Period I can be split into at least two phases. If we count only operations which obliterated or radically changed what went before, we have only our five periods. But builders busied themselves in this court at least eight times, very possibly more. It is therefore quite possible that the earlier levels go well back into the city's history, to a time the Acropolis was a comparatively modest affair, or even when it was merely a peripheral domiciliary district.

Pottery

We were disappointed, though not surprised, that a cut so rich in positive stratigraphy was very poor in sherds, so badly needed for estimating the time periods involved in our cut. The sequence has possible ceramic value, however, apart from the sherds found in it. It is fairly certain that the stone buildings of the earliest period made use of the present Court I floor, or that they rest on a substructure descended directly to bed rock, disassociated from concrete pavement or floor at some level in the area of Court 1 is highly improbable from a Maya point of view. An earlier floor 3.65 m below the latest, pierced by a pit just northwest of the center of Structure J-2, on the adjoining side of the same court. At a depth of 2.60 m below that earlier floor and its supporting fill, for the most part directly on bed rock we obtained a fairly rich collection of sherds and animal bones, apparently refuse. It is practically certain that they pre-date the building of our earliest Period V, as they lie below two floors, one of which almost surely is connected with the Period V structures. The sherds certainly are not very late, and they may be very early, in the history of the city.

Despite the nearly complete collapse of all the vaults in these buildings, we believe restorations from our fragmentary data will be of use, if interpreted with caution. It is only fair to point out the probable sources of error.

The elements which must be known for a positively correct cross section of a ~~xxxx~~ simple Maya vault are the amount of the offset at the spring, the angle of soffit slope, ~~the~~ and the width of the exposed portion of the capstones, assuming we know the width of the room. From these elements we can lay off a true cross-section, and measure the vault height, and the height at the which the slopes would meet if projected into the ceiling.

There are sufficient remnants of vaulting still extant on Structures J-9, J-2, <sup>(end room)</sup> J-8, Room of J-6, J-23 (end room), J-21, J-22, Room 6 of J-2, J-11, J-6-2nd~~nd~~ Rooms 1 and 2 of J-6, and in the East Group, the sanctuary of ~~P~~-7, to justify the assumption that stepped or curved vaulting was <sup>not used</sup> ~~unknown~~ at Piedras Negras. That is, we are sure we are dealing with simple flat (though sometimes rather irregular) soffit slopes. Without this knowledge, reconstructions would be of very doubtful value.

Offsets of about 10 cm at the vault spring have been observed on Structures J-9, J-2, J-8, ~~J~~ Room 3 of J-6, J-6-2nd and Rooms 1 and 2 of J-6. Offsets of about 5 cms have been observed on Structures J-21, J-22, and J-11. However, on Structures J-9, J-8, and J-11, the offset is present at one point, absent at another, in the same room. It is absent on remaining measured sections of main vaults in the following buildings:

It is quite possible that offsets were the rule in these as in the other structures, and were merely absent at the points now visible through careless construction. It cannot be supposed that such irregularity affected the actual vault height (to the cap-stones). Such irregularities

were, without any serious doubt, absorbed by irregularities in the soffit slope, or by by an irregular line marking the junction of the slopes with the underside of the cap-stones.

However, when the vault height is unknown and must be calculated, <sup>from measurements on the lower portion only,</sup> failure to allow for an offset which was in general the rule, will affect the calculated height, because the angle of slope as measured at such an exceptional point will be greater (i.e. farther from the vertical) than where the offset is present. The more ~~near~~ the error in this direction, the lower the point at which the theoretically restored ~~vault~~ slope will meet the cap-stones. In the above mentioned cases, where offsets were absent at the measured points, the true vault heights were possibly higher (but not lower) than those which we use. If we allowed for this possible error in the cases cited, the <sup>differences</sup> ~~discrepancies~~ between vault heights in supposed early and late buildings would be greater, and not less than the actual measurements indicate. Differences in weight would likewise be greater since, other things being equal, ~~they~~ weights vary <sup>directly</sup> with the vault height. Where a vault remnant is quite low, and the measured angle steep, as on Structure J-11, the error in vault height calculation may be considerable. In this case, which ~~is~~ involves the probably maximum possible error on this score, if ~~we~~ restore an offset of five ~~cm~~ cms. the height would be increased by about 70 cms.

Where an entirely hypothetical vault is assumed we are <sup>of</sup> course on dangerous ground, and these assumptions must be justified on general grounds in each case. In such cases, even if the angle of soffit slope <sup>is correctly assumed,</sup> ~~were known,~~ the mere failure to introduce an offset which had in fact been present will operate to <sup>increase</sup> ~~reduce~~ the calculated height. Among the low calculated heights, we may be in error on this account in Structures J-13 and J-10. By eliminating the supposed 10 cm offsets in these buildings, the calculated vault heights would be raised <sup>to by</sup>

<sup>20</sup> *(the first 19 cms in the second)* *(about 22 cms)*  
~~fix and~~ about ~~17~~ cms in ~~each~~ case, if the slopes are correctly assumed  
For a slope of 24 degrees (assumed for J-21) the error would be 22 degree  
at 28 degrees. ~~An error of 1 degree in assumed (or measured) soffit~~  
slopes will affect the ~~height~~ vault height <sup>also in</sup> in a variable manner,  
depending on the width of the room. For Structure J-13, if the correct  
angle was <sup>27</sup> 29 instead of 28 degrees, the height would be calculated  
at 6 cms. more. In the case of J-21, assuming an error in the other  
direction, that is a soffit slope of 25 instead of 24 degrees from  
vertical, the calculated height would be reduced by about 12 cms.

If we are wrong in assuming that 30 cms of cap stones were  
left exposed, the error is of the same kind as omission to allow for  
an offset. If 10 cms more were exposed, this is to be divided between the  
two half vaults and the vault height would be reduced by one-half the  
amount for a 10 cm offset. <sup>10 cms</sup> If less than 30 cms of cap were left visible,  
the height would be greater by approximately the same amount.

Our measurements of soffit slopes were made in the following  
manner. A ~~knux~~ pumb-bob was suspended from the highest <sup>remaining</sup> visible point  
on the slope. A meter stick was held horizontally against the wall at  
the spring of the vault, and was then moved slightly up and down until  
it gave the lowest possible reading for the horizontal distance to  
the string. The ~~string~~ cord was then grasped where the stick crossed it,  
and measured for the vertical component. This method is not all that  
it should be. The horizontal measurement, taken in this manner, is as  
accurate as the subject matter warrants, but the possible error is  
greater for the vertical distance. We believe 5 cms is the maximum  
error ~~in the vertical distance~~ likely to be made in measuring the  
vertical component in this manner. <sup>and this would change the angle about 1 and one-half degrees.</sup> The effect on calculated vault  
height again would vary with the room width. For Structure J-13, if  
the angle was  $26\frac{1}{2}$  instead of 28 degrees as assumed, the height would be  
about <sup>8.5</sup> 10 cms higher. For Structure <sup>J-21</sup> J-13 the same error in the opposite  
direction would reduce the calculated height about <sup>16</sup> 15 cms.

It is unfortunate that measurements on actual vaults in

the last of the double-range buildings of the  
the two crucial buildings, J-13/~~and J-21~~, ~~at the end of the~~ supposed  
J-21 at the beginning  
early and/beginning of the supposed late vault period respectively,  
are lacking. As a test of whether or not we ~~are~~ may be fooling ourselves  
when we draw conclusions from vault reconstructions, let us stack  
every card against ourselves in respect to these buildings. That is,  
we shall try to raise the possible height ~~of~~ (and vault weight) of  
J-13, and lower that of J-11 by arbitrarily choosing unknown  
elements. ~~in the right direction~~ The reconstructed <sup>vault</sup> height of J-13  
is 1.05. By eliminating the supposed offset we raise the height 20 cms.;  
17cm; by ~~increasing the height~~ reducing the soffit slope  $\alpha$   
from an assumed 28 degrees to  $26\frac{1}{2}$  degrees, we can add  $\frac{8.5}{3}$  cms more;  
and by assuming that only 20 cms of cap stones were left exposed, we  
add  $\frac{10}{2}$  cms more, and reach a possible height of ~~1.33~~ 1.43 m.

The reconstructed height of J-21 is ~~2.58~~ <sup>2.40</sup>. Here by adding a  
10 cm offset we reduce height by  $\frac{25}{22}$  cms; by ~~decreasing~~ increasing the  
slope angle  $1\frac{1}{2}$  degrees we reduce  $\frac{16}{3}$  cms more; and by widening the  
cap-stone exposure we bring it down  $\frac{11}{25}$  cms more, with a resulting  
height of  $\frac{1.91}{2.08}$  cms. There is no reason whatever to suppose that any such  
diabolically regular series of errors has been made, but even so,  
the difference <sup>51</sup> is  $\frac{1}{3}$  cms, an increase of <sup>35</sup>  $\frac{1}{4}$  per cent.

The same sort of tactics cannot be applied to the last of  
the supposed early period structures, a single range built-on type,  
~~Structure 3~~ Room 3 of Str. J-6, since the offset was plain, the  
soffit measurements unusually satisfactory, and the actual roof level  
known with practical certainty. We can, however, assume a  $1\frac{1}{2}$  degree  
error in measuring soffit slope, which would raise the vault height  
about 10 cms to 1.60 m, leaving a roof ~~height of~~ thickness of 40 cms,  
which is surely close to the minimum. Allowing for this adjustment,  
the difference between the vault height of the highest of the supposed  
early period buildings and the ~~lowest~~ ~~---and---ear---~~ the earliest of

the supposed later periods ~~ix~~ arbitrarily reduced as above is 31 cms, or 19 per cent.

We conclude therefore that although our reconstructions are not to be taken as literally correct, failure to correctly allow for missing offsets, exposures of cap-stones, <sup>and</sup> errors <sup>in</sup> ~~and~~ measuring slopes, cannot account for the marked differences in vault heights observed in our early and later vault periods.

We still must explain our reasons for selecting various features specific in/hypothetical reconstructions where definite data was lacking.

I<sup>all</sup> we have assumed a cap-stone exposure of 30 cms, which is the figure for Structures J-10 and the Sanctuary of P-7, the only buildings with cap-stones in place.

Since measured slopes run from 24 to 30 degrees, we are here especially likely to go wrong. *in guessing the angle of an entirely missing vault.* A slope of 28 degrees has been used for Structures J-2, J-13 and J-10 in the supposed early period <sup>as</sup> it is practically identical with that measured on ~~J-2xxRxxxxxxfx~~ Room 3 of J-9 of the same period. We deduct the half-degree for convenience and because we would rather err in the direction of higher vaults rather than lower, when dealing with a period characterized by low vaults. We

We use the same figure rather than a lesser one in two later period buildings. This is done in J-22 in the absence of recorded data because it gives a low <sup>rather than high</sup> vault height in a period characterized by high vaults. This slope very likely was steeper. It is used for Room 1 of J-6 because it gives a reasonable roof thickness, <sup>for</sup> the roof height being approximately known.

We use slopes of 24 degrees on J-21 and J-18, without offsets, in conformity with J-11, which they resemble in several particulars, apart from dimensions.

It should be stated that greater angles could have been used on these buildings, with consequent lower and lighter vaults, without interfering appreciably with half-vault stability. Our only evidence

for these steep slopes is the measurement on J-11, and a still steeper one on J-23, where we resort to an end room which, however, is of the same width as the galleries. It is perhaps worth while to state that <sup>merely</sup> increasing the angle soffit slope of J-21 from 24 to 28 degrees would only reduce the vault height by ~~1.67~~ 73 cms, to 1.67, which is quite close to a possible vault height for Room 3 of J-9 in the early period. However, it is more likely that this slope agreed with or approached that <sup>of</sup> the similar Structure J-11, and anyway it is more properly compared with the last of the double range palaces, J-13. The real basis for assuming vault slopes in J-21 and J-18 were the same as in J-11 is that they belong together, and differ from the three ~~of~~ supposedly earlier double range palaces in so many other particulars - greater absolute room widths, lesser absolute wall thicknesses.

In two single range buildings which we believe belong to the later period, we use a slope of 28 degrees for a special reason. In each case the approximate roof height is known, in both cases offsets are present, and the only unknowns are the slope and the cap stone exposure and the roof thickness. Sticking to our 30 cm cap exposure, and figuring that a roof thickness was probably not less than 40 cms, slopes of about 28 cms result. A slope of 24 degrees, ~~or 24~~ for instance, would reduce the roof thickness of Str. J-22 ~~to~~ from 45 to 10 cms. Since the roofs of these buildings formed terraces projecting from substructures or platforms of others, an esthetic motive for keeping down height was probably involved. In the case of ~~Room 1 of~~ Room 1 of J-6, this height had probably been already determined by Room 3.

We can say then, that none of our assumptions are mere guesses, though the resulting figures are without question only approximations. Some of the gaps can be filled by further work. In particular, a

a little excavation will give main vaults slopes for the important Structure J-21, for J-22 and possibly for J-13.

So far we have rehearsing ~~xxxxxxx~~ the inaccuracies in reconstructing the inside lines of the vaults. However, ~~the-~~ ~~design of the vaults side, the upper zone of the building~~ Vault height depends on these alone. When we come to the total height of the building, and weight, other factors enter.

In no case which we know is the <sup>thickness</sup> width of an outer half-vault at the base the same as the wall thickness. Not only must this, but whether the outside or upper zone is vertical or sloping, and if sloping the angle, must be known before we can calculate weight. From the point of view of stability, we must know how the half-vault is placed on the wall.

Two factors we have disregarded - the weight and stabilizing effect of mouldings or cornices, and the actual roof thickness. The influence of the former was surely negligible. Our data on roof thicknesses is so fragmentary that we have not calculated it for the unknown cases.

We cannot get anywhere, however, in the important matters of actual weight and stability, without knowing or reasonably approximating the design of the upper zone - the outside of the half-outer half-vault. For ~~xxxxxxx~~ all three of the supposed early period double-range palaces, this is known to a satisfactory height. The two earliest are "inset" - that is the surface of the upper zone, projected ~~down~~ downward through the medial moulding, meets the ~~outer~~ wall behind the ~~xxxxxxx~~ outer surface of that wall. The first is vertical, the second sloping. The third is sloping, but outset - the plane of the upper zone, projected through the moulding, is outside the wall.

In the later period we have only one outer zone partially intact. It is definitely outset, and it is practically certain that it is vertical. There is only one course remaining above the medial moulding, but it is

but a mass of hearting still rises behind and above it at such a steep angle that if the upper zone was not vertical, it was nearly so.

In our reconstruction of this building we make it vertical on this evidence and that fact that even so, the half vault is barely stable as a separate unit. ~~xxxxxxx~~ It is possible that the upper zone on this building did slope slightly, in which case slight outward thrusts would be introduced, ~~and~~ the weight would be slightly less.

This outset vertical upper zone we have applied to Structures J-21 and J-18 because of the other similarities between these three buildings already mentioned. In the case of J-23 we lift ourselves by our bootstraps and assume that because we think all four are late, that J-23 had the same type upper zone.

For the single range ~~pl~~ palaces we skate on thin ice, since not a single upper zone remains among them. We have here again had to assume that other evidence has established at least the major groups of our chronology, and apply known upper zone designs on an intelligent guess-work basis. So far as these buildings are concerned, we have merely shown that our suggested upper zones are possible from the point of view of stability, and, perhaps, probable from the point of view of chronology. ~~xxxxxxx~~ We have not used any sloping zones, because we have ~~xxxx~~ precedent for a vertical one in the supposed earliest building, and a vertical zone seems to us more suitable for buildings which really form parts of substructures. This is of course a pure guess. In the early <sup>period</sup> buildings ~~xxxxxxx~~ (Room 3 of J-6, J-8 and J-10) the zone is inset, in agreement with <sup>the earliest</sup> the early double-range buildings. In the others (J-22, Room 6 of J-2, and Room 1 of J-6) it is outset, in conformity with J-11, the latest double range palace, and also because, even so, the center of gravity of the outer half-vault is found to be close the inner side of the wall. <sup>amounts of</sup> The ~~actual~~ insets or outsets used are those of the known buildings.

For an index to weight, and in figuring stability, we use a quadrilateral figure. Its base is the line running from the inner base of the vault (including the amount of offset if any) to the point where the plane of the surface of the outer zone meets this line when projected downward through the medial moulding. From the inner end of this line a second rises on the ~~xxxxxxx~~ soffit slope until it reaches a point over the center of the room. This is the line representing the point where the other half-vault, similarly projected into the roof, would meet it. A horizontal line is run through this point, ~~and~~ where it meets the line representing the outer surface of the upper zone. This point is joined to the outer end of the first or base line, and so coincides with ~~exposed-portsions-of~~ the surface of the upper zone except where it passes through mouldings. The little triangle of masonry just above the capstone, which lies outside this figure, is ignored, but was with almost certainly more than balanced by the weight of the outside mouldings, which are also ignored, and which, though not so far to the other side of the center of gravity, are greater in actual weight. These omissions reduce the cross-section area and therefore indicated weight slightly below a true figure, but hardly affect the stability appreciably.

These slight omissions aside, the half-vault cross sections on which our figures are based, include all of the half-vault visible from the inside, plus about 22 to 32 cms of the roof thickness, depending on the soffit slope involved in a particular case.

Anyone who cares to assume a total roof thickness for a complete cross-section should add the whole amount to our vault heights, which are to the cap-stones only, but should remember that we have figured half-vault weights and stability to a point over the center of the room, which is within the roof itself.

Taking the above quadrilateral figure as a basis, we have found ~~the~~ its center of gravity by the graphic method described by

Mr. Roys. In the column summarizing this, zero means that the  
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center of gravity ~~was-found-to-be~~ of the outer half vault, as described above, is directly over the inner side of the front wall. \* Figures with a plus sign indicate the number of centimeters within the wall a plumb line dropped from the center of gravity would lie; those with a minus sign how far outside the wall - therefore within the room, such a line would lie.

We have not calculated actual weights, for we have made no investigations as to the actual weight of a given mass of masonry, but we have ~~fixure~~ figured the cubic content of a linear meter of each half vault. This is, of course, the ~~same-as-the~~ <sup>figure for</sup> area of the cross section multiplied by one, and is expressed in meters. Weight must, of course, vary directly with cubic content. We remind the reader again that to get the actual full weight of a half vault, there would have to be added to our figures the weight of upper mouldings and ~~in-each-case,~~ parts of the lower mouldings, ~~in-such~~ a small triangle above the cap-stones, all of which are small factors; and in addition a thick upper layer of the roof, which was certainly considerable. The latter addition would ~~addixx~~ detract somewhat from stability, and very probably acted to introduce slight outward thrusts in the more advanced buildings. Our figures indicate that all of them, however, could be raised to vault height, and 20 to 30 cms of roof could be added, before thrusts put in their appearance.

In this matter of vault weight there is one factor which we cannot allow for owing to the bad state of repair of the buildings. Vaults may have been very greatly lightened by the introduction of niches, as at Palenque. One such was present in a transverse vault in Structure J-21. It is fairly certain that they were absent in the early Structure J-9. About the others we cannot say. This is the

most serious lack in our information from the point of view of structural progress. If, as vault heights became greater, the weight was kept down by only semi-solid vaults, while technical progress may still be inferred, it was in the direction of design rather than improved weight sustaining masonry, or perhaps a combination of both. Such niches would add to rather than subtract to stability for a half-vault as a whole.

