PRELIMINARY FIELD REPORT No1: Vol 2-Final Structural Report

April 2000

"Documentation and Conservation of King Khasekhemwy's Funerary Monument at Abydos"

David O'Connor, Matthew Douglas Adams

with

William C. S. Remsen, Anthony Crosby and William Kelly Simpson

Egyptian Antiquities Project

USAID Agreement No. 263-G-00-93-00089-00

Awarded to

THE AMERICAN RESERCH CENTER IN EGYPT (ARCE)

Address: 909 North Washington Street, Suite 320, Alexandria, VA22314

By the

USAID Program Office of Productive Sector Development / Office of the Environment / USAID / Egypt

In collaboration with the United States Agency for International development and the Egyptian Ministry of State for Antiquities.

DOCUMENTATION and CONSERVATION of the SHUNET el ZEBIB MONUMENT

(c. 2,700 BC) **Abydos, Egypt**

PRELIMINARY FIELD REPORT NO. 1
(IN THREE VOLUMES)

VOLUME 2 - FINAL STRUCTURAL REPORT

Submitted APRIL 2000 to the

Shunet el Zebib Archaeological Conservation Project
David O'Connor, Project Director, Matthew Adams, Associate Project Director

University of Pennsylvania Museum-Yale University-
Institute of Fine Arts, New York University Abydos Expedition
David O'Connor and William Kelly Simpson, Co-Directors

produced by Conor Power, PE, Structural Technology, Inc. for

William C. S. Remsen, AIA, CSI, Architectural Team Leader
International Preservation Associates, Inc.
21 Eliot Street, South Natick, Massachusetts 01760-6040, USA
Tel. (508) 652-0216, Fax (508) 652-0166, E-mail wremsenipa@aol.com

This report was prepared for
The Egyptian Antiquities Project of the American Research Center in Egypt, Inc. (ARCE)
2 Midan Kasr Al Dubara, Garden City, Cairo Egypt
Tel. and fax (20-2) 354-8622, E-mail: arceeap@internetegypt.com
under USAID Grant N0. 263-G-00-93-00089-00 (formerly 263-0000G-00-3089-00)

Structural Technology Inc.

37 Buckingham Drive   Billerica, Massachusetts 01821   (978) 663 - 5232

February 2, 2000

Attention: Mr. William C. S. Remsen
International Preservation Associates
21 Eliot Street
South Natick, Massachusetts 01760-6040

Re: Structural Evaluation
Shunet El Zebib Monument, Abydos, Egypt

Dear Mr. Remsen:

Between February 16 and February 24, 2000, the author performed a structural evaluation of the monument identified as the Shunet Ez-Zebib located in Abydos, Egypt. Our purpose was to assess the current structural condition, to identify observable structural deficiencies and areas of danger, to prioritize problem locations that were discovered and to indicate potential systems of worker protection that we feel are mandatory during excavation near or adjacent to the existing walls. Since many areas of moderate to extreme danger exist on this site, we will also present a justification for "preconservation" processes that we feel must be performed before any consideration is given to excavation. Although methods of construction and deterioration are discussed in detail by other members of the architectural and conservation team, those which have had a significant structural effect on the present condition are discussed below.

The information contained in this report represents primarily the results of a visual inspection only. No destructive examinations were undertaken; however, two local excavations were undertaken by Matthew Adams, Associate Project Director which were used to determine the foundation properties for the structure. Two bricks and a mortar sample, which were taken from collapsed portions of the structure, were used to determine the density of the mud brick assembly and approximate strength of materials.

Appendix *A* contains Photograph Nos. 1 to 126 which indicate typically observed conditions at the site. In nearly all of the photographs two rule devices are used for dimensional reference. The first consists of a stadia rod marked in increments of .5 meters with a total height of 7.6 meters; the second consists of a rule device marked in increments of .05 meters, and .5 meters with a total height of 1.5 meters. Drawing S1, attached in Appendix *B*, represents a compilation of information gathered at the site including through wall sections, locations of photographs described in this report, suggested worker protection systems and prioritized areas of danger.

Our report is divided into the following areas of analysis:

A. A Brief Description of the Structure, Materials, Foundation and Soil Bearing Properties

B. Mechanisms of Deterioration Including a Discussion of Vibration and Seismic Considerations

C. Specific Wall Structural Deficiencies, Prioritized Areas of Concern and Methods of Dealing with Them

D. Summary

Our statements of opinion concerning the area observed are as follows:

A. A Brief Description of the Structure, Materials, Foundation and Soil Bearing Properties

A1. Overall Description.

Depicted in Photograph Nos. 1 and 2 as well as shown on Drawing S1 Shunet El Zebib occupies an extensive area and contains walls of massive proportions. The monument, which is rectangular in plan consists of an enclosure surrounded by two sets of mud brick walls. The longitudinal axis runs approximately in a northwesterly direction but for purposes of this report all walls will be referenced to the "job north" direction shown on Drawing S1 and as indicated on Photograph No. 2.

The outside dimensions of the inner set of walls, hereinafter identified as the main enclosure walls, are approximately 127 meters in length and 65 meters in width. The bases of these walls measure at least 5.3 meters in width and their present maximum height from the bottom of the foundation is on the order of 11 meters. As described by Photograph No. 3 pilasters were constructed on the exterior face of the main enclosure walls. Four openings into the enclosure have been identified and these are indicated on Drawing S1 along with the defined nomenclature for wall description used throughout this report.

The exterior length and width of the outer set of walls, hereinafter referred to as the perimeter walls, are approximately 137 meters and 77 meters respectively, while their maximum observed height above the foundation base is nearly 6 meters. Since the perimeter walls have undergone extensive deterioration above existing grade, their width was difficult to ascertain at the time of our visit but they appear to be on the order of 3 meters wide at the base.

Surprisingly, at certain locations such as that indicated by Photograph No. 4, the original surface on the walls is present and consists of a coating of mud over which has been placed a weak plaster of lime and very fine sand. Structurally, given their age and the materials used for construction, these walls are in remarkable condition, represent, to a degree, the limit of engineering with mud brick, and are worthy of whatever conservation and protection can be afforded them.

A2. Constructed Properties of the Masonry and Their Effect on Longevity

Unit Dimensional Properties

Table I indicates a range of brick and mortar dimensions from a sampling of specimens found throughout the Shunet. The definitions of items listed in the table will be provided further in the report.

Table 1. Brick and Mortar Dimensions Derived from Random Samples

Type of Brick or Mortar Sample	Sample Range and Average in Centimeters			
	Length	Width	Depth	Thickness
Through Wall Headers	25 - 28 Avg. 27	12 - 13 Avg. 12.5	7 - 11 Avg. 8.8	
Veneer Wall Stretchers	24 - 28 Avg. 26	12 -13 Avg. 12.8	9 - 10 Avg. 9.5	
Veneer Wall Headers	24 - 27 Avg. 25.5	12 - 13 Avg. 12.8	9 - 10 Avg. 9.75	
Mortar Head Joints (Vertical Joints)				0 - 2 Avg. 1.3
Lower Mortar Bed Joints (Horizontal Joints)				.25 - 2 Avg. .9
Upper Mortar Bed Joints				1 - 2 Avg. 1.4

The main enclosure walls were generally constructed using a two-width thick brick veneer attached to a massive core. The construction present within the Shunet and particularly within the core has certain properties that have a substantial effect on the longevity and stability of the existing construction.

The Exterior Veneer

The veneer generally consists of alternating courses of headers and stretchers as shown on Drawing S1 and as depicted by Photograph Nos. 5 through 8. Headers are bricks oriented with their end toward the face of the wall while stretchers have been laid with their length parallel to the face of the wall. Throughout the Shunet the brick lay-up pattern shown on Drawing S1 predominates but often two stretchers courses will alternate with one header course. Other inconsistencies occur but the important structural consideration is that the veneer is almost always simply two brick widths in thickness. The exterior pilasters are bonded to this veneer at every other course. The term "bonded" refers to the use of bricks which lap the joint between two architectural elements; the actual bricks performing this function are described as bond bricks or bonders. This terminology is illustrated on Drawing S1 and is shown by actual example in Photograph Nos. 5 to 7.

At those limited number of locations where bonding could be observed by the author, the exterior veneer appeared to be, by today's standards, poorly bonded to the interior core. The bond bricks appear to be irregularly placed and relatively few in number. The mud mortar used within the construction is quite adhesive and does contribute to the bond between the veneer and core; however, gaps in its use can be observed Photograph No. 7. As will be discussed below, the bonding method of the core is significantly stronger in the transverse direction (perpendicular to the face of the wall) than that of the veneer. The result of these findings and one proved by observation is that the veneer has and will, if exposed, degrade at a far more rapid rate than that of the core.

As indicated by example in Photograph Nos. 8 and 9, the exterior veneer has largely disappeared from the upper portions of the construction but very occasionally portions of the two width brick pattern can be discerned. This information, while not of significant structural use can be used to determine the approximate face of the wall and provides a numerical indication of deterioration near the observed location.

The Interior Core

Because of the absence of the veneer noted above, the interior core is the primary structural element of concern today. Its construction is radically different from that of the veneer. Photograph Nos. 9 and 12 illustrate the typical appearance of core brick throughout the Shunet. Note that in elevation as indicated by Photograph Nos. 9 and 10 bricks are stacked one above the other with all of their ends oriented toward the face of the wall. In this state the bricks are said to be stack bonded along the length of the wall. Intuitively, this condition creates vertical lines of weakness and in fact modern building codes require that longitudinal metal reinforcement be added in any construction in which this method of bonding is employed. Note also that the vertical (head) joints, between stacks are generally not well filled with mortar resulting in limited adhesion.

It should be noted that in rare cases these stacks are joined by bonders; two examples are shown in Photograph No. 12. In other situations the bricks in one layer are not stacked but have been laid diagonally along the wall or a joint reinforcement using fiber matting has been employed in the bed joints. We must stress, however, that such situations are rare.

In the longitudinal direction, therefore, where a brick mass is unrestrained, such as at the ends of standing walls, the wall may be considered significantly unresistant to vertical cracking. Such cracking is shown in Photograph No. 9 where the crack runs nearly the entire height of the wall. Numerous other examples will be specifically described in Section C of this report. Note also that when cracking is initiated the likelihood of erosion in the open joint is greatly increased.

In marked contrast, a section through the wall, depicted by Photograph Nos. 11 and 12, indicates that the construction in transverse section is characterized by bricks that generally overlap one another in a lengthwise arrangement known as running bond. In the transverse direction, therefore, the walls may be considered to be highly resistant to vertical cracking.

Note, however, that this increased resistance also implies that when a mass of wall surface has been disturbed through a degradation process and cracks indicate that the mass will fall perpendicular to the wall, the quantity of brick that may be dislodged will generally be quite large. This is best illustrated by Photograph No. 13 where large cracks are present and the extent of disturbance is quite large but the mass has not yet fallen; the wall still possesses sufficient reserve strength to prevent collapse. This is an unusual circumstance (unfortunately not unusual for the Shunet) where strong construction increases the consequences of failure.

One other feature of such construction is that bricks will tend to corbel over degraded areas and large openings rather than arch over them. Arching refers to the ability of brick to span longitudinally over openings. Corbelling simply refers to bricks which are stepped upward and outward from the wall. Photograph Nos. 14 and 15 illustrate areas where corbelling predominates; the west wall shown is severely undercut, but, due to the strength of construction in the transverse direction, failure of the upper section has not taken place. Similarly, the resulting ovoid surface shape over the large monastic cells shown in Photograph No. 16 and many other openings present elsewhere results primarily from corbelling rather than arching. Note that the corbelling present in one of the cells extends nearly to the top of the wall. This construction property is of great use when structurally evaluating the significant observed defects in the present structure.

As indicated by example in Photograph No. 17, the four corners of the structure appear to be well bonded. The use of both headers and stretchers laid in a radial pattern was observed. Thus, we would not anticipate a general separation of intersecting walls at the corners.

Summary of Anticipated Behavior

The anticipated behavior leading to degradation of the structure based solely on the construction methods can therefore be summarized as follows:

- The wall veneer, located on the outer two brick widths of the walls, has and will, if exposed, degrade at a far more rapid rate than that of the core.
- The interior core, the primary structural element of existing concern, is fundamentally weak in the longitudinal direction. At wall ends the brick mass is unrestrained and therefore significantly unresistant to vertical cracking and erosion.
- Where crack patterns indicate that a mass of wall surface is disturbed and that the mass will separate perpendicular to the face of the wall, the quantity of brick likely to fall will be large.
- The wall possesses limited ability to arch over degraded areas in the longitudinal direction; potential failures will follow corbelled zones of weakness.

Brick Testing and Computed Stresses

As part of our analysis we also performed an on-site compression test of one brick sample. Such testing is normally performed in a laboratory as a "prism" unit consisting of a masonry sample three bricks in height and including mortar. Since our test method was crude by comparison, we can only state that the brick strength as measured on site was on the order of 400 to 700 kPa (60 - 100 psi). This value is lower than that which we would anticipate. Thus, as part of the analysis of masonry on this project, we recommend that a sample be tested which can be reconstructed from mortar and brick specimens that have fallen from the structure. This information will be useful during potential shoring operations that are described in Section C of this report.

The density of the brick mass was computed using several site specimens and calculated as 1511 kg/m^3 (100 pcf). Since the Shunet resists primarily gravity loads, actual compressive stresses based upon this density were computed and found to be, for most locations, approximately one-half the field measured value. However, there are locations where severe undermining and/or degradation has taken place that may be at maximum stress; such locations will be delineated in Section C of this report.

Soil Bearing Studies

Two local excavations were undertaken by Matthew Adams, Associate Project Director that were used to determine the foundation properties for the structure. As depicted by Photograph No. 18 the Shunet's walls and pilasters rest upon a one course thick brick footing that bears on what can be described as a "dense or stiff to very stiff fine sand". The most common method of determining soil bearing capacities today consists of using a Standard Penetration Test during soil boring operations. The test involves the use of a 140 pound hammer, a split barrel sampler and requires a boring rig. While producing accurate results for different strata, the use of this method is somewhat impractical at Abydos and in the author's opinion unnecessary for the following reasons:

a. The use of other empirical guides for strength is well established and in fact such guides are used by many engineers to check the validity of the Standard Penetration Test. These involve manipulation of the undisturbed soil using the fingers and other devices. One of the more common such guides is found in Design Manual 7.1 - Soil Mechanics published by the Naval Facilities Engineering Command. Using the values published therein, the author would assign an estimated allowable bearing capacity of approximately 4000 to 6000 pounds per square foot for the soil found immediately below the Shunet footing. Assuming a possible Shunet constructed height of 40 feet, the original soil pressure would not have exceeded these values. Given the reduction in width and height, the existing structure is well within these values. (American Standard Units were used in this paragraph since nearly all empirical data was accumulated on the basis of those units.)

b. As depicted by Photograph No. 11 the structure has been constructed in "lifts". While siting down these lifts, the author did not observe sudden changes in elevation or excessive differential settlement which would indicate a weak bearing capacity or a weak underlying strata further below the footing.

The sands upon which the existing structure bears are easily disturbed. During archaeological excavation adjacent to this wall the lower edge bricks of the structure may be subject to slight distortions if the soil adjacent to or below them is disturbed in any manner. Such distortions while generally not a concern in modern cohesive structures, should be avoided in the Shunet due to the inability of the walls to span over areas of reduced capacity. We recommend that as soon as excavation of an area is completed, a sand protective backfill be placed against the wall base. At the wall surface such backfill should have a height of at least 30 cm above the footing and should extend outward at a 1 : 2 slope. The author assumes that following completion of site excavation and documentation a more extensive backfilling operation will be undertaken since this is one of the best methods of protecting the structure.

B. Primary Structural Mechanisms of Deterioration Including a Discussion of Vibration and Seismic Considerations

In its present state, the Shunet construction has been degraded to such an extent that even the short term survivability of some of its major elements is doubtful. Based upon an analysis of potential past seismic history, the author believes the existing deterioration results primarily from factors that have operated over a long period time rather than having been produced by short infrequent events. However, in its present unconserved state, the potential for damage produced by even the slightest earthquake ground motion is great; hence, this subject, as well as other short term events, will be treated separately in this section.

B1. Long term Deterioration

The long term factors contributing to deterioration of the Shunet are studied in detail in other portions of the main report; the author's purpose herein is to prioritize the structural effect of these factors on the Shunet. Sources of deterioration observed included bird excavations, man-made intrusions, rain and wind erosion of the surface, insect damage consisting primarily of mud-wasp accretions, and dog, jackal, and/or fox excavations. The manifestations and specific locations of these types of deterioration are described in Section C but descriptive examples are described below.

Dog, jackal and/or fox excavations at the base of the wall combined with wind-sand abrasion of the lower wall surfaces have produced the most significant threat to the stability of the overall structure. Examples of such deterioration are shown in Photograph Nos. 19 through 22. The damage depicted by Photograph Nos. 19 and 20 is believed to be relatively recent. Although not readily visible, this undermining of the wall at this particular location extends at least 1.5 meters in depth and is 3 meter wide. Numerous such cases were noted. Based upon the conclusions presented in Section A, we would expect this damage to eventually result in conditions similar to that described by Photograph Nos. 14 and 15 where long segments of wall have been undercut. Such undercutting severely reduces the ability of the structure to resist seismic loads, produces areas of somewhat unstable overhanging brick and is particularly dangerous when similar conditions occur on the opposite side of the wall.

Man-made penetrations of various sizes have been made throughout the Shunet. The two massive areas of degradation illustrated by Photograph No. 16 result from excavations made for the installation of monastic cells; a total of six cell locations were observed. Although such cells were originally constructed to an approximate 2 meter height, the deterioration resulting from this work now extends nearly to the top of the wall. As will be indicated, undercutting occurs on the opposite side of several of these types of intrusions. Secondary excavations for various compartments within these cells have resulted in local areas of extreme instability when they have been installed in close proximity to the original surface. Numerous other lower level penetrations of lesser size are present throughout the structure; several are visible in Photograph No. 16. Many of these are also man-made according to Matthew Adams, Associate Project Director.

A large number of much smaller excavations are visible on all surfaces. While it is not possible to identify the specific cause for each case, we did observe that a number of the resulting spaces are occupied by wrens and hawks.

Small to medium sized penetrations generally do not have to be repaired to insure the overall stability of the wall; however, each must be individually investigated since many contain areas of loose overhanging brick and at certain locations their presence results in locally unstable conditions.

Although erosion by wind and rain obviously produces serious conservation problems, it does not severely diminish the structural integrity of the walls except at those locations where such erosions are concentrated. In general, the walls tend to be covered by a thin mud wash; occasionally large mud droplets such as those depicted by Photograph Nos. 23 and 24 do occur. Such mud droplets appear to originate primarily from the top and from less steeply inclined face surfaces of the structure that have assumed a crumbly dust-like appearance and therefore are quite friable. Mortar washout of head joints tends to occur primarily in the immediate upper sections of wall surfaces; precipitation does not appear to be of sufficient magnitude to penetrate the inner core. Areas where rain and wind erosion are of serious structural concern are delineated in Section C.

One unusual source of degradation results from the accretions produced by mud wasps. Although these occur throughout the Shunet, their presence is particularly evident on the interior face of the south enclosure wall. Typical examples are illustrated in Photograph Nos. 25 through 27. These accretions have the consistency of light weight concrete; the material is very hard and extremely cohesive. Photograph Nos. 25 through 27 indicate that the nests are generally constructed on overhanging surfaces of brick and enlarge to a point where their weight can no longer be supported. Due to their cohesive properties, they loosen and fracture bricks when they finally dislodge. Note also that any protective shoring method employed during excavation adjacent to the wall must consider the large nature of these falling objects and the fact that they do not disintegrate on impact.

These forms of degradation have, of course, been present throughout the life of the Shunet and, with the exception of man-made intrusions, none can be eliminated. Continued deterioration has produced a structure that is quite sensitive to any form of disturbance including further degradation. Collapse of large wall sections with an attendant loss of historic fabric has already occurred and there is every indication to believe that collapse in the near future is a distinct possibility.

B2. Short Term Destructive Events and Their Potential for Damage to the Shunet

Short term destructive events include earthquakes, excessive wind pressure and localized vibration near the site. As stated above, the author believes that any disturbance to this structure is likely to result in a potential for failure. However, forces generated by high winds will only affect the Shunet if it is allowed to remain in its completely unconserved state. By calculation, the likelihood of high winds causing a major collapse is extremely low and thus this effect will not be discussed.

Seismic Hazard Probabilities and Potential for Damage

The region of Egypt has a historical record of earthquakes dating back 4150 years, a number of which have caused extensive destruction. For example, the Magnitude 5.9 Dahshour earthquake of 1992, located 429 kilometers from Abydos caused considerable building damage and killed or injured over 7000 people. Egypt lies adjacent to the boundary between the Arabian and African Tectonic plates; this boundary runs along the entire axis of the Red Sea, and follows the Gulf of Aqaba where it continues along the Dead Sea Rift. Throughout the world most earthquakes occur near such boundaries.

The Arabian Plate is moving roughly northeastward with respect to the African Plate. This condition creates a shearing action along the Gulf of Aqaba; the Sinai Peninsula created by the two arms of the Red Sea is a result of such movement. However, the land masses on either side and along the length of the Red Sea tend to be spreading apart. At extensional (spreading) boundaries, earthquakes tend to occur at a shallow depth below the earth's surface and are usually smaller than Magnitude 8. Of importance to this study is that this situation leads to larger and more damaging earthquakes occurring at either end of the Red Sea rather along its entire length. Specifically for Egypt, the greater the distance from the Sinai, the less likely a severe earthquake will occur. For example, within a 100 kilometer radius of Abydos there have been no earthquakes reported in the last thirty years while there have been more than 250 seismic events in the Sinai region in the same time period.

As will be explained below, Abydos appears to lie at the center of low seismic activity. Using the National Earthquake Information Database the author studied "significant" earthquake activity which occurred near Abydos from 2150 BC to the present. The term "significant" refers to earthquakes which can be destructive in areas extending to approximately 100 kilometers from the epicenter. Table 2, below, represents these findings. The damage levels indicated in the table refer to those which would occur at the calculated epicenter; obviously, the further from this location the less damage is likely to be produced. This table indicates that during the last 4000 years the closest significant earthquake occurred 242 kilometers from Abydos.

The information presented above is confirmed by the maps described by Figures No. 1 and 2. Completed and released in late 1999, Figure No. 1 represents the first quantitative analysis of global earthquake hazards. The map was compiled by international scientists as part by of a program funded by a number of groups including the United Nations and is of immense interest to engineers. Figure No. 2 represents an enlargement in the region of Egypt. In simplified

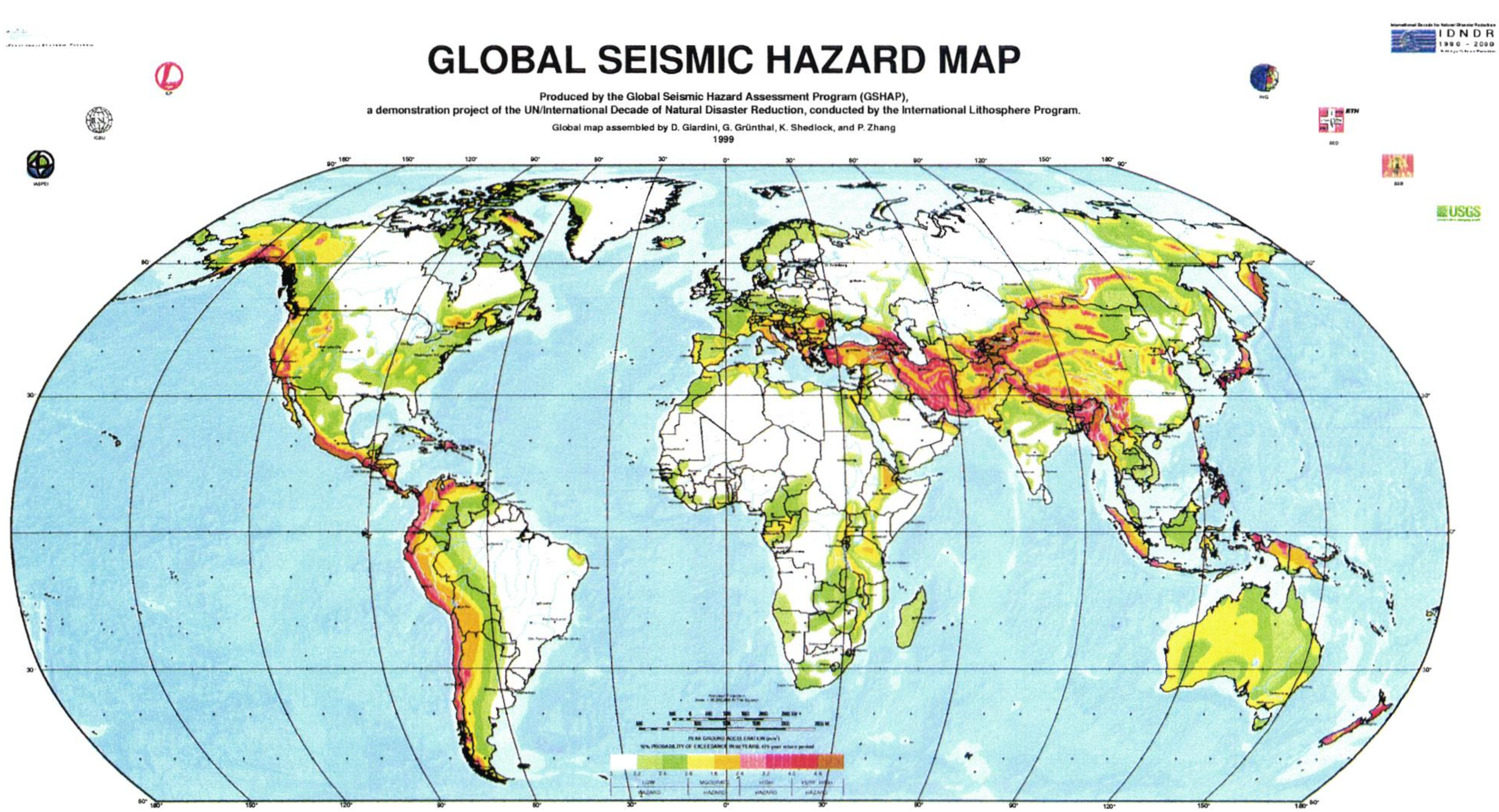


Figure No. 1 Global Seismic Hazard Map

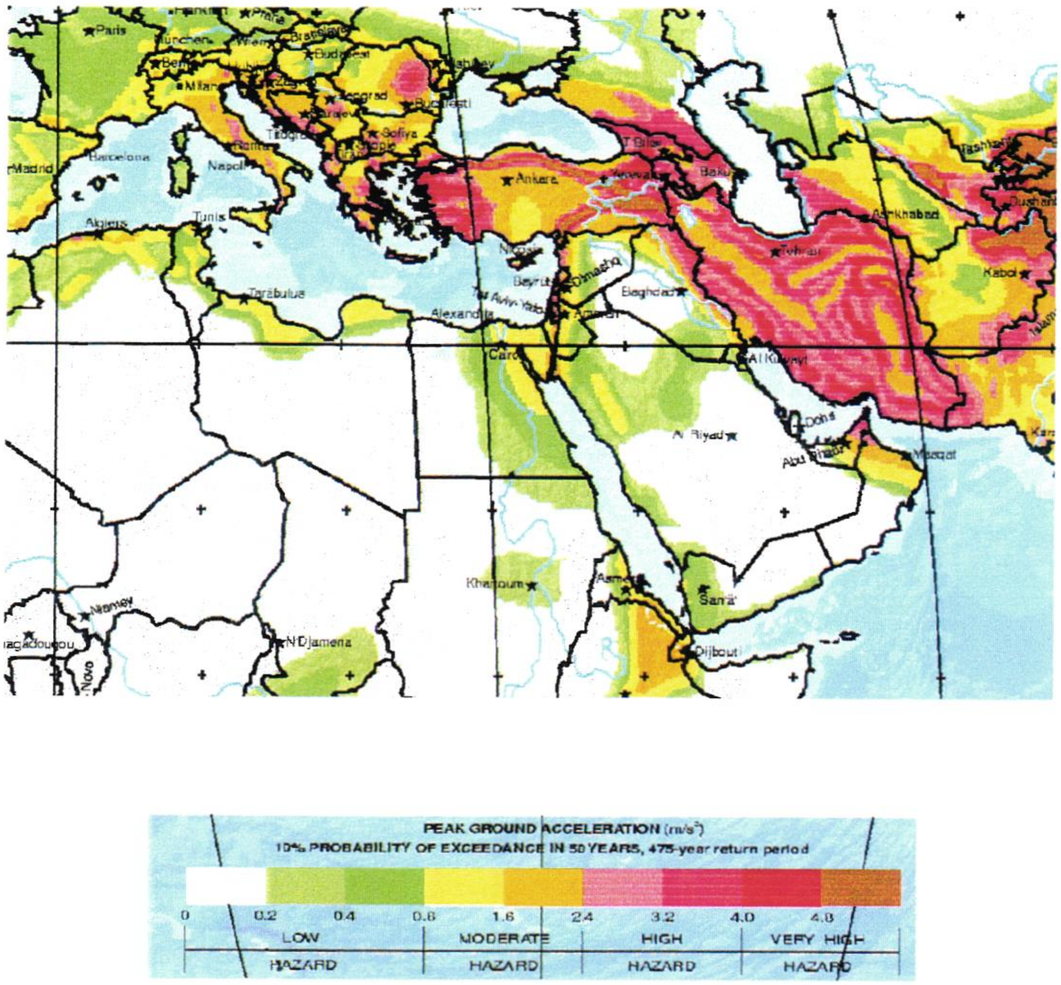


Figure No. 2 Earthquake Hazard Map, Egypt Area

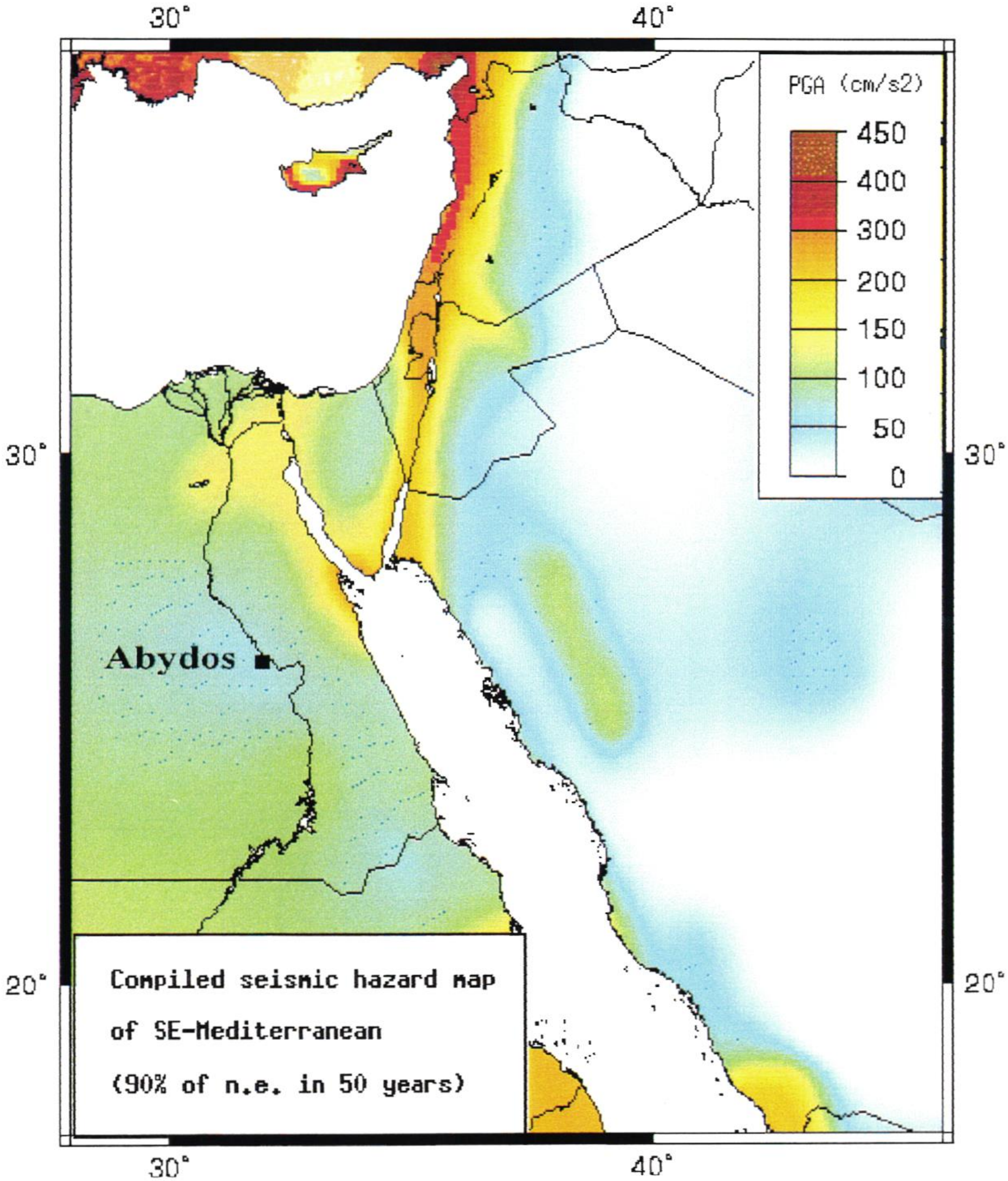


Figure No. 3 Seismic Hazard Map for Southeast Mediterranean

From "*Compilation of the GSHAP Regional Seismic Hazard for Europe, Africa, and the Middle East*, 1999 GSHAP, Grunthal et. al.

terms the different colors on the map represent the estimated hazard at particular locations as shown by the enlarged scale below the map. Abydos falls within a region of low hazard.

Table 2. Significant Earthquakes Since 2150 BC Occurring Near Abydos

Year of Event	Estimate of Damage at Epicenter	Radial Distance of Event from Abydos
2150 BC	Most Buildings Destroyed	660 km
33 BC	Considerable Damage to Well Built Structures	614 km
758	Slight to Moderate Damage in Well Built Structures	614 km
885	Most Buildings Destroyed	415 km
1067	Slight Damage in Well Built Structures	446 km
1201	Considerable Damage to Well Built Structures	242 km
1481	Slight to Moderate Damage in Well Built Structures	451 km
1752	Slight to Moderate Damage in Well Built Structures	614 km
1854	Most Buildings Collapse	414 km
1969	Most Building Destroyed	273 km
1981	Considerable Damage in Poorly Built Structures	250 km
1992	Considerable Damage in Poorly Built Structures	429 km

The information presented in Figure No. 2 is a somewhat simplified version of a more detailed earlier study performed as part of the compilation for the Global Seismic Hazard Map Program; these more detailed results are presented in Figure No. 3. An examination of this figure indicates that, within Egypt, Abydos actually lies within one of the lowest areas of seismicity along the Nile River. However, the possibility of a slight, although infrequent, ground motion still exists.

As stated previously, portions of the Shunet walls have been undercut by various forms of deterioration. At such locations the structure may be regarded as top-heavy and thus highly susceptible to any seismic forces. Given the desire to maintain the structure as a ruin, these undercuts will not be totally eliminated during conservation work. However, the ability of the structure to survive the slight and infrequent ground motions anticipated can be greatly increased by a light rebuilding of wall bases that have been degraded. The extent of repair is largely judgmental and is based upon the risk that all parties involved in the conservation effort are willing to undertake and upon the impact to the final appearance of Shunet. As a rough structural guide we would attempt, where possible, to rebuild the undercut areas such that the base of the wall is at least 90% of its present maximum thickness and such that the undercut is filled to within 0.5 meters of the present maximum wall dimension.

The Potential for Vibration Damage

During our visit to the site, some concern was expressed over vibration in the Shunet caused by farm vehicles passing within close proximity to the southwest corner of the Shunet. Most of the studies performed on the vibration effects to structures are based upon the work of John Wiss developed in his paper "Construction Vibrations: State of the Art" presented in the 1981 Journal of Geotechnical Engineering of the American Society of Civil Engineers. In that paper he proposed acceptable levels of vibration for historic and other structures which were expressed in terms of a value known as peak particle velocity. Since this value can be measured by a portable seismograph he was able to derive a predicted vibration versus distance relationship for various pieces of construction equipment; for the interested reader his results are presented in Graph No. 1 located in Appendix *C*.

At the time of his research acceptable levels of vibration for historic structures were largely judgmental; however, certain reasonable values have come to be adopted which limit damage risk. Over the past ten years the author has been given the opportunity to have construction vibration levels monitored adjacent to a large number of historic structures some of which are more fragile than the Shunet. Based upon this experience an acceptable level of vibration for the Shunet has been indicated in Graph No. 1. Based upon this information, trucks or farm vehicles should not be considered to create unacceptable vibrations unless they pass within 5 meters of the Shunet walls.

C. Specific Wall Structural Deficiencies, Prioritized Areas of Concern and Methods of Dealing with Them

In its present state the Shunet is an extremely dangerous structure; friable surfaces with loose brick and excessive cavitation are typical characteristics of all walls examined. At numerous locations the overall stability of parts or sections of wall is seriously in doubt. This section will describe these known deficiencies and potential methods of repair. The conditions are of such severity that to undertake excavation near the walls without any preconservation would be irresponsible. However, any repair or preservation treatment initiated will be a hazardous operation that must be undertaken using methods to reduce the potential for injury to those involved in a conservation or stabilization program.

We understand that the general intent is to maintain the Shunet as a ruin; however, this implies that not all deficiencies will be corrected to the extent such that a "safe" structure will result. Indeed to achieve a totally "safe" structure would result in considerable alteration of the present appearance.

The stabilization methods presented in this section recognize this understanding and considerable judgment has been employed to describe repairs that may not totally eliminate all safety concerns but which will greatly improve the existing dangerous conditions while retaining much of the existing appearance. Also, given this understanding, we recommend that no excavation be performed within a horizontal distance equal to the wall height even after repairs have been completed. We further recommend that all repairs and conservation treatments be assigned to a competent contractor who is fully aware of risks associated with this work and who will assume all liability for worker and structure protection. Such a contractor would perform his operations under the direction of an architect. Excavation, if attempted, should not proceed until the contractor's work at a particular location is fully complete.

We also recognize that the archaeological staff desires to undertake excavation adjacent to the walls and is willing to assume all the risks and liability associated with such action. Thus methods of worker protection are delineated below for repair of or excavation adjacent to the existing walls. However, these methods are intended to mitigate risk, not eliminate it, in the event that the above recommendation is not adhered to.

Since long term factors contributing to the deterioration of the Shunet are studied in specific detail in other portions of the main report, this section will focus on those existing deficiencies and conditions that have the greatest effect on overall safety and stability of standing walls. While this report is not a design document, potential repair approaches for dealing with the conditions discovered are described. Also each repair designated has been assigned a priority according to the following definitions:

Urgent - Those defects which affect the overall stability of the structure and which are likely to result in a massive failure or loss of important historic fabric if left unrepaired.

High - Those defects which affect the local stability of the structure and which are likely to result in a massive failure if left unrepaired.

Normal - Those defects which if left unrepaired will produce accelerated deterioration of the structure or which affect the stability of nearby brick masses.

Low - Those defects which are likely to produce a local failure of small size.

Note that all defects indicated in this section pose a serious life safety risk regardless of their size.

Problems associated with the outer perimeter wall are considered to be of low priority within this section only and are not discussed within this structural report; however, the conservation issues associated with the perimeter wall are discussed in the other portions of the main report.

For the exact location of our comments below the reader may wish to coordinate the use of the photographs noted with the information presented on Drawing S1 of Appendix *B*. The following deficiencies and conditions were observed:

C1. East Main Enclosure Wall

As shown by Photograph Nos. 28 and 29 the East Main Enclosure Wall has been divided into four sections to aid in the description provided below.

East Main Enclosure Wall - "Section 1"

1. As depicted by Photograph Nos. 30 and 31, a large somewhat detached mass occurs at the southeast corner of the structure designated as "Section 1". Through-wall cracking is evident throughout this area. A secondary smaller, but extremely unstable, mass is delineated in Photograph No. 32 and is surrounded by brick which is severely cracked. Calving is also evident at this location. For purposes of this report the term "calving" will be used to identify a brick mass which has separated from the main structure along crack lines which do not always follow mortar joints. The term "delamination" will be used to identify a brick mass which separates from the main structure along somewhat distinct mortar joint planes.

The stabilization of both the large and secondary detached masses should be assigned an urgent priority and the repair of each should be undertaken as a unit. Due to the extensive cracking at the secondary unit, we believe that an effective repair cannot be undertaken without local rebuilding. The main objective of such work should be to tie the large detached mass back to the south wall of the structure by bridging the existing cracks and rebuilding severely cracked areas. Such bridging need not extend above the level of the top of the secondary mass but every attempt should be made to "tooth" new brick to the existing work and to eliminate the sharp erosion junctures which now exist.

These repairs are relatively easy to perform and can be undertaken without exotic equipment but we would require the contractor to scaffold the interior corner and exterior locations in order to reduce the need to walk on the upper wall surface during repairs. Scaffolding and the terminology associated with its use will be described in more extensive detail below. Outriggers can be extended off the scaffold or, where appropriate, extensions from the scaffold could rest upon sandbag pads supported on existing brick surfaces.

Filling of the cavities that are shown in Photograph No. 32 and that occur below the secondary mass should be assigned a high priority.

Correction of every wall defect such as those indicated in Photograph No. 33 is not totally necessary from a structural viewpoint. However, such items, designated as low priority within this section only, present conservation issues and are discussed in the other portions of the main report.

East Main Enclosure Wall - "Section 2"

The interior and exterior views of "Section 2" of the East Main Enclosure Wall are described by Photograph Nos. 34 and 35.

2. At Location "A" a slight but continuous crack occurs at the top 3 meters of wall as shown by Photograph Nos. 36 and 37. Since particularly loose conditions combined with severe erosion occur at the interior, the repair of this item should be given urgent priority. During our discussion of basic wall properties we stated that the brick mass is largely unrestrained at the ends of standing walls and therefore unresistant to vertical cracking. As will be indicated repeatedly below, this type of crack is, unfortunately, quite common.

The easiest and most effective repair would involve rebuilding approximately the top .75 meters of wall for a distance of at least 1.5 meters on each side of the crack. The upper brick would be removed, a fiber reinforced mesh would be installed over the resulting bed joint area, and the top would be rebuilt directly over the mesh. If the crack is severe, supplemental stainless rods placed vertically through the mesh could be mud grouted in drilled holes in order to act, in combination with the mesh, as tee staples. As part of this repair, the sharp erosion patterns at this location near the top of the wall and visible in photographs would be eliminated or reduced in dimension by toothing new brick to existing work. Three cavities occur below this deficiency and their priority of repair has been indicated in Photograph No. 37.

3. Excessive erosion occurs at Location "B" as described by Photograph Nos. 34 and 38. Based upon present information this high priority repair would be undertaken by once again reducing the sharpness of the erosion pattern as previously described.

4. At Location "C" depicted by Photograph No. 34 loose brickwork and moderate cavitation were observed. Local high priority rebuilding is recommended in order to reduce the potential for accelerated deterioration.

5. Location "D" shown in Photograph Nos. 34 and 39 represents a particularly dangerous urgent priority condition in that the cavity extends behind a portion of the wall surface creating a thin veneer of unstable brick. The repair is relatively easy and simply involves local rebuilding with new brick toothed to the existing work.

6. At Location "E" delineated by Photograph Nos. 34 and 39, cavitation and erosion at the top of the wall have produced an area of loose overhanging brick which, because of the height and position, should be assigned an urgent priority for local rebuilding. During this work the sharp erosion pattern visible in Photograph No. 39 should be eliminated.

7. Between locations "B" and "E" very loose individual bricks were recorded within the top two meters of wall surface. One such brick was dislodged with a slight touch of the stadia rod. Such conditions are not likely to dramatically affect the structural integrity of the structure; however, they do present a known safety hazard. Regrettably, throughout the Shunet, numerous small defects occur which have produced or are likely to result in individual brick failure.

Removal of individual bricks simply to eliminate a safety hazard would appear to be inconsistent with preservation practice; the locations of the bricks are known and their original position can usually be deduced. Structurally, these have been assigned a low priority for repair. However, we believe that if this project receives reasonable funding, many such deficiencies can be corrected with minimum cost. For purposes of this report and based upon our stated recommendation concerning excavation adjacent to the walls, the question of individual brick treatment is a conservation issue that is addressed in other portions of the main report.

8. A large mass of corbelled overhanging brick occurs at location "G" shown in Photograph No. 40; a moderately sized cavity also exists on the south side of this overhang. Since the

surface below this projection has undergone considerable erosion, this is an example where a loose corbelled brick condition cannot be completely eliminated without extensive modification of the present appearance. As a reasonable treatment we would undertake this urgent repair by filling the south cavity and rebuilding the brick surface such that only the top three courses are corbelled. All new work would, of course, be "toothed" to that existing and any loose brick would be reset.

9. As depicted by Photograph Nos. 35, 40 and 41 a extremely large cavity is present at Location "F". A significant mud bee accretion occurs at the upper portion of the cavity; cracking indicates obvious downward movement on the south brick surface. The accretion and all loose brick should be removed, two half meter square by one-brick width deep shear keys should be installed on each side wall and the brickwork should be rebuilt at least to 0.5 meters of the existing general surface, "toothing" wherever possible. All loose brickwork at the outer surface within 0.5 meters of the existing cavity should be stabilized or rebuilt. Of extreme importance, this urgent repair should not be undertaken without buttressing at Location "H" and without worker protection installed against failure at Location "G". A suggested manner in which this work could proceed is described in detail below.

10. At Location "H" described by Photograph Nos. 35 and 42 a 3.5 meter length of wall has been undermined, presumably by dog activity, to at least a 1.5 meter depth. Such a condition does affect the overall stability of the wall and should be corrected on an urgent basis. However, the repair, if not performed with care and adequate preparation, could be quite dangerous. A method for dealing with this situation is indicated below. The cavity should be filled to the maximum extent possible; mechanical placement of infill brick should be employed in order to prevent workers from extending more than an arm beneath the wall during the repair. At least the outer 0.8 meters of the cavity should be filled in a solid, compact manner.

11. The upper wall surface indicated as Location "I" in Photograph Nos. 35 and 42 contains two large cavities, one depression and a number of conditions of loose brick. We recommend that this normal priority repair be completed as previously described for other locations.

Many of the repairs indicated for "Section 2" require work to be performed on the upper sections of wall at approximately a 7.5 meter height. A ladder certainly could be used to effect such work but not without further damage to the existing friable surface and certainly not without a loss of quality over other approaches that may be used. One such approach is to use scaffolding for both rebuilding and worker protection.

Scaffolding is simply an inexpensive, temporary, lightweight assemblage of metal piping that can be used to create working platforms and frames both of which may extend to a considerable height. Although scaffolds can be constructed in a variety of materials they are most often leased or purchased from companies which specialize in the manufacture of prefabricated modular assemblies. Sectional scaffolding and tube and clamp scaffolding are the two most widely used types employed in the construction industry. Catalogs and specifications describing each system and the type of frames that can be constructed have been attached as Appendix *D*.

Scaffolding is available in Egypt and, as shown by Photograph No. 43, was present during the author's examination of the reconstruction of pylons at Karnak. The framework shown in this photograph represents a combination of sectional and tube and clamp scaffolding. Simple planking was used for the working platforms.

The chief limitation of scaffolding for work at the upper portions of the Shunet wall is that it should not be constructed to an unsupported height that exceeds four times its minimum base width. At Karnak the scaffolding is, of course, much higher; however, it has been braced back to a stable structure at appropriate intervals. Attachment to the Shunet walls, for purposes of stabilizing the scaffold, should never be permitted. A variety of techniques can be used to overcome this limitation but we recommend simply clamping two sets of scaffolds together to, in effect, create a wider base.

On Drawing S1 we have indicated an example of how scaffolding may be employed to repair the deficiencies at the interior of "Section 2". This setup is intended to illustrate the typical use of this product during repair; however, the contractor must evaluate its applicability to his own needs. Based upon wind conditions observed at the site during our visit and to increase the rigidity of the system for practical work, note that we recommend that the base be sandbag weighted if the height of the scaffold equals or exceeds three times it base width. The work would proceed according to the following sequence:

a. The ground surface would be reasonably leveled by adding material from previously excavated locations.
b. Scaffolding, erected on plank footings, would be constructed to the height required to effect the repairs necessary at the upper portions of the wall.
c. All scaffold bases would be sandbag weighted; however, a 5 meter wide sandbag buttress would be installed against the undermined portion of the wall identified as Location "H". This buttress would interlock with and stabilize the scaffold but its primary purpose would be to reduce the risk of wall failure at this location.
d. The work at Locations "A", "B", "G" and "I" would be completed before any work is performed at the large cavity designated as Location "F".
e. The scaffold would be lowered to a one level height and substantial planking would be installed for protection of worker personnel.
f. Sandbags would be removed from one-half of the undermined length of Location "H" and as much of the void as possible would be filled with new brick. After a proper masonry setup time, the remaining sandbags would be removed and the void work would be completed.
g. The scaffolding would be removed.

As indicated above, scaffolding is also widely used to protect workers and the public during construction activities. Photograph No. 44 describes such a situation in the United States where sectional scaffolding has been installed along the sidewalk area adjacent to a fire damaged structure. For this structure wood planking was used to absorb the impact of objects which might fall from the structure; at the Shunet much stronger systems should be employed based upon the risk of failure of the wall. Scaffolding companies can supply closely spaced aluminum or steel beams covered by layers of plywood where the risk to workers is substantial; very heavy wood beams can also be employed where the risk is less severe.

As previously stated, we recommend that no excavation be performed within a wall height distance of the walls even after repairs have been completed; however, we recognize that the archaeological staff desires to undertake excavation adjacent to the walls and is willing to assume all the risks and liability associated with such action. On Details 4 through 6 of Drawing S1 we have indicated subjective magnitudes of risk and have suggested possible overhead protection methods which could be provided by sectional scaffolds. A relatively short length of such scaffolding could be easily moved to different locations as the excavation proceeds. These methods are intended to mitigate risk, not eliminate it.

The repair schemes delineated above are applicable with slight modification throughout the Shunet and will be referred to throughout the remainder of the report.

East Main Enclosure Wall - "Section 3"

12. The low height interior portion of the wall designated as "Section 3" on Photograph Nos. 28 and 29 contains some of the most dangerous conditions existing at the site; however, the exterior face shown by Photograph Nos. 45 and 46 is in remarkable condition despite the low priority local failure of several existing pilasters. The interior of this wall described by Photograph No. 47 is characterized by numerous undermining conditions, active movement of brick masses, extensive cracking and the presence of inclined brick surfaces. A potential for immediate failure exists at virtually any point along the entire length; all repairs indicated below should be assigned an urgent priority.

13. Within this section, thirteen undermined locations were identified; examples are described by Photograph Nos. 48 through 50. Many of these undermines occur at critical locations of concentrated load resulting from horizontal arching around previous wall failures such as those depicted at Location "J" and "K". The crack patterns shown in Photograph Nos. 51 to 54 indicate recent movement and the potential for massive calving of the existing brick volume in the near future. Additionally, numerous examples of local calving were observed.

14. A particularly dangerous condition occurs at Location "L" depicted by Photograph No. 55 where an extremely large rotated mass of wall exists. Extensive past and continuing undermining activity is evident.

The repair of "Section 3" could be accomplished by sequential rebuilding between sections of wall temporarily braced by sandbag buttresses. The buttress dimensions are indicated on Detail 13 of Drawing S1. The clear distance between buttresses should not exceed the buttress height. As general requirements intended to increase the stability of the buttresses we recommend that every other sandbag level be reinforced with fiber mesh and/or driven rebar between levels, that cloth rather than plastic bags be employed and that elongated bags be used in an interlocking pattern.

As indicated on the drawing we recommend the inclusion of horizontal steel beams to increase worker protection during undermining repair operations and at all other times whenever practical. The use of scaffolding located between buttresses and tied to them using tube and clamp methods should also be considered. At undermined locations the work should be accomplished in short one meter stages, which are fully completed and cured before proceeding to the remaining work.

Such work is inherently dangerous if the workers performing it are not continually supervised. Local rebuilding of smaller calves is required; however, considering the movements that have occurred, all parties should give consideration to dismantling and rebuilding larger portions of the wall rather than attempting the procedures indicated.

East Main Enclosure Wall - "Section 4"

The exterior and interior views of "Section 4" are described by Photograph Nos. 56 and 57. This portion of the East Main Enclosure Wall is characterized by excessive cavitation, the presence of a very friable surface, through wall and local cracking, erosion, base undercutting, areas of loose brick and overhanging projections of uncertain stability. The repairs indicated below are intended to greatly improve but not totally eliminate the existing dangerous conditions in order to avoid radically altering the present appearance.

15. At Location "M" delineated by Photograph Nos. 58 to 60 a large through wall crack with concentrated erosion at the same location has produced a detached mass of brick at the south end of the section. As shown this mass has experienced diagonal cracking on its west side and it lies above an undercut portion at the southeast corner. This situation has resulted in the need for an urgent repair of a dangerous condition. The diagonal cracks may indicate that a shear failure has occurred within the mass.

Since, the southeast corner of this section contains one of the best locations to observe the original construction methods employed by the Shunet builders and since the potential for failure during repair is great, we recommend that the top 2.5 meters of the mass be dismantled, that the southeast corner be rebuilt to a degree necessary to eliminate the undercut, that all loose brick conditions be corrected and that the top be reconstructed. The mud wasp accretion delineated in the photographs should be removed. As previously described for other such situations we recommend that fiber reinforced mesh be installed across the crack at a level of .75 meters below the upper for a distance of 1.5 meters on either side of the crack. Whenever possible, new brick should be "toothed" to that existing and the sharpness of the erosion juncture which now exists should be reduced.

16. At and near Location "N" designated by Photograph Nos. 61 and 62 many local areas of high instability exist including areas of loose overhanging brick, a large through wall penetration, an excessively eroded portion of wall containing loose brick and a somewhat concealed cavity having a fragile exterior surface. Although not all of the overhanging brick situations can be totally corrected, the severity of these high priority conditions can be greatly decreased by local rebuilding of the upper wall sections near this location to at least the general existing surface.

17. As indicated by Photograph Nos. 62 and 63 a very long continuous through wall crack occurs at the north end of the section. This urgent repair should be undertaken using those procedures previously described at similar locations.

18. Undercutting, cavitation and slight undermining conditions are somewhat concentrated on the lower portion of the west face as shown by Photograph No. 62. These are normal priority repairs.

C2. West Main Enclosure Wall

Specific locations on the West Main Enclosure Wall are delineated on Photograph No. 64. These will be used to identify areas of interest in the discussion which follows. The following discrepancies were observed:

1. A somewhat dangerous overhang occurs at the southeast corner as shown by Photograph No. 65 through 67. Since the brick below this condition extends beyond the defect, this high priority repair should be relatively easy to correct. The apparent small calve also indicated would be removed or rebuilt.

Near this same location at the position designated on Photograph No. 66 another overhang containing loose brick exists. Since the surface below this area has deeply eroded, this is another example of a situation that cannot be rectified without extensive modification of the present appearance. At this position we therefore recommend as a high priority repair that all small cavities and open joints be filled, that all loose brick be reset, and, if possible, the surface be rebuilt slightly outward beyond the existing contour using methods previously described.

2. A vertical through wall crack occurs near the southwest corner as shown by Photograph Nos. 65 and 67. This crack is not as serious as those at other locations and its normal priority repair can be undertaken without the need for reinforced fiber mesh.

3. Three areas of slight undermining occur near the southwest corner as described by Photograph Nos. 65 and 68; the repair of these should be assigned a normal priority.

4. At the south end of the Location "A" a vertical crack occurs at the position indicated by Photograph No. 69. This low priority condition appears to be one of the few cases that may have resulted from differential settlement. As shown by Photograph Nos. 70 and 71 a large sand dune exists at the interior southwest corner; producing increased bearing strata loads at that location.

6. A very long through wall vertical crack occurs just north of Location "A" at the position indicated by Photograph Nos. 71 through 73. Extensive erosion of mortar joints has produced numerous conditions of loose brick along the entire joint. Calving and other brick disturbance were also observed within the somewhat detached mass created by this crack. Based upon present information we believe that, as a high priority repair, this crack can be surface-sealed by local rebuilding along its entire length without the need for the installation of fiber reinforced mesh.

7. A large cavity produced by the construction of a monastic cell is shown by Photograph Nos. 72, 74 and 75. As indicated, a secondary chamber extends into the north side of the cell. Continuing loss of brick is evident on all surfaces; corbelling extends nearly to the top of the wall. Distinct downward movement, diagonal cracking and areas of very loose brick were

observed at and below the large mud wasp accretion delineated in Photograph Nos. 72 and 74.

On the interior side of the wall, shown by Photograph No. 71, the surface is typically characterized by deep base undercutting and excessive cavitation with significant areas of loose brick. A crossection through the wall at this location is delineated by Detail 2 on Drawing S1.

As will be described below, five similar cavities exist along the west wall. If such large cavities are allowed to exist, excavation adjacent to these walls would pose an extreme life safety risk and accelerated deterioration of the original monument will continue. We therefore recommend as urgent repairs that these areas be filled using reversible techniques with bricks whose age can be readily identified.

On original cell surfaces a bond breaker can be used to separate new work from old; however, at all other locations every attempt would be made to "tooth" to the existing construction and/or to install shear keys into the side wall. In order to indicate the presence of the cell, the reconstruction could be held back from the general existing surface by approximately 0.5 meters. Within three meters of such conditions, on both sides of the wall, existing smaller cavities would be filled and areas of loose brick would be reset as previously described. Scaffolding, similar to that described for the east wall and shown on Drawing S1, would be also employed at such locations to effect the repair.

8. In accordance with the above recommendations an area of loose overhanging brick with deeply eroded bed joints identified in Photograph No. 71 should be locally reconstructed.

9. A monastic cell also exists at Location "C" as indicated on Photograph Nos. 64 and 76 through 79. A wall section at this location is shown by Detail 3 of Drawing S1. The presence of a secondary chamber in the south portion of cell has produced an extremely unstable wall condition at the southeast corner of the cell as described in the photographs. At other areas, excessive cavitation, local calving and numerous conditions of loose brick also exist. A local wall undercut occurs at the north exterior face adjacent to the cell. Corbelling has reached to the top of the wall. This cavity should be filled as described above; additional areas to be filled are delineated on the photographs.

10. Between Location "B" and "C", on the interior side of the wall, an area containing particularly loose brick and a moderately sized cavity exists and is identified as Location "H" on Photograph Nos. 71 and 80. This cavity should be filled and the areas of loose brick should be reset as previously described. Moderate wall undercutting and slight local undermining are also present at the position identified as Location "I" on Photograph No. 81. As a high priority repair we recommend that this undercut portion of wall be reconstructed.

11. Local failures between two monastic cells in close proximity to each other have combined to create a large unstable section of wall identified as Location "D" on Photograph Nos. 64, 82 and 83. Crack patterns indicate the potential for a massive calving failure at this location. The interior side of the wall at this location contains numerous deficiencies and has been severely undercut as shown by Photograph Nos. 84 and 85; local undermining is also present. The overall stability of this section of wall has been greatly reduced. Our previous recommendations for repair apply to this urgent item.

12. Severe undercutting, local undermining and the presence of extensive areas of loose brick characterized the section of wall identified as Location "K" on Photograph Nos. 84, 86 and 87. Given the proximity to the monastic cells on the opposite side of the wall, we recommend that these deficiencies be corrected on an urgent basis.

13. An area of loose overhanging brick occurs immediately adjacent to Location "D" at the position indicated on Photograph No. 88. Repair of this normal priority item simply involves local rebuilding and resetting of individual bricks.

14. The wall gap designated as Location "E" by Photograph No. 64 corresponds approximately to the position of the original west entrance. Very significant vertical cracks occur at each of the end walls that frame this area. The first is described in Photograph Nos. 88 and 89 while the second is indicated by Photograph Nos. 90 and 91. The conditions at the latter position are further complicated by the presence of an extremely unstable mass of brick identified in Photograph Nos. 92 and 93.

Due to the instability of these locations we recommend that two rows of scaffolding be placed within Location "E" and that the end walls be temporarily be braced against such scaffolds. Sandbags should be used to both stabilize the scaffolding and to buttress the base of the walls. The vertical cracks should be repaired as previously described using fiber reinforced mesh; sharp erosion patterns and loose brick conditions should be eliminated.

We do not believe that the unstable mass delineated in Photograph No. 92 can be repaired effectively without dismantling and reconstruction; however, should an attempt be made to save this section intact, additional buttressing and scaffolds could be employed for that purpose.

Between Location "E" and "F" the typical interior and exterior wall characteristics include excessive cavitation, erosion, friable surface conditions, and the presence of numerous small areas of loose brick. Sensitive areas of small size are shown on the Photograph Nos. 94 through 96 and have been assigned a normal priority for repair.

The portion of the West Main Enclosure Wall encompassing Location "F" and "G" and illustrated by Photograph Nos. 96 and 97 contains a number of extremely unstable brick masses all of which must be repaired on an urgent basis.

15. Locations "F" and "G" represent the positions of former monastic cells but extensive degradation has removed considerable evidence of their existence. As shown by Photograph Nos. 98 to 100 these areas have undergone and are continuing to undergo extensive brick loss. Both locations should be repaired using methods previously designated. Location "G" is particularly unstable since the cavity is now quite large, it occurs near the end of the wall and since the wall adjacent to it has been completely penetrated by two large cavities.

16. These large cavities designated as Cavities "1" and "2" on Photograph Nos. 96, 97 and 101 to 103 are interconnected within the wall mass. Nearly all brick within the vicinity of these deficiencies has been disturbed; all surfaces are extremely fragile as indicated in the

photographs. In order to mitigate the possibility of failure during restoration, we recommend rebuilding without extensive removal of loose brick. Such loose brick would be consolidated using mud grout gravity injection and open joint compaction to the fullest extent possible. The wall would be built outward to conform to the general contour of the existing surface that exists beyond these deficiencies.

17. The through wall crack shown in Photograph Nos. 96 and 99 and the loose brick associated with it should be repaired using methods previously described.

18. In order to increase the general stability of the north portion of this wall, the eroded north west interior corner delineated in Photograph No. 96 should be rebuilt.

C3. North Main Enclosure Wall

The north Main Enclosure Wall shown in Photograph No. 104 has been arbitrarily divided into two sections to aid in locating prominent structural characteristics indicated below. The following deficiencies were observed:

1. A large overhang occurs at the present east end of Section 1 at the location described by Photograph No. 106. This high priority condition can be corrected by rebuilding below the overhang according to the procedures previously indicated.

The remainder of the exterior wall is characterized by low to moderate cavitation and erosion which have combined to produce a friable surface.

2. A large failure separates "Sections 1 and 2" as depicted by Photograph Nos. 105, 107 and 108. The presence of loose and fallen bricks indicate a continuing process of degradation. A mud wasp accretion occurs below a significant area of moderately unstable, overhanging brick on the north side of the failure while excessive cavitation, calving and areas of loose brick were noted mainly on the south side of the opening created by the wall loss. Deep and widespread erosion was observed at the position noted as Location "C" in Photograph No. 108.

Given the relatively good condition of the north interior wall, the ease with which the work could be undertaken from the top of an existing dune, and the potential for massive loss of historic fabric after excavation, the repair of this missing section should be assigned an urgent priority. All cavities shown in Photograph No. 107 should be filled, calved brick should be removed and rebuilt, loose brick conditions should be reset, Location "C" should be filled and the failed portion of wall should be reconstructed.

3. A large crack was noted at Location "D" described by Photograph No. 109. A number of small cavities are also indicated. For reasons discussed above we highly recommend that these normal priority items be corrected during any preservation process.

4. Two vertical cracks of moderate size were observed on the exterior side of "Section 2" at the positions shown on Photograph Nos. 110 and 111. Based upon present information the

brick at these two locations can be rebuilt without the need for joint reinforcing as normal priority repairs.

5. The interior view of "Section 2" is described by Photograph No. 112. At three cavities designated as Location "A" very loose conditions and local calving were observed. Similar deficiencies were observed at the area designated as Location "B". These situations should be corrected as previously described on an urgent priority basis. Given the ease with which work can be undertaken, we recommend that other low priority repairs be completed during the stabilization process.

C4. South Main Enclosure Wall

The South Main Enclosure Wall is described by Photograph No. 113. The following deficiencies were noted.

1. Local areas of loose brick combined with the presence of small calves occur at the southwest corner indicated in Photograph Nos. 114 and 115. One of the cavities delineated is two meters in depth and appears to be man-made. These normal priority items may be repaired as previously described.

2. The remainder of the exterior surface delineated by Photograph No. 116 is characterized by moderate cavitation, the presence of a very friable surface, local cracking, erosion, and local areas of unstable masonry. Three normal priority areas of concern are indicated on the photograph; Location "A" represents an 4.5 meter projection of loose brick.

The interior of the wall is shown by Photograph Nos. 117 through 120. The amount of brick and their distribution within the sand dune shown in Photograph No. 118 appears to indicate that a failure of massive proportions may have occurred at the southwest corner.

3. The remainder of the south wall depicted by Photograph Nos. 120 and 121 has been severely undercut on the interior face for nearly all of its length. Additionally, the base is moderately cavitated as shown by Photograph No. 122 and extensive local areas of loose brick occur. As an urgent priority repair we recommend that all such unstable masonry be reset and that all cavities greater than 0.3 meters in length or width be filled using procedures indicated at other locations. Somewhat continuous mud wasp accretions, which are visible in the photographs, should be removed.

As an additional high priority repair made in order to significantly increase seismic resistance and overall wall stability, the undercut should be filled to within 0.5 meters of the present maximum wall dimension.

4. As delineated by Photograph Nos. 122 and 123 moderate head joint erosion occurs at a number of locations along the top surface of the wall but is especially severe at and near the position indicated as Location "C" in Photograph No. 123.

At Location "B", shown on Photograph Nos. 113 and 123, very excessive erosion occurs particularly at the top exterior portion of the wall. This area should be reconstructed such that the rebuilt section extends at least to within 80 percent of the general existing wall surface and such that the sharp erosion patterns are eliminated.

These repairs should be assigned an urgent priority.

5. Two calving locations are indicated on Photograph No. 122; that occurring near the east corner is very dangerous because of its massive size. A side view is depicted in Photograph No. 124.

An extremely unstable section of wall occurs near the south entrance to the structure as delineated by Photograph Nos. 125 and 126 where extensive cracking has produced the potential for collapse of a large portion of the existing corner.

We do not feel that these urgent priority conditions can be effectively corrected without local dismantling and reconstruction.

D. Summary

This report assesses the current structural condition of Shunet El Zebib, identifies and prioritizes observable structural deficiencies and areas of danger and indicates potential worker protection methods that we feel are mandatory during excavation or repair near or adjacent to the existing walls. Since many areas of moderate to extreme danger exist on this site, a justification for the use of "preconservation" processes, which we feel must be performed before any consideration is given to excavation, is presented. Long term factors contributing to the deterioration of the Shunet are studied in specific detail in other portions of the main report; this section focuses on those existing deficiencies and conditions that have the greatest effect on overall safety and stability of standing walls. Potential repair approaches for dealing with the conditions discovered are described.

The main enclosure walls were found to be generally constructed using a two-width thick brick veneer attached to a massive core. The construction present within the Shunet and particularly within the core has certain properties that have a substantial effect on the longevity and stability of the existing construction. Specifically, the anticipated behavior leading to degradation of the structure based solely on the original construction methods can be summarized as follows:

- The wall veneer, located on the outer two brick widths of the walls, has and will, if exposed, degrade at a far more rapid rate than that of the core.
- The interior core, the primary structural element of existing concern, is fundamentally weak in the longitudinal direction. At wall ends the brick mass is unrestrained and therefore significantly unresistant to vertical cracking and erosion.
- Where crack patterns indicate that a mass of wall surface is disturbed and that the mass will separate perpendicular to the face of the wall, the quantity of brick likely to fall will be large.

- The wall possesses limited ability to arch over degraded areas in the longitudinal direction; potential failures will follow corbelled zones of weakness.

These findings were substantiated by observation of existing conditions.

In its present state the Shunet is an extremely dangerous structure; friable surfaces with loose brick and excessive cavitation are typical characteristics of all walls examined. At numerous locations the overall stability and short term survivability of parts or sections of wall is seriously in doubt. The conditions are of such severity that to undertake excavation near the walls without any preconservation would be irresponsible. Any repair or preservation treatment initiated will be a hazardous operation; methods to reduce the potential for injury to those involved in a conservation or stabilization program are provided.

A study of both short and long term forms of degradation is presented. Short term factors include seismic events and those caused by induced vibration from farm equipment operating adjacent to the site. The report findings were based upon a study of earthquake history for the last 4000 years and upon recently developed quantitative analyses of global earthquake hazards. Abydos was shown to lie within one of the lowest areas of seismicity along the Nile River. However, the possibility of a slight, although infrequent, ground motion still exists. Also, given their present location, farm vehicles were shown not to cause unacceptable levels of vibration.

Sources of long term deterioration observed included bird excavations, man-made intrusions, rain and wind erosion of the surface, insect damage consisting primarily of mud-wasp accretions, and dog, jackal, and/or fox excavations. The manifestations of and specific locations of these types of deterioration are described in detail and methods of repair are delineated. These repair methods were formulated with the understanding that the structure is to be preserved as a ruin; this implies that not all deficiencies will be corrected to the extent such that a "safe" structure will result. Indeed to achieve a totally "safe" structure would result in considerable alteration of the present appearance.

These forms of degradation have, of course, been present throughout the life of the Shunet and, with the exception of man-made intrusions, none can be eliminated. Continued deterioration has produced a structure that is quite sensitive to any form of disturbance including further degradation. Collapse of large wall sections with an attendant loss of historic fabric has already occurred and there is every indication to believe that collapse in the near future is a distinct possibility.

If you have any questions or comments concerning this report, please call us at your earliest convenience.

Very truly yours,

Conor M. Power, P. E., Pres.,
Structural Technology Inc.

Attachments

1. Appendix *A* - Photograph Nos. 1 to 126

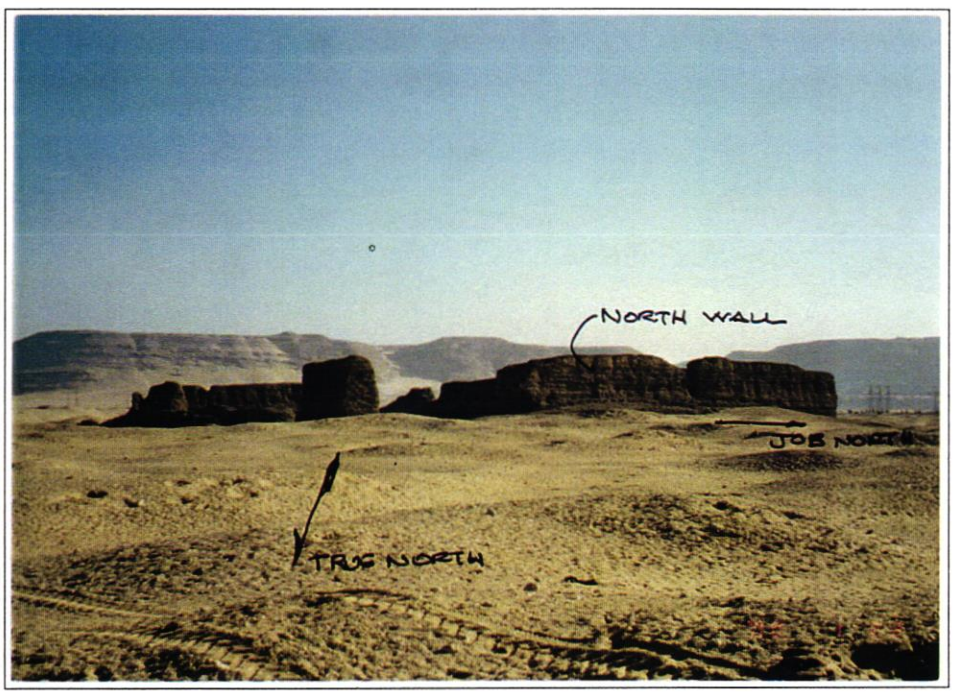
2. Appendix *B* - Drawing S1

3. Appendix *C* - Graph No. 1

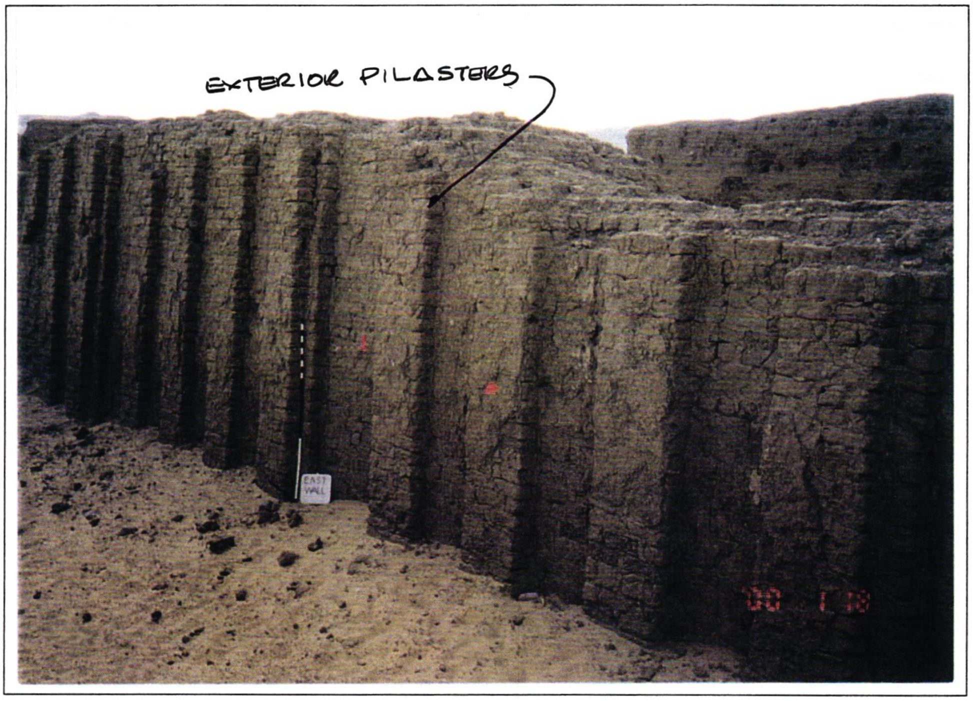
4. Appendix D - Scaffolding Catalogs

Appendix *A* - Photograph Nos. 1 to 126

Photograph No. 1 Shunet El Zebib South View

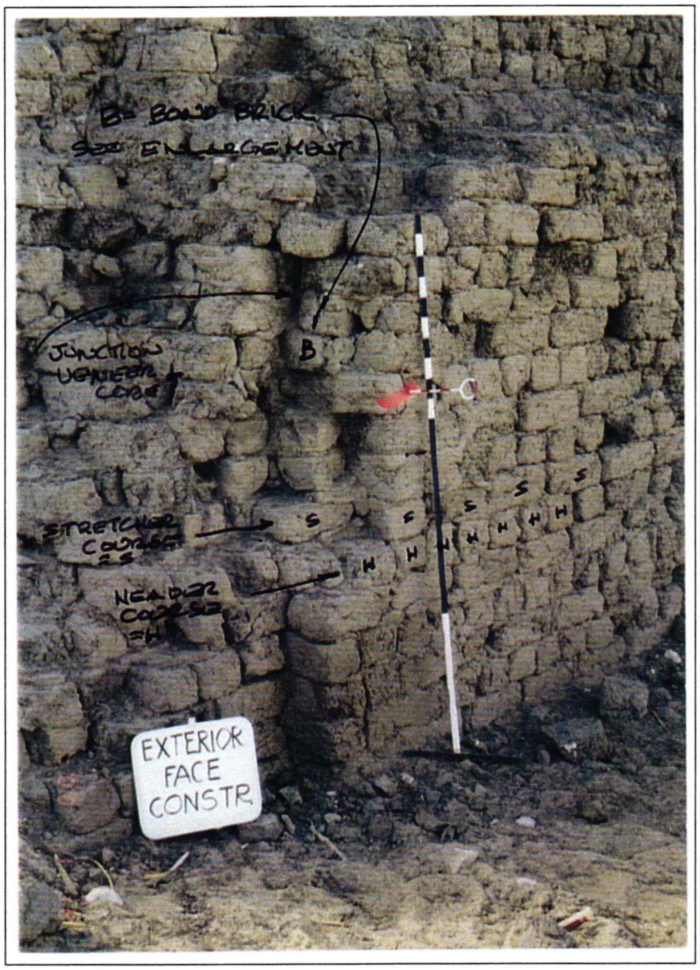


Photograph No. 2 Shunet El Zebib North View



Photograph No. 3 Exterior Pilasters - Main Enclosure Wall

Photograph No. 4 Original Surfaces at Grade



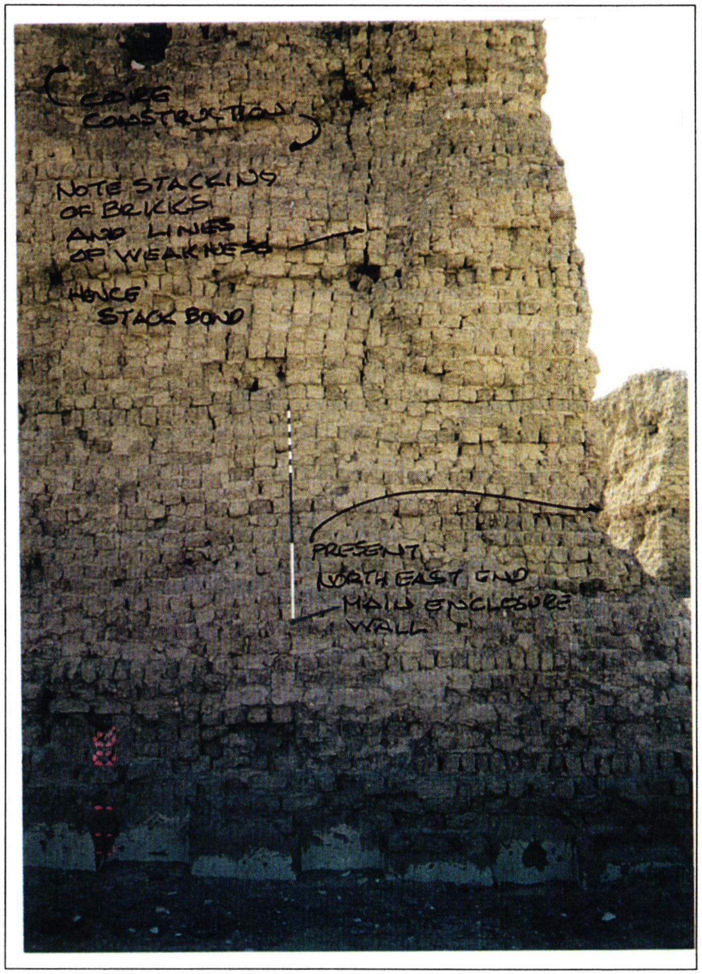
Photograph No. 5 Veneer and Core Wall Coursing

Photograph No. 6 Veneer Coursing

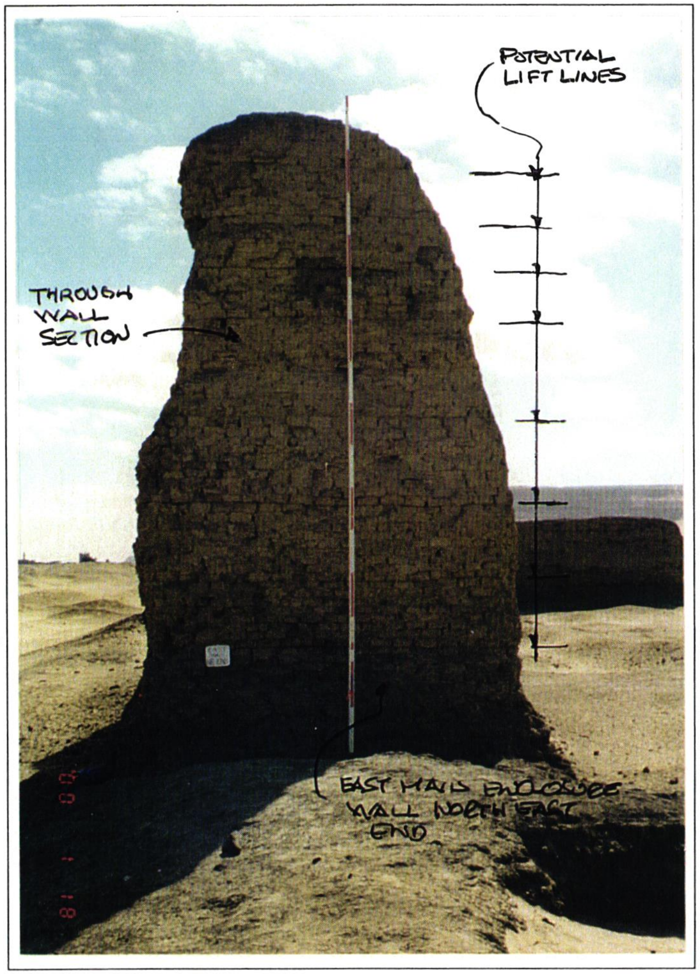
Photograph No. 7 Bond Bricks

Photograph No. 8 Veneer and Exposed Core

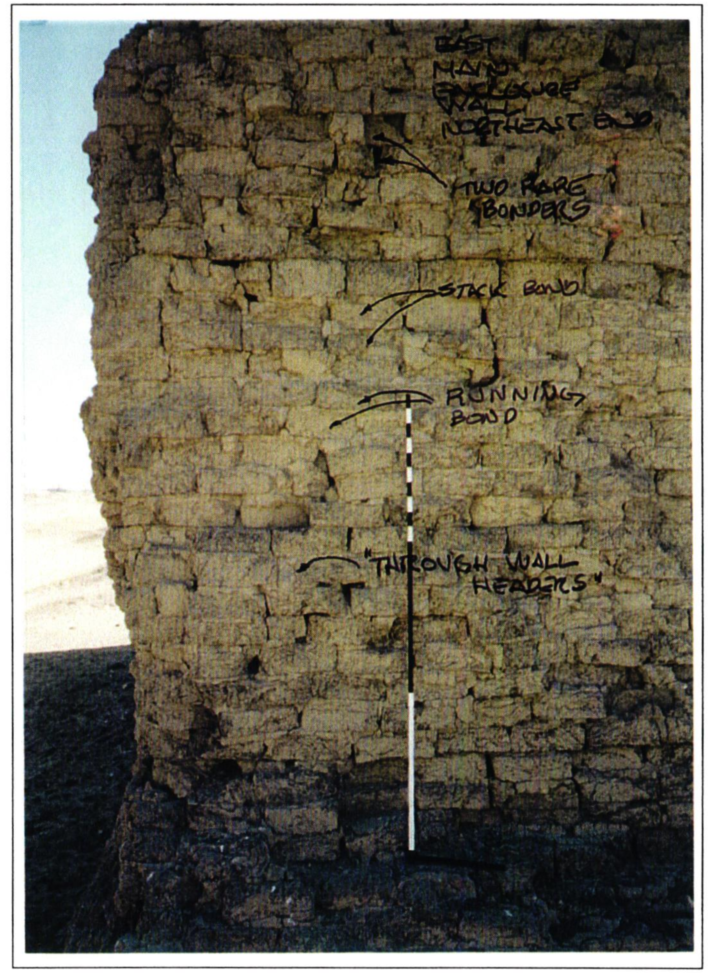
Photograph No. 9 Veneer and Exposed Core



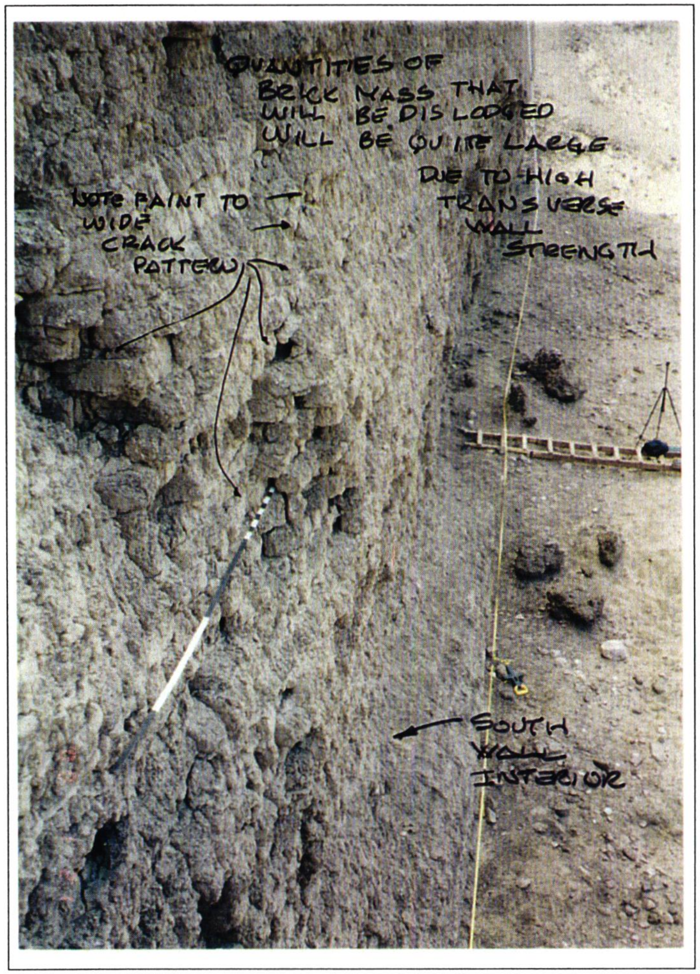
Photograph No. 10 Interior Core Construction



Photograph No. 11 Transverse View Core

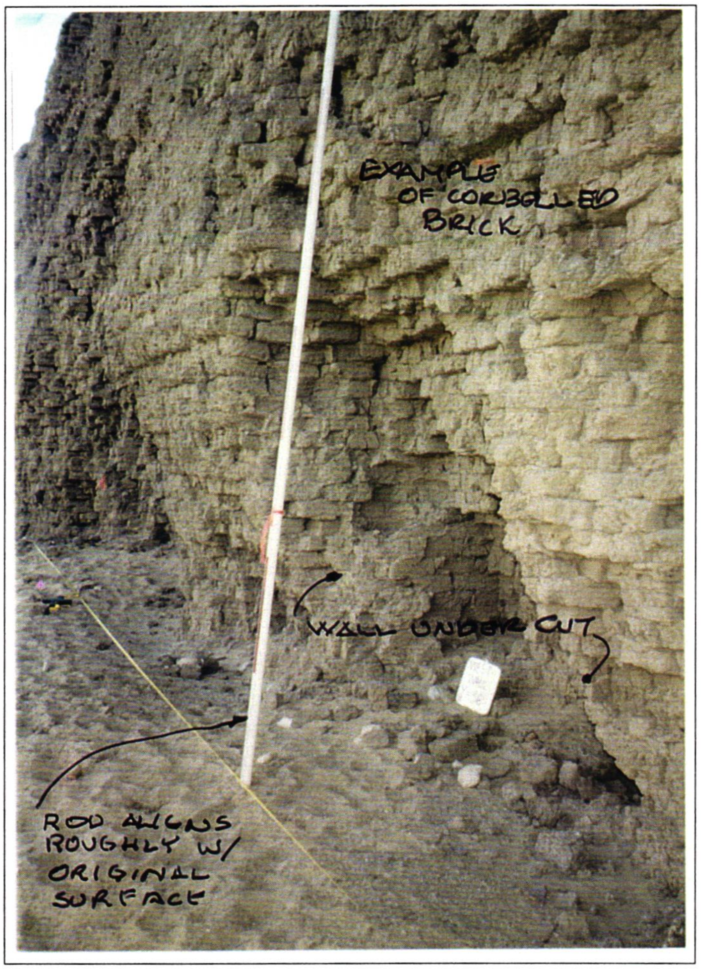


Photograph No. 12 Transverse View Core

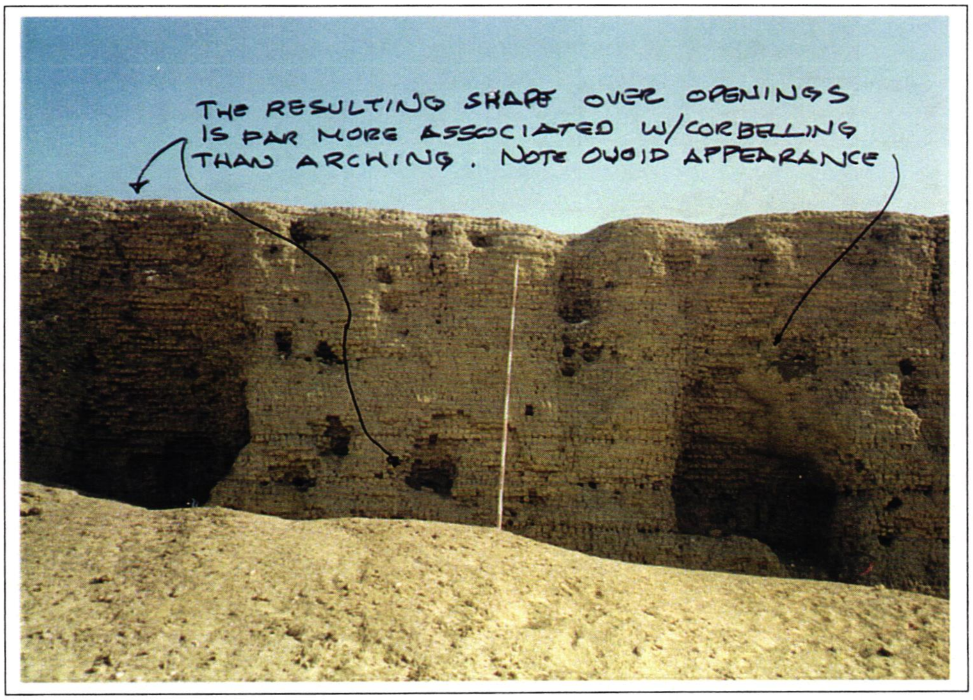


Photograph No. 13 Core Properties

Photograph No. 14 Corbelled Brick Example

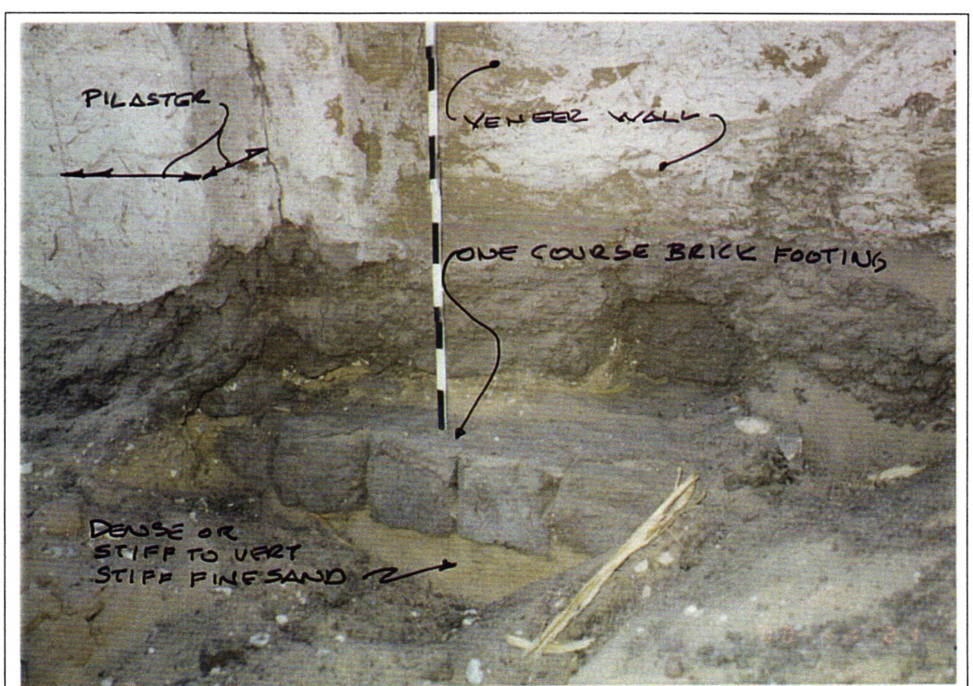


Photograph No. 15 Wall Undercutting

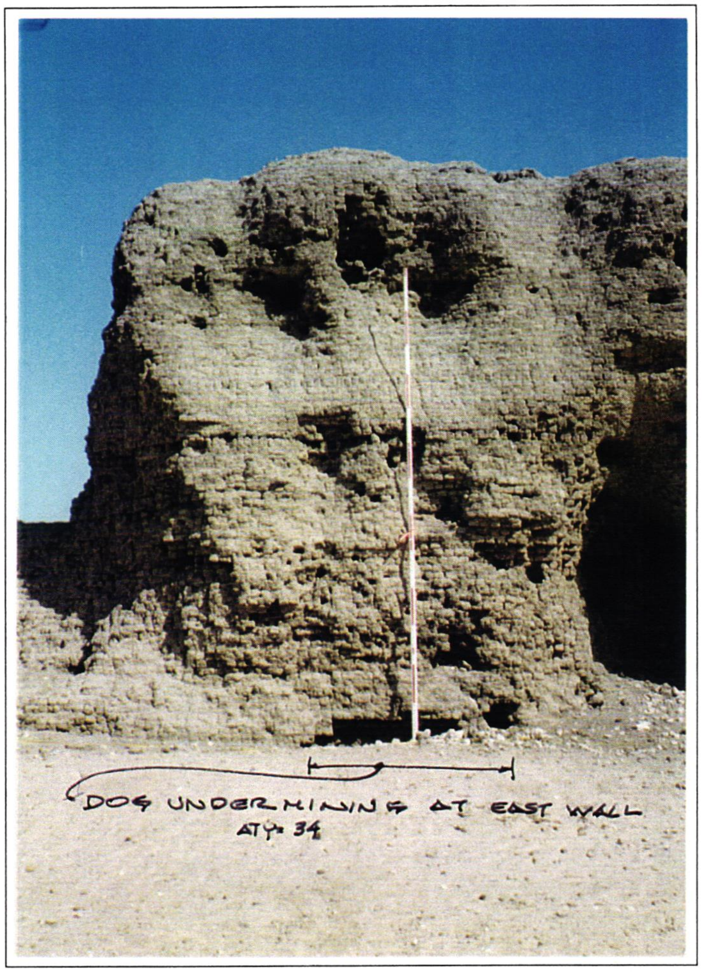


Photograph No. 16 Ovoid Cavitation

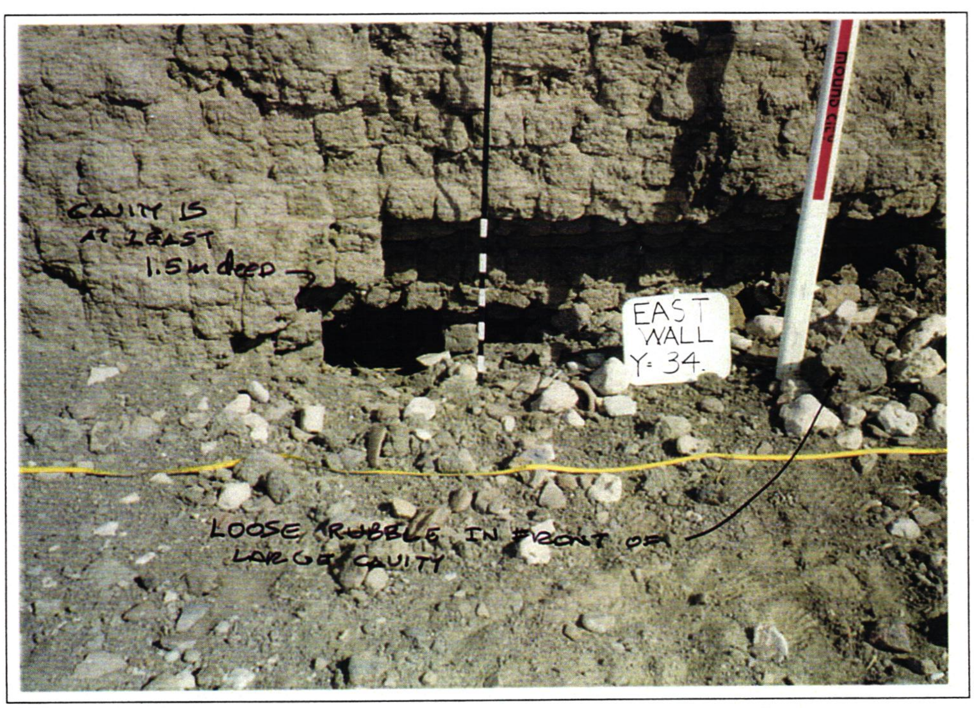
Photograph No. 17 Bonding at Main Enclosure Wall Corners



Photograph No. 18 Foundation Characteristics



Photograph No. 19 Base Undermining



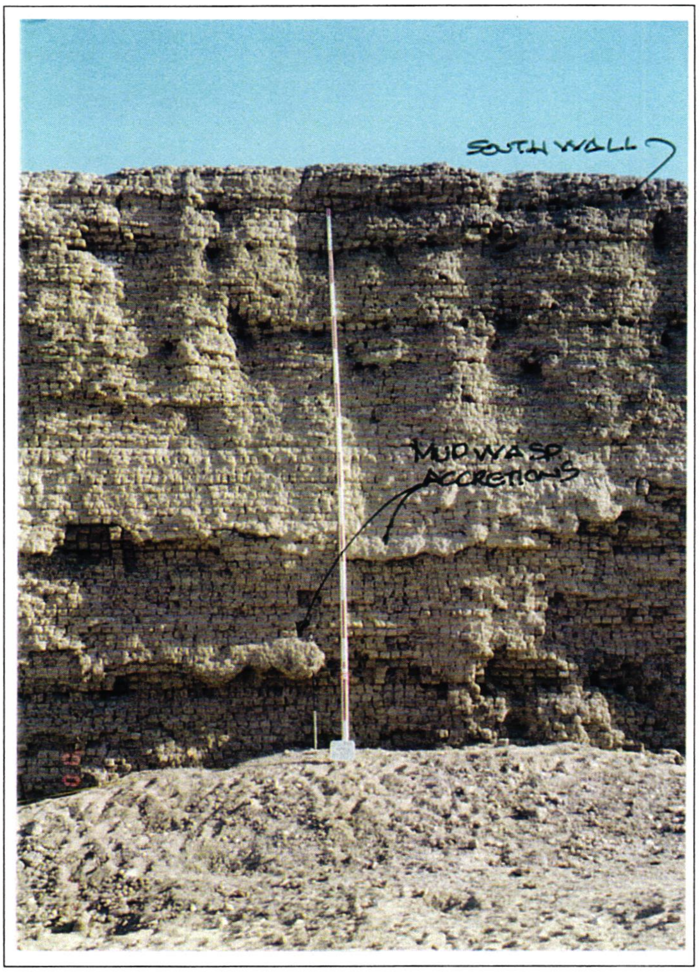
Photograph No. 20 Base Undermining

Photograph No. 21 Base Undermining

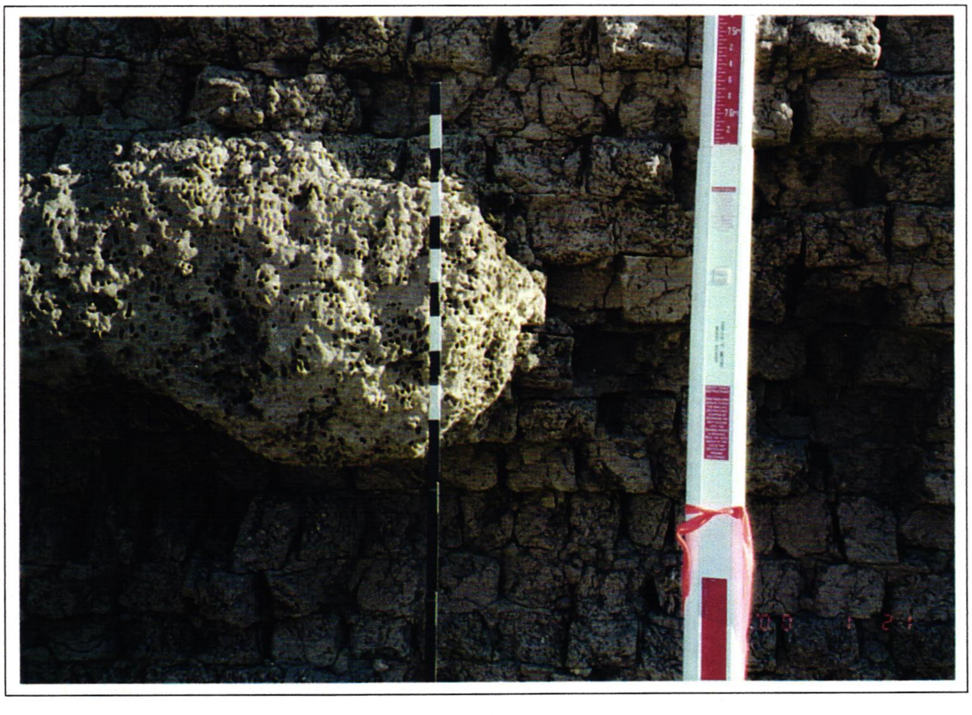
Photograph No. 22 Base Undermining

Photograph No. 23 Mud Wash and Droplets

Photograph No. 24 Mud Wash and Droplets

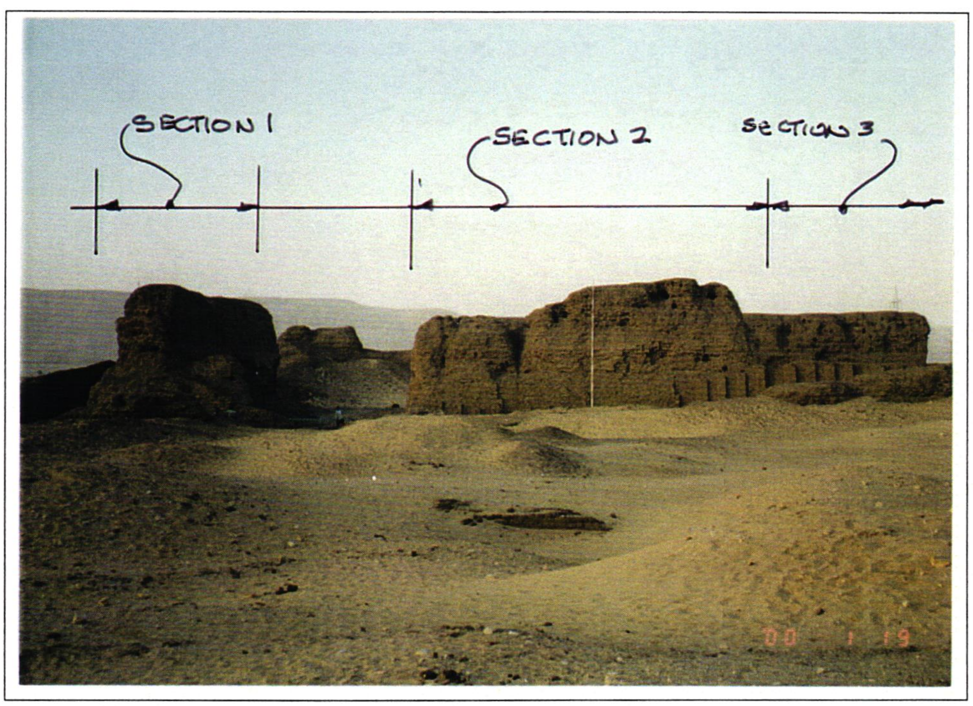


Photograph No. 25 Mud Wasp Accretions

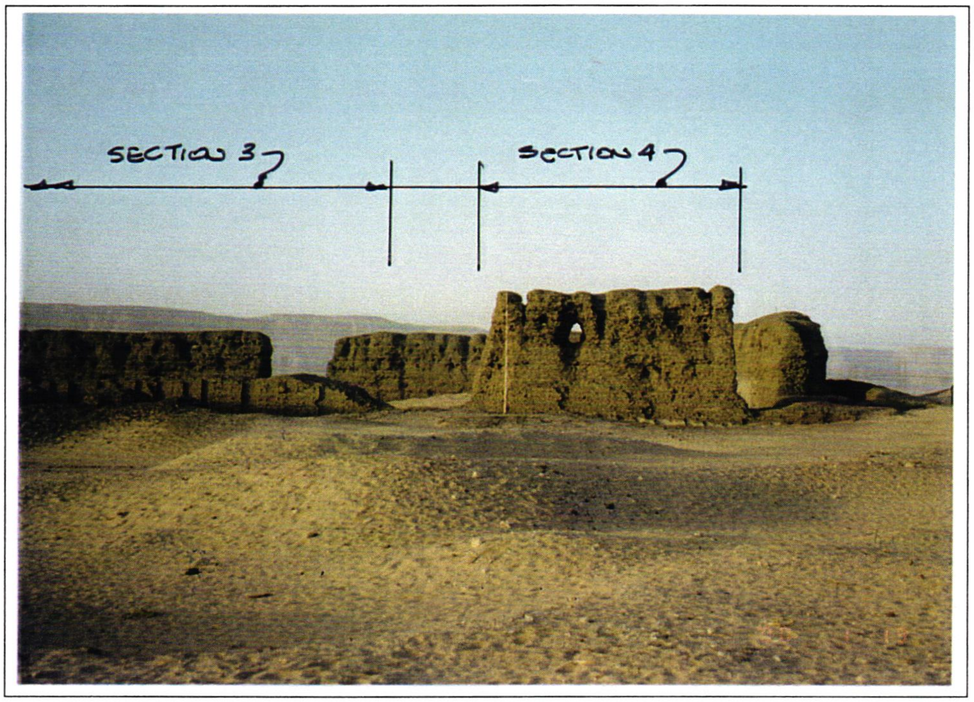


Photograph No. 26 Mud Wasp Accretion

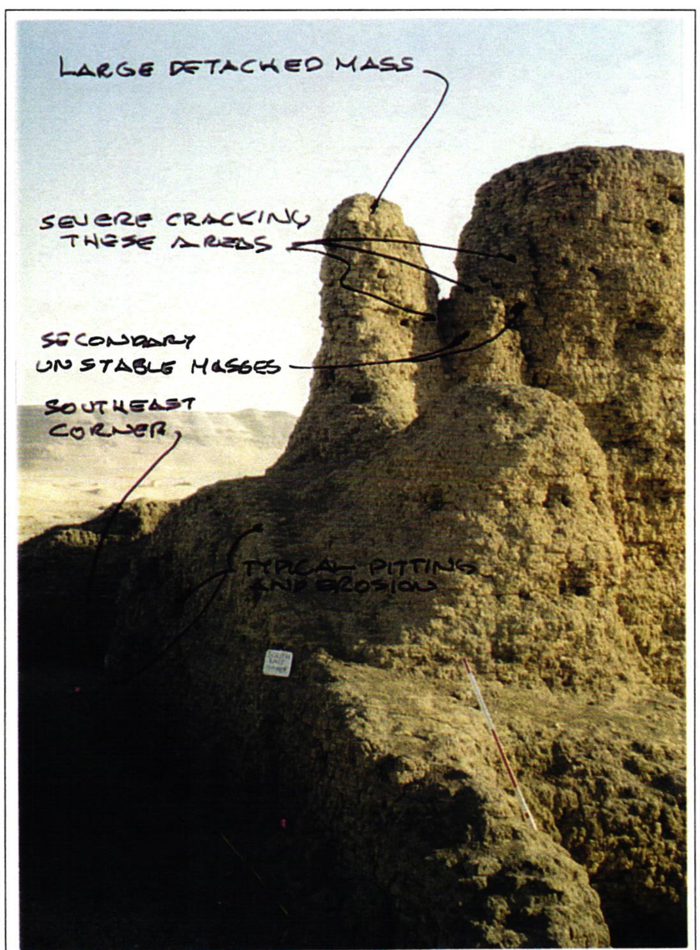
Photograph No. 27 Mud Wasp Accretion



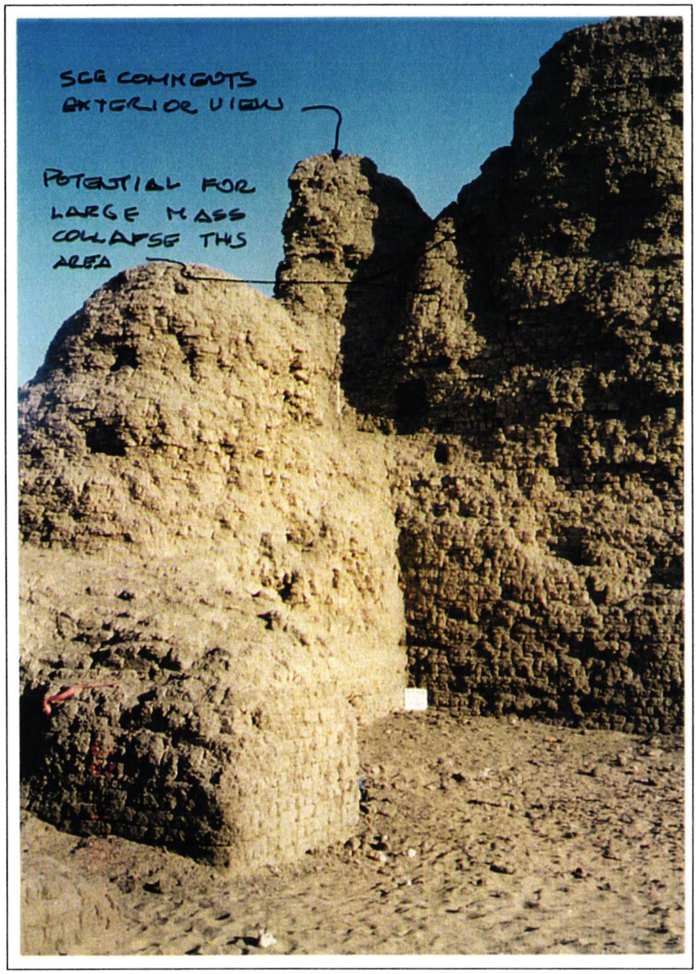
Photograph No. 28 East Main Enclosure Wall Divisions



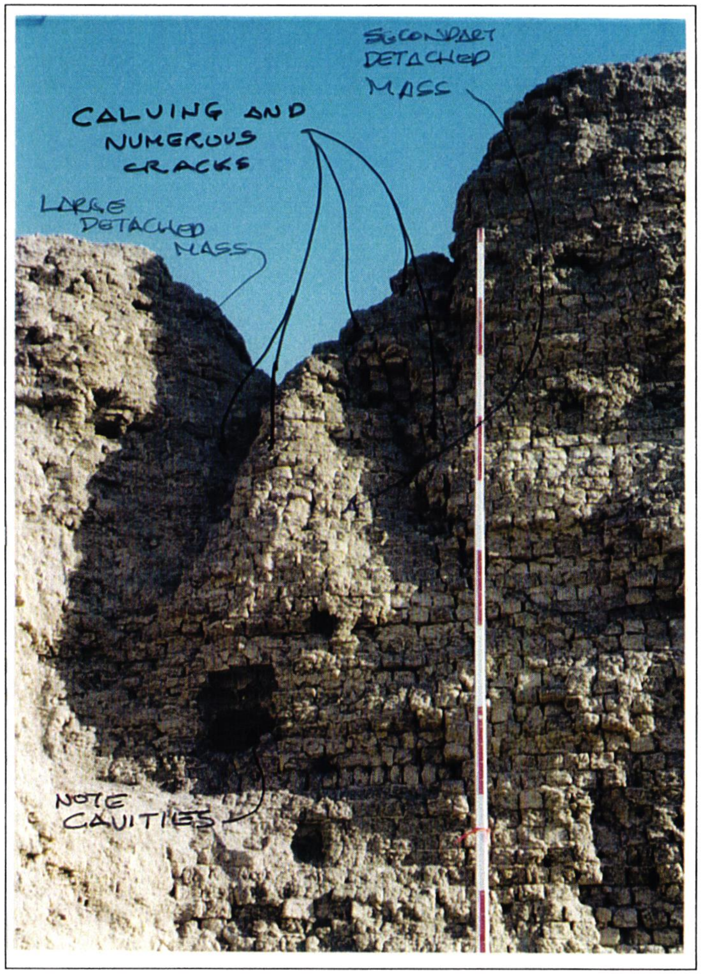
Photograph No. 29 East Main Enclosure Wall Divisions



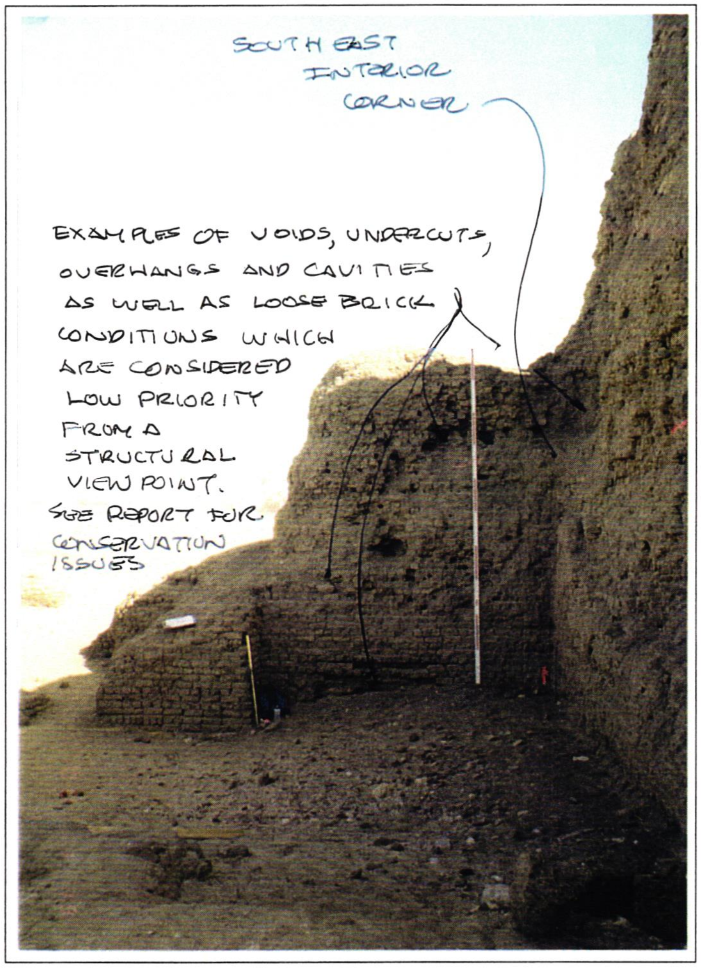
Photograph No. 30 Detached Mass Southeast Corner



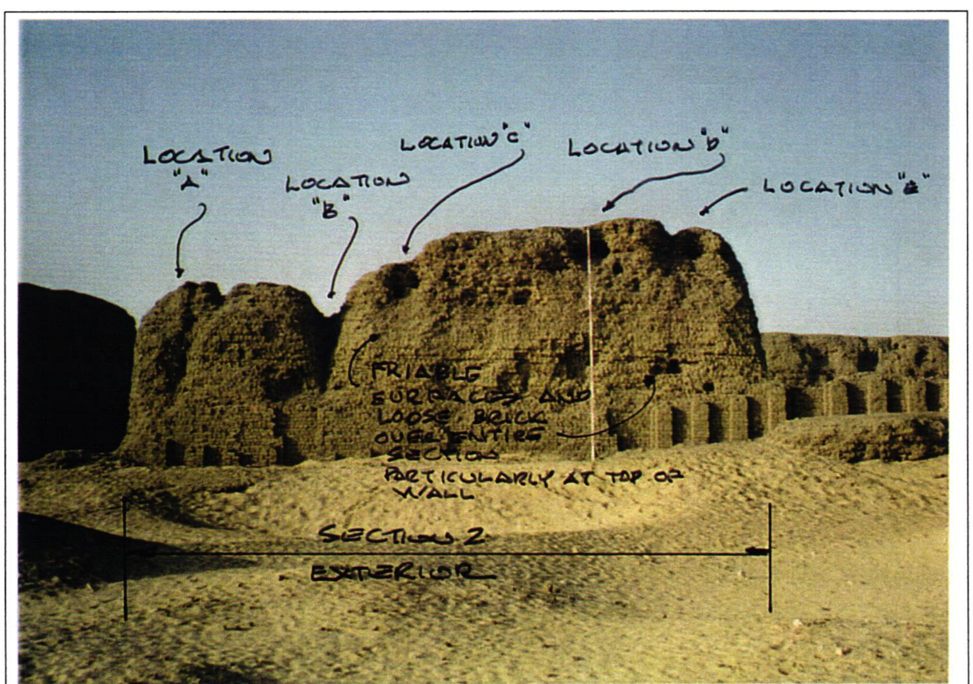
Photograph No. 31 Southeast Corner Cracking



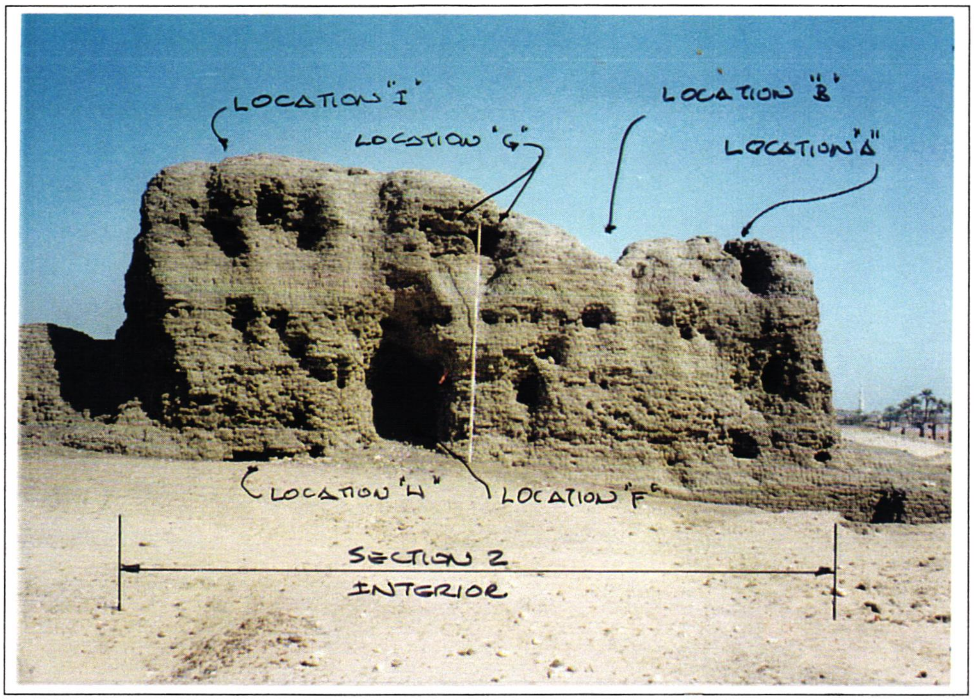
Photograph No. 32 Southeast Corner Cracking



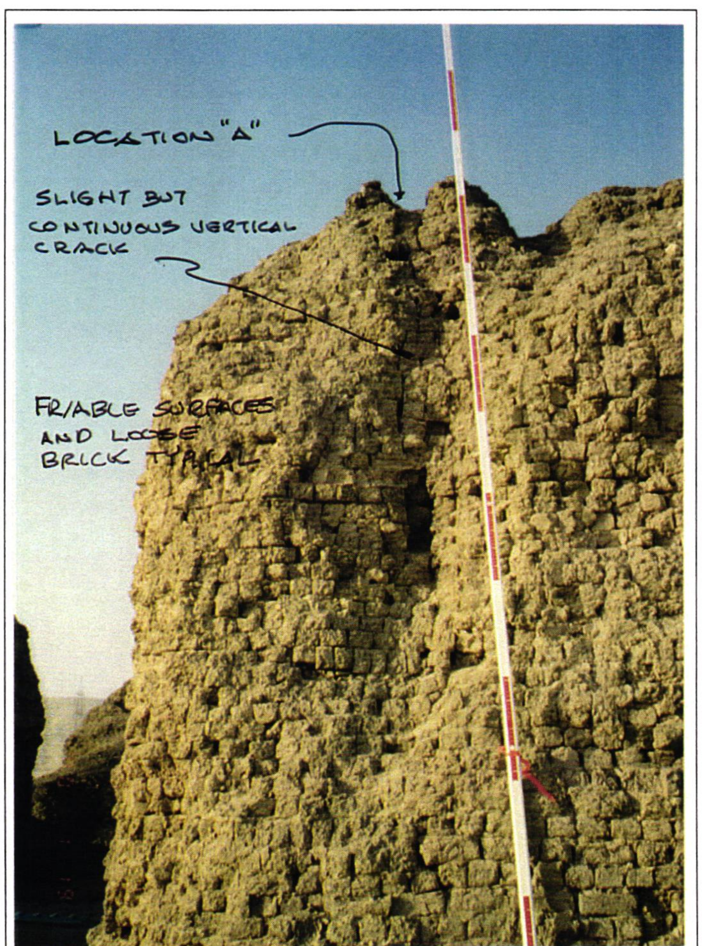
Photograph No. 33 Low Priority Structural Examples



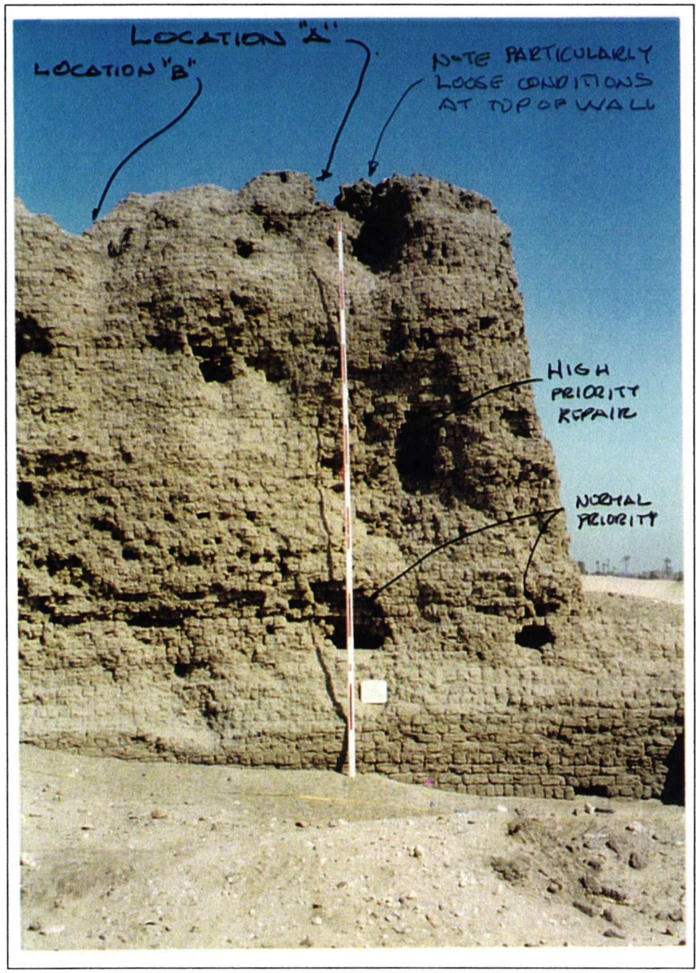
Photograph No. 34 "Section 2" East Main Enclosure Wall



Photograph No. 35 "Section 2" East Main Enclosure Wall Interior View

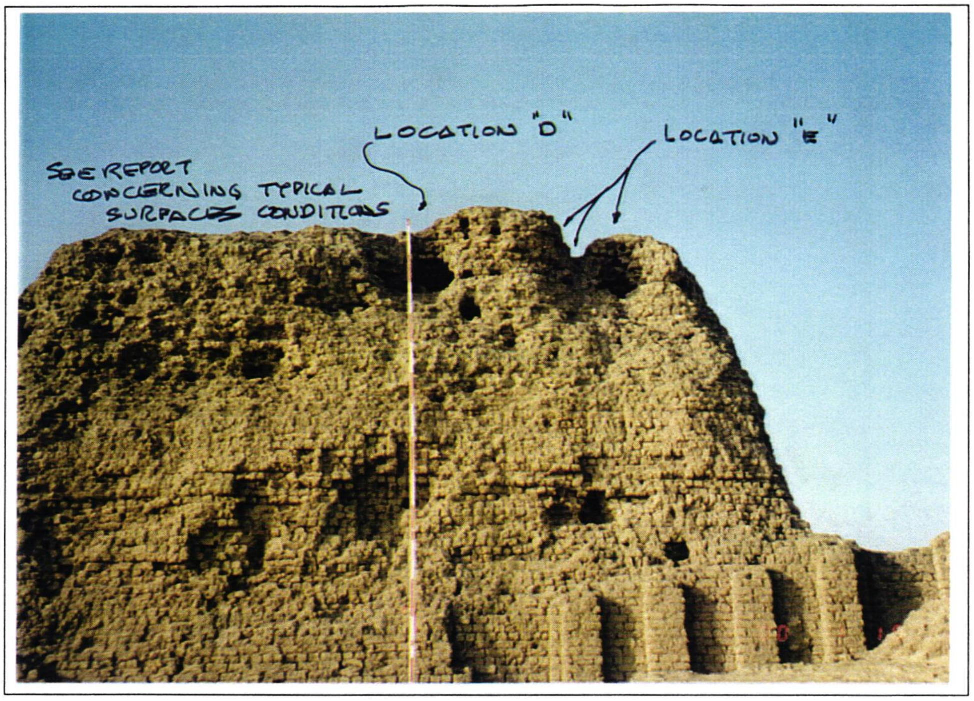


Photograph No. 36 Location "A" Vertical Wall Crack

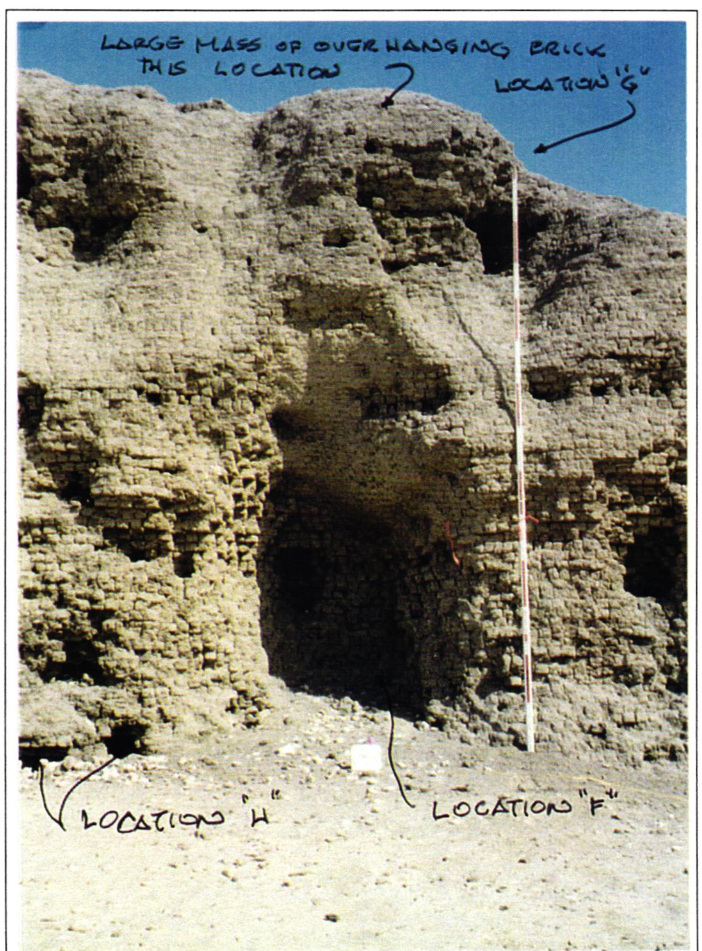


Photograph No. 37 Location "A" Vertical Wall Cracking

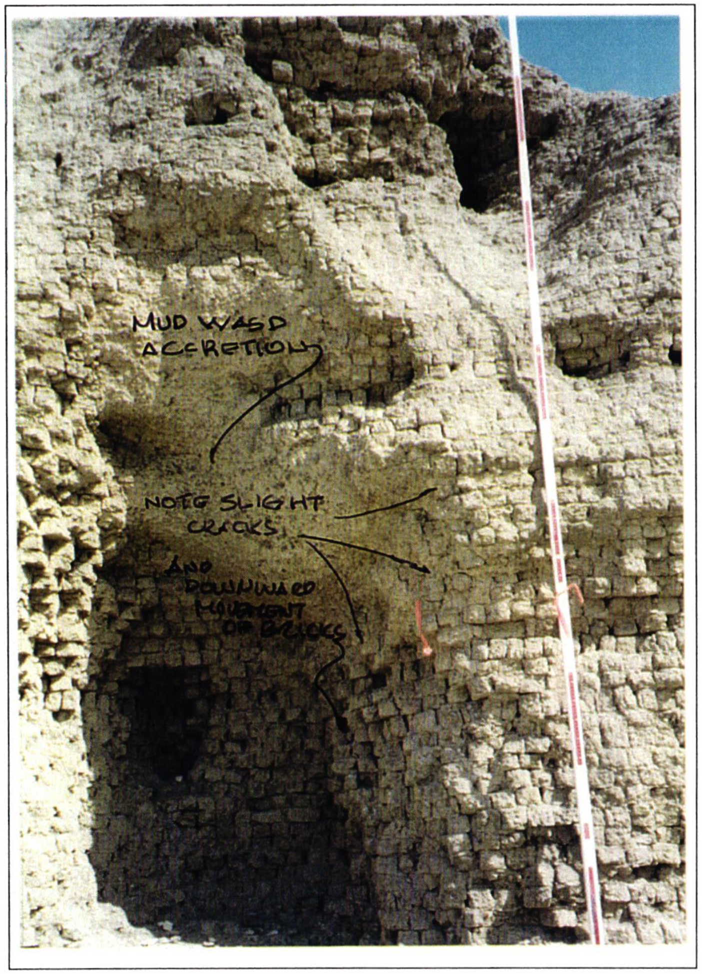
Photograph No. 38 Erosion at Location "B"



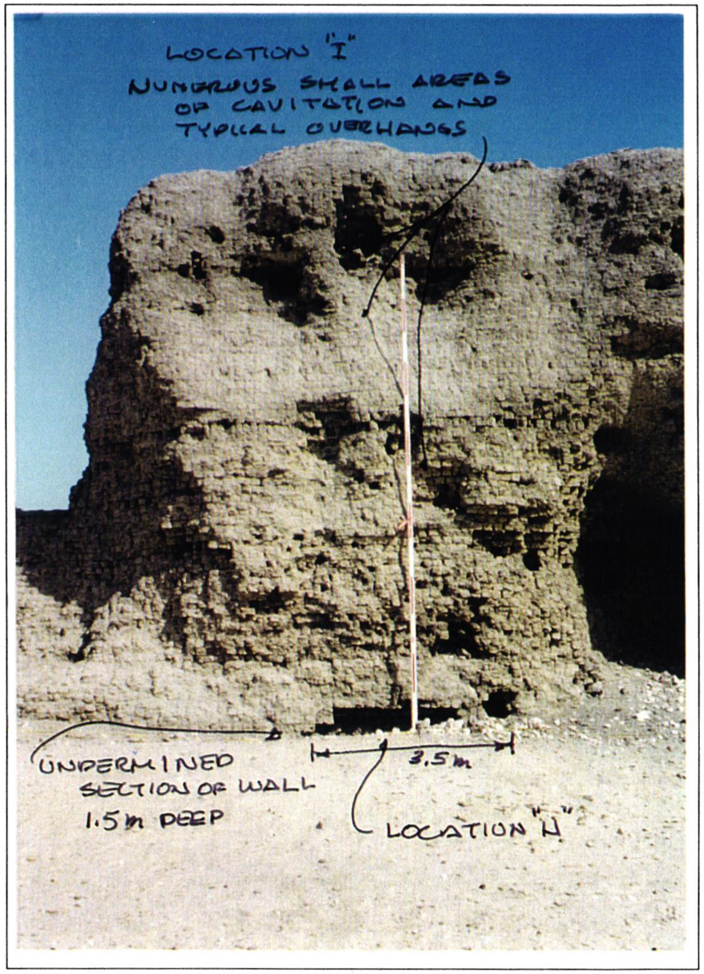
Photograph No. 39 Location "D" and "E" East Main Enclosure Wall Exterior View



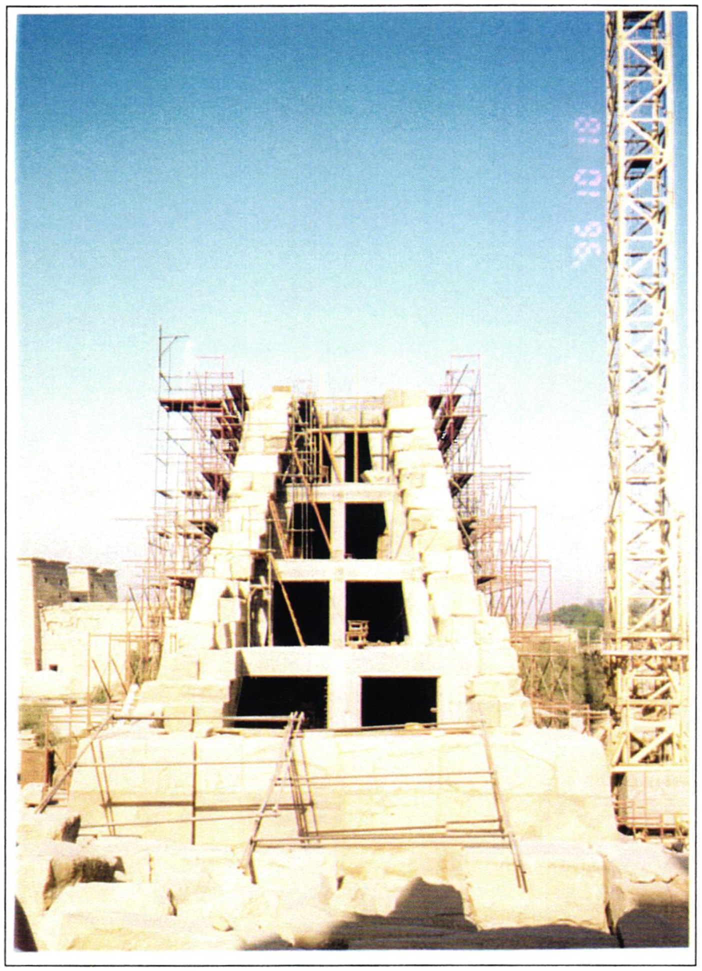
Photograph No. 40 Location "F" and "G" East Main Enclosure Wall Interior View



Photograph No. 41 Cracking at Location "F"

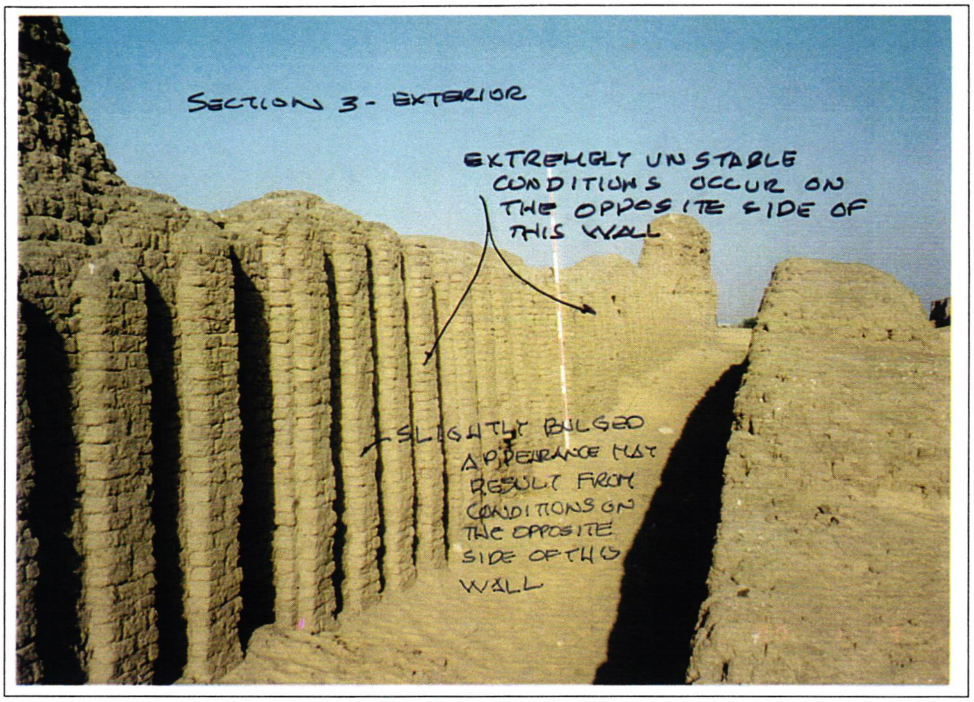


Photograph No. 42 Undermining at Location "H"

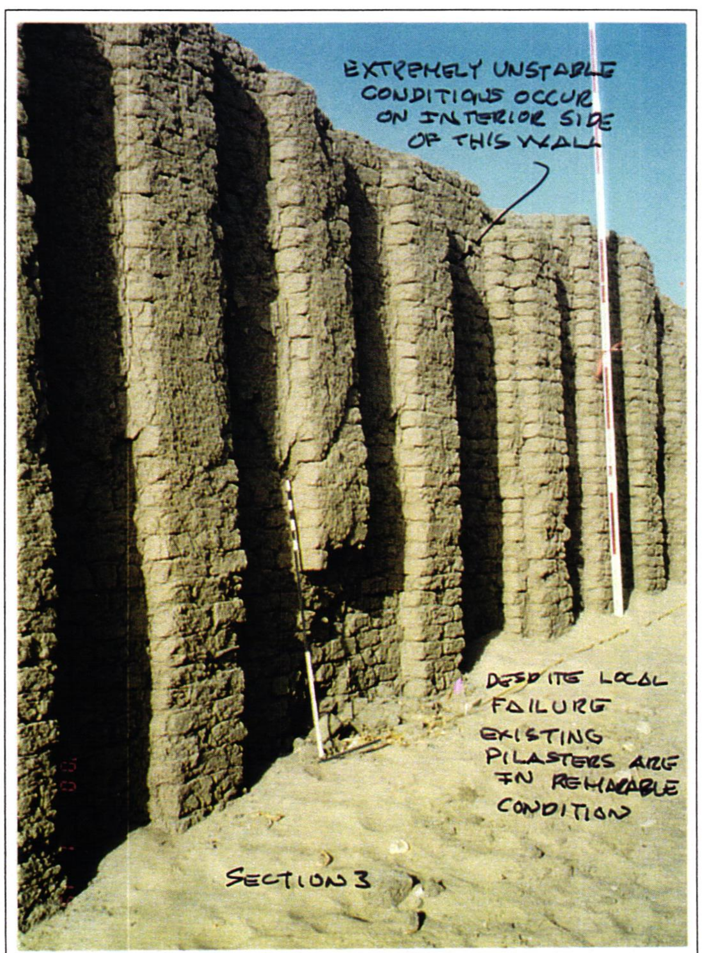


Photograph No. 43 Scaffolding Present at Karnak Reconstruction

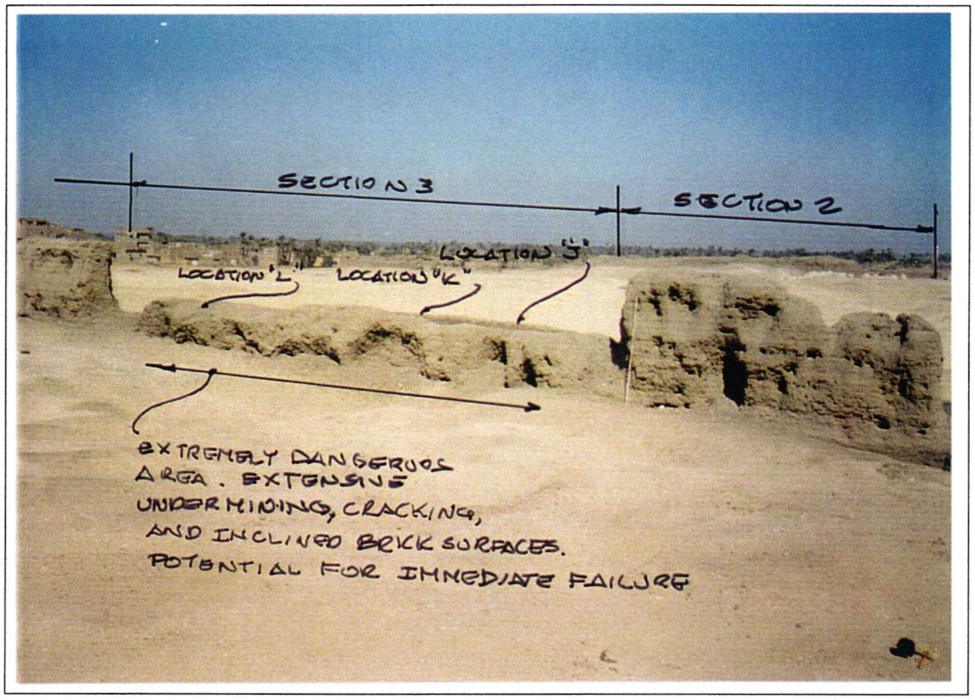
Photograph No. 44 Scaffold Protection at Modern Site



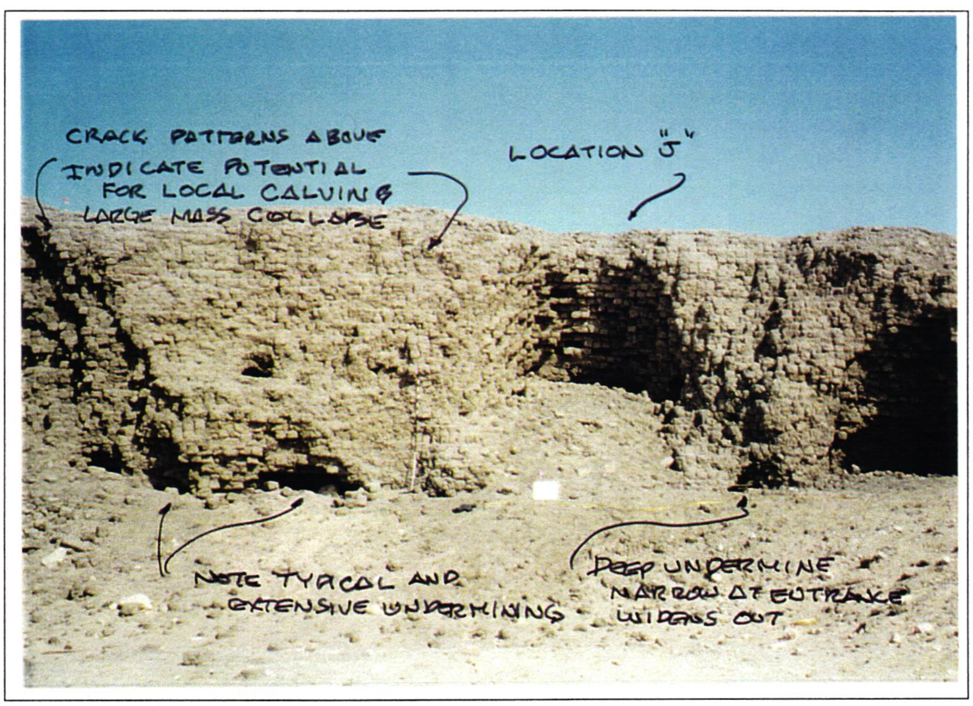
Photograph No. 45 "Section 3" East Main Enclosure Wall



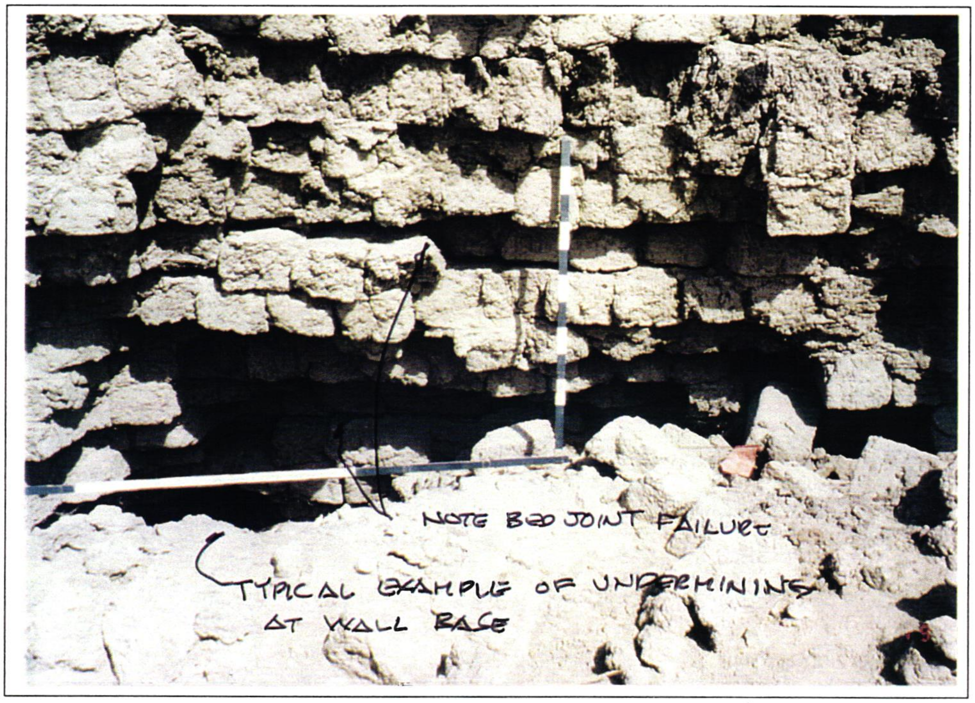
Photograph No. 46 Loca l Failures at East Main Enclosure Wall



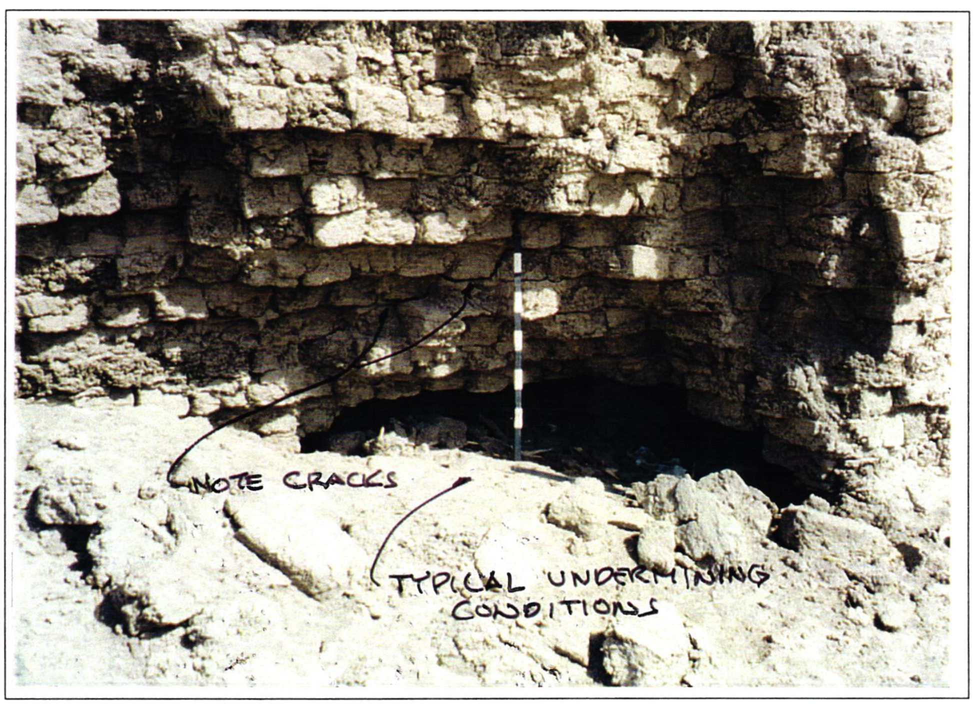
Photograph No. 47 "Section 3" East Main Enclosure Wall Interior View



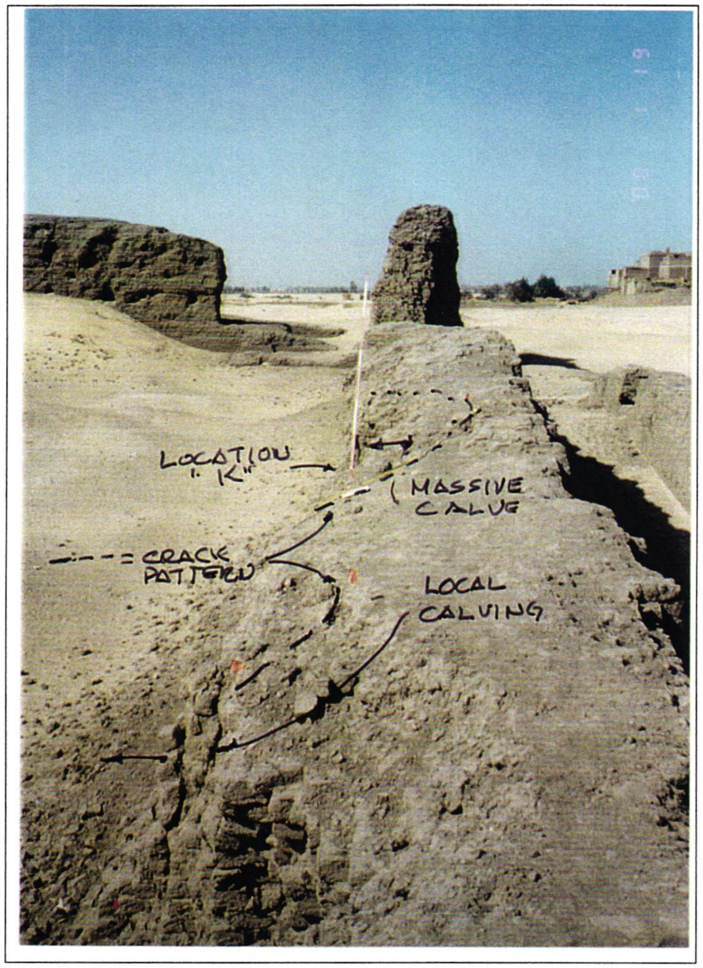
Photograph No. 48 Failures at "Section 3"



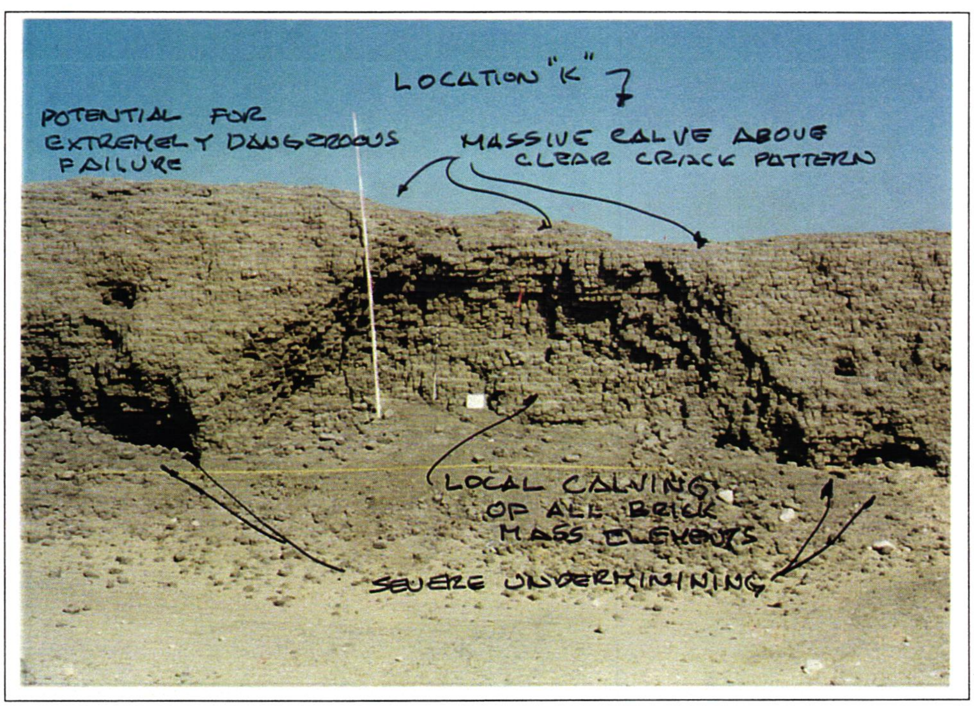
Photograph No. 49 Undermining at East Main Enclosure Wall



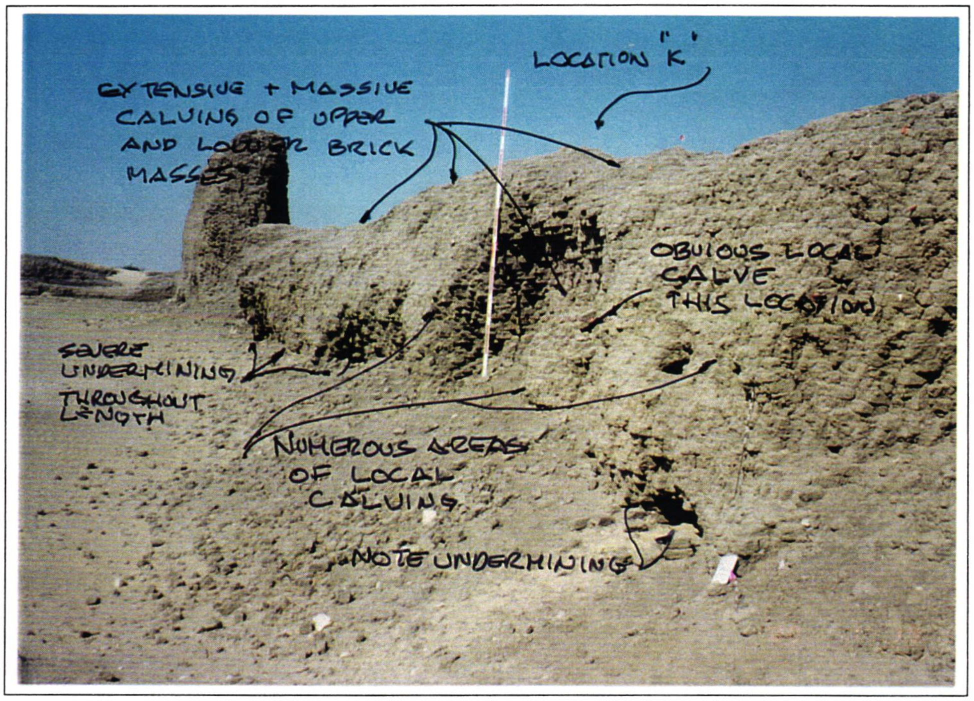
Photograph No. 50 Undermining at East Main Enclosure Wall



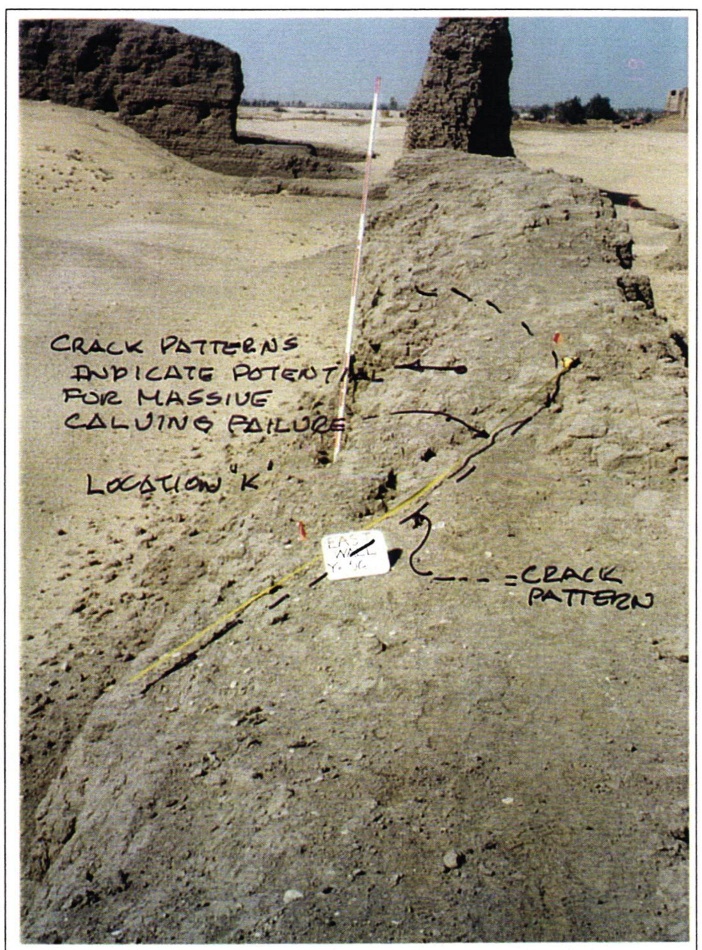
Photograph No. 51 Massive Calving at "Section 3" East Main Enclosure Wall



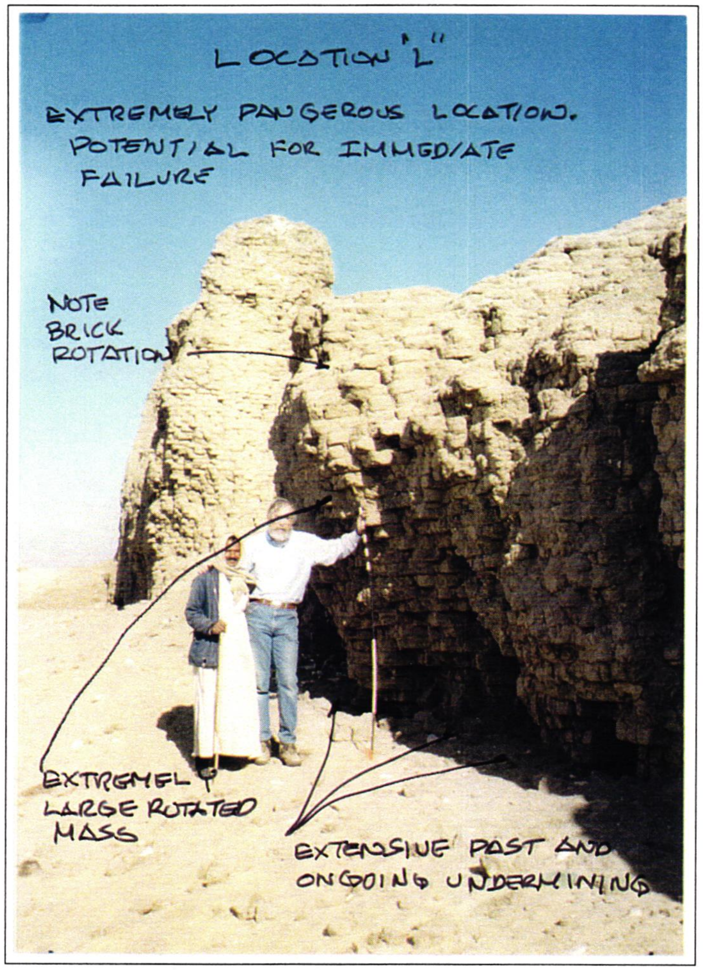
Photograph No. 52 Failures at "Section 3" Interior



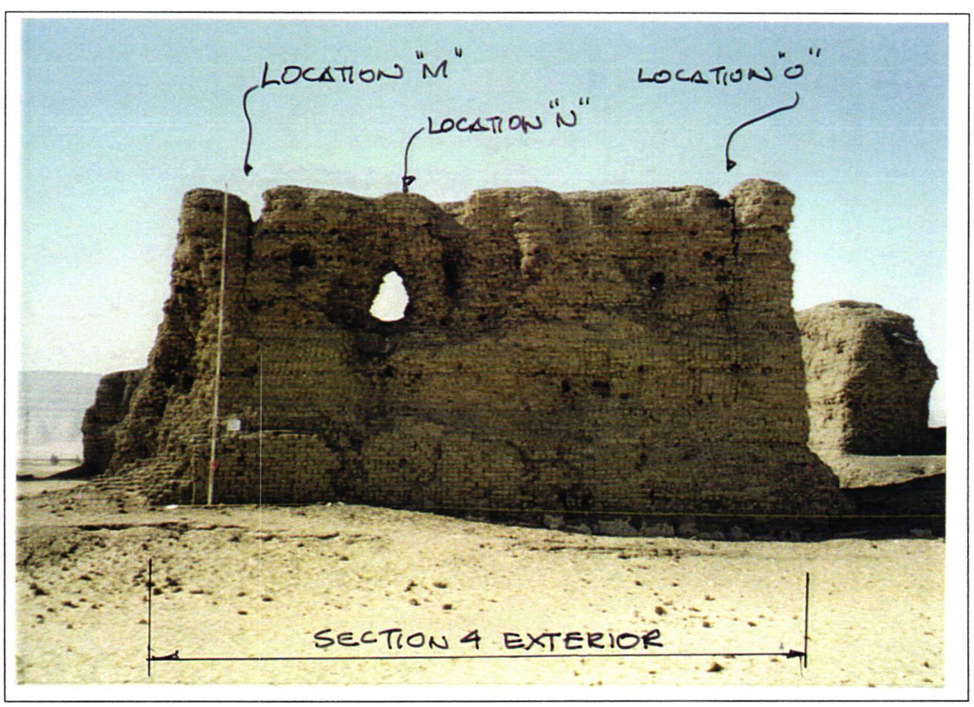
Photograph No. 53 Massive Calving at "Section 3" East Main Enclosure Wall



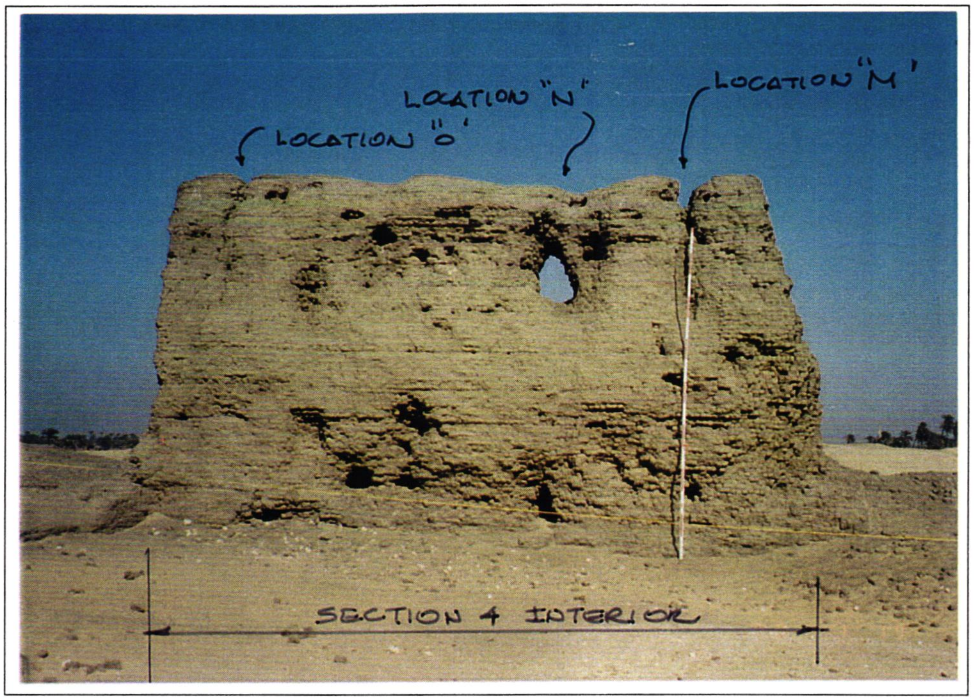
Photograph No. 54 Massive Calving at "Section 3" East Main Enclosure Wall



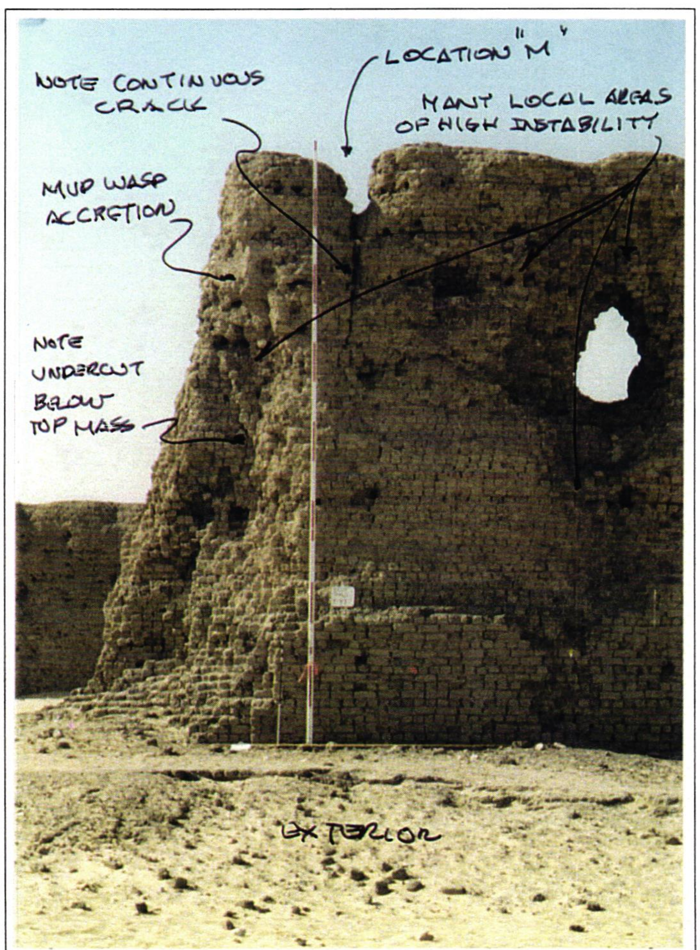
Photograph No. 55 Extremely Rotated Massive



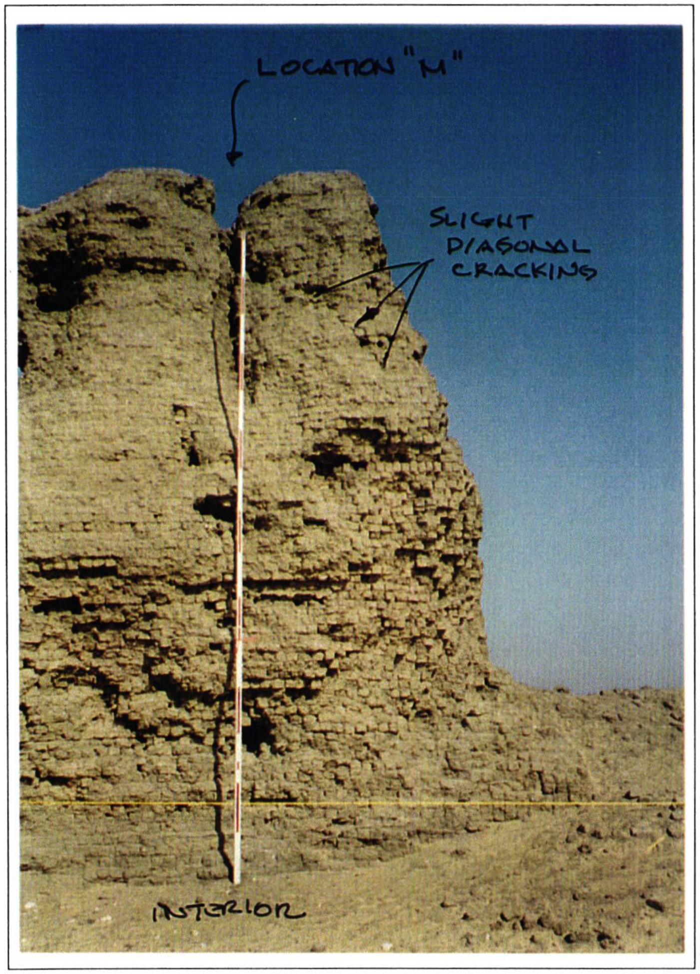
Photograph No. 56 "Section 4" East Main Enclosure Wall Exterior View



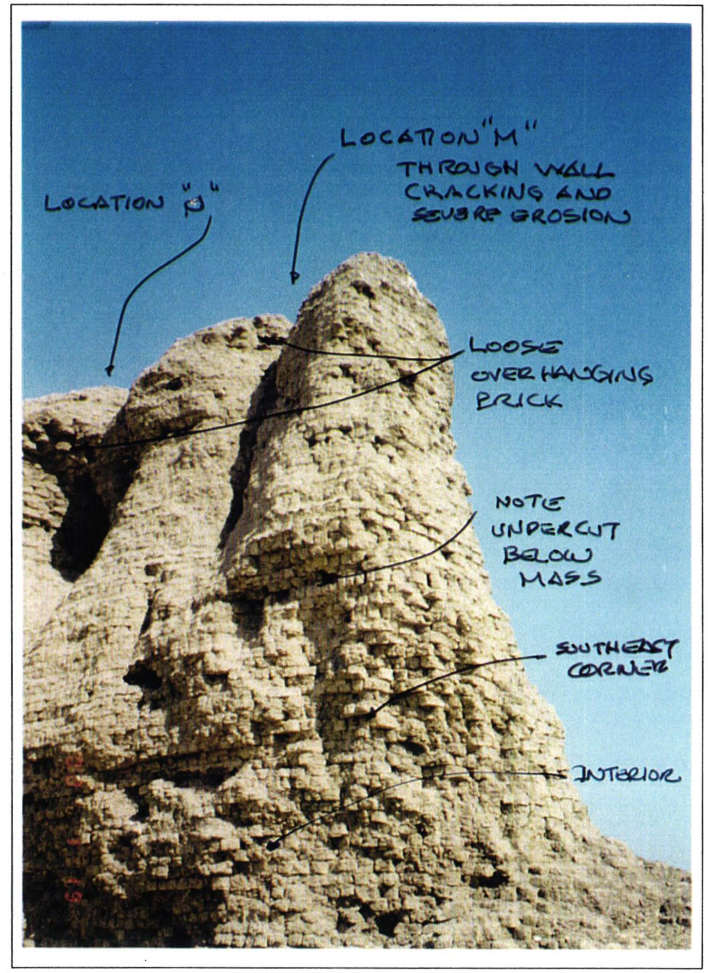
Photograph No. 57 "Section 4" East Main Enclosure Wall Interior View



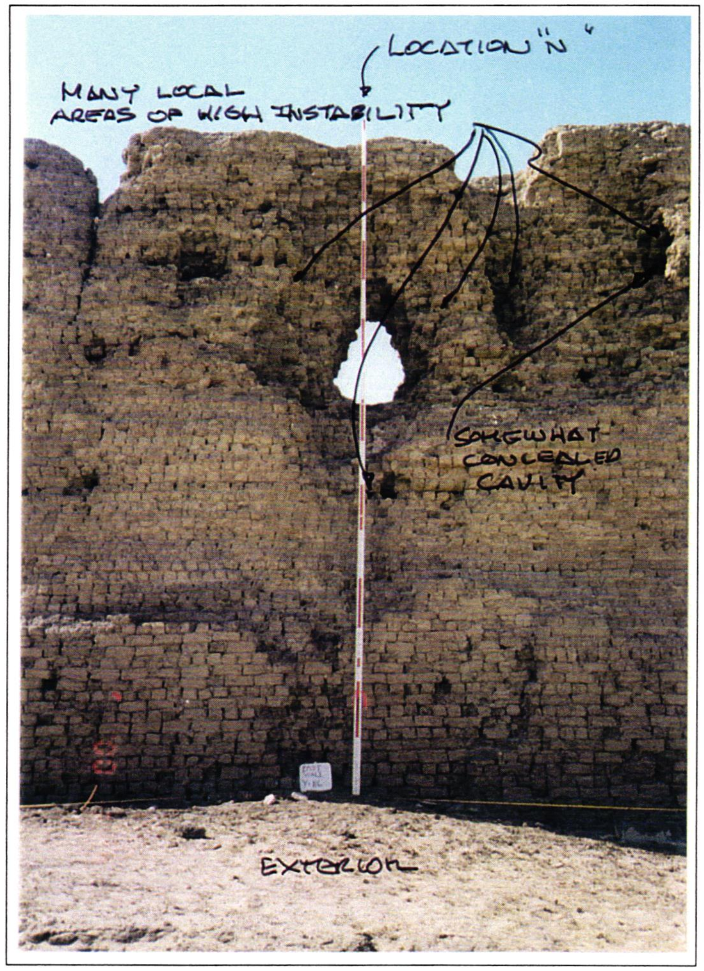
Photograph No. 58 Cracking at South End of "Section 4"



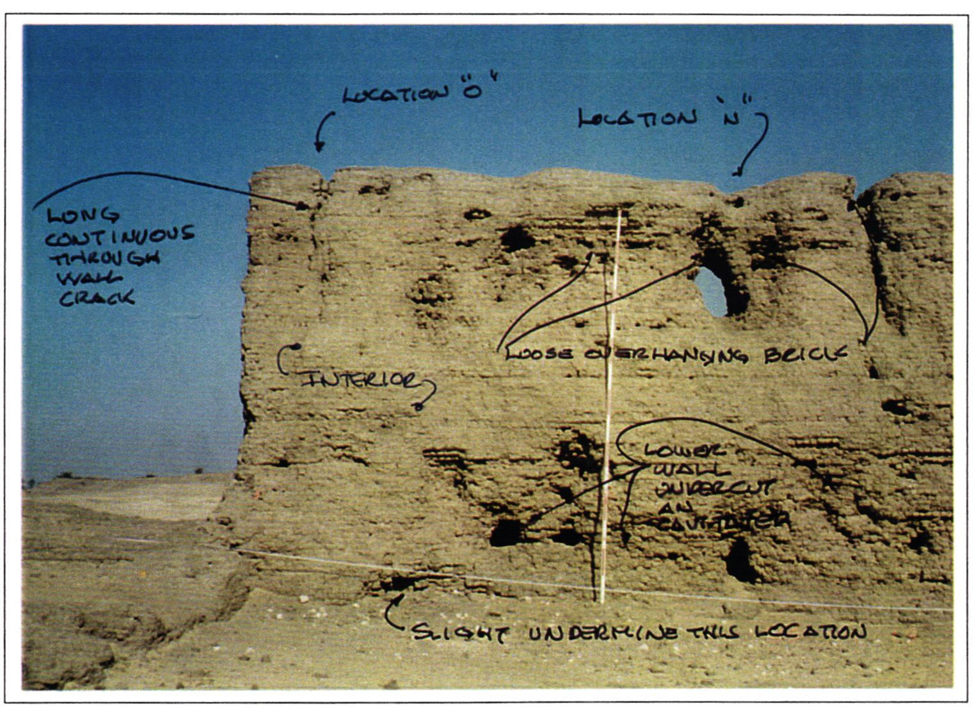
Photograph No. 59 Cracking at South End of "Section 4"



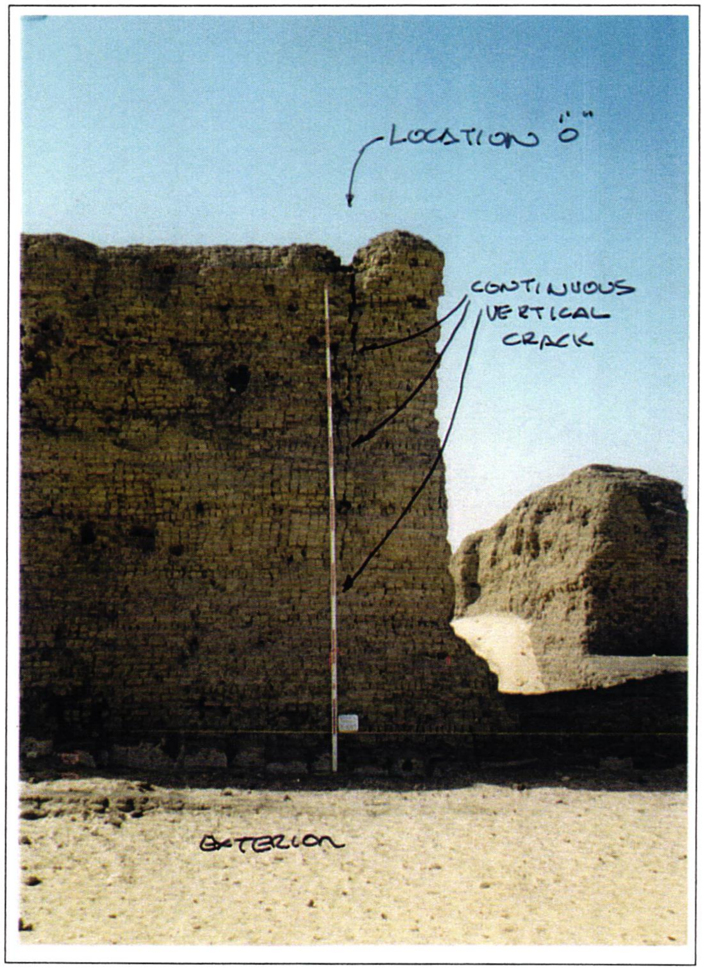
Photograph No. 60 Cracking at South End of "Section 4"



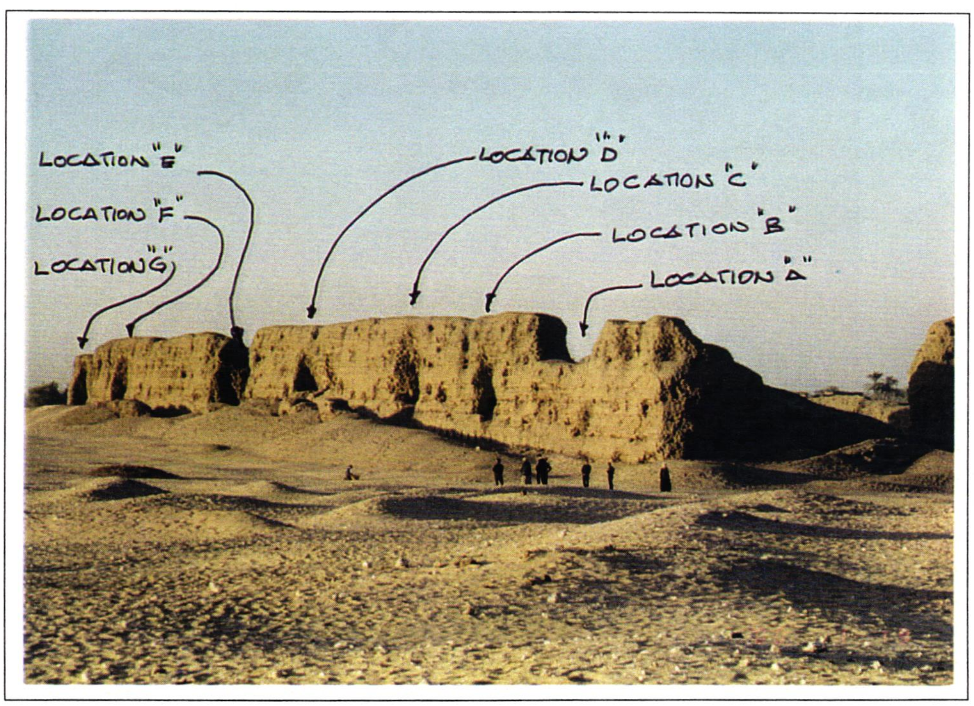
Photograph No. 61 "Section 4" Deficiencies at Location "N"



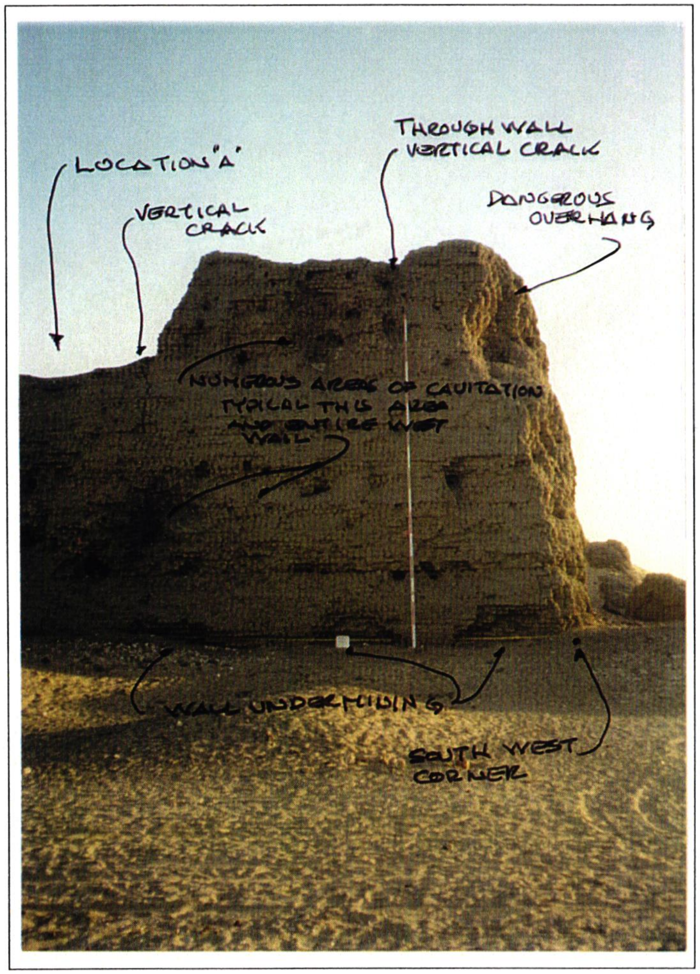
Photograph No. 62 "Section 4" East Main Enclosure Wall North End



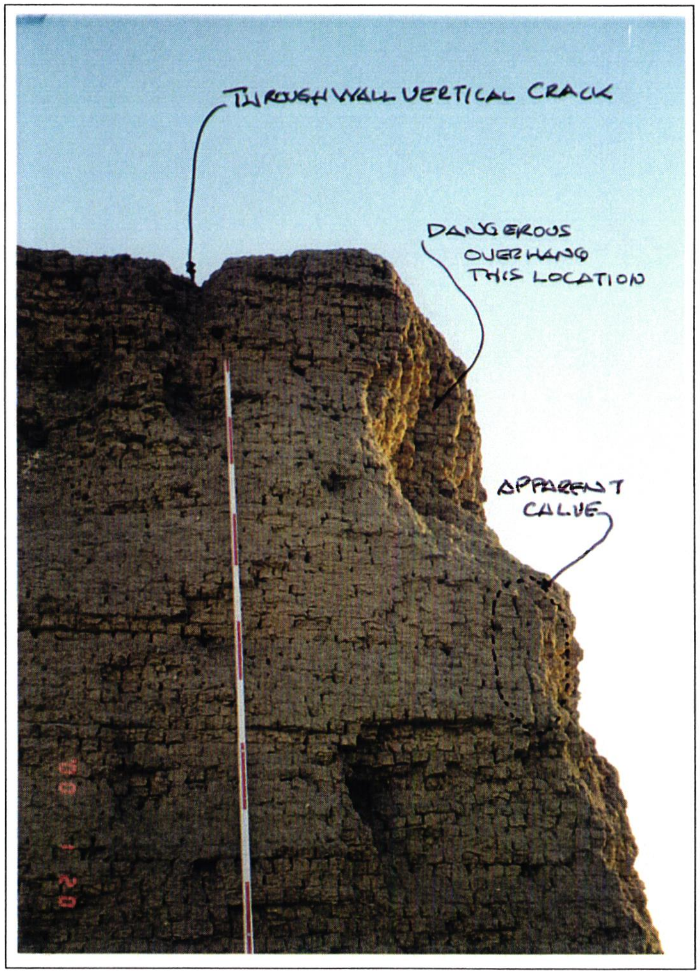
Photograph No. 63 "Section 4" East Main Enclosure Wall North End Exterior View



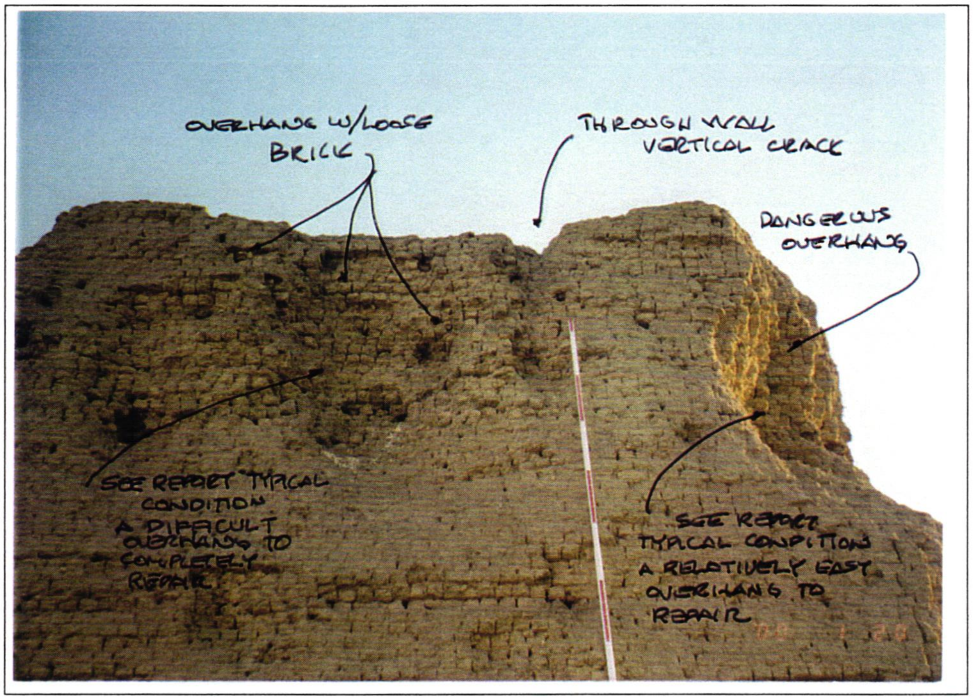
Photograph No. 64 West Main Enclosure Wall Reference Locations



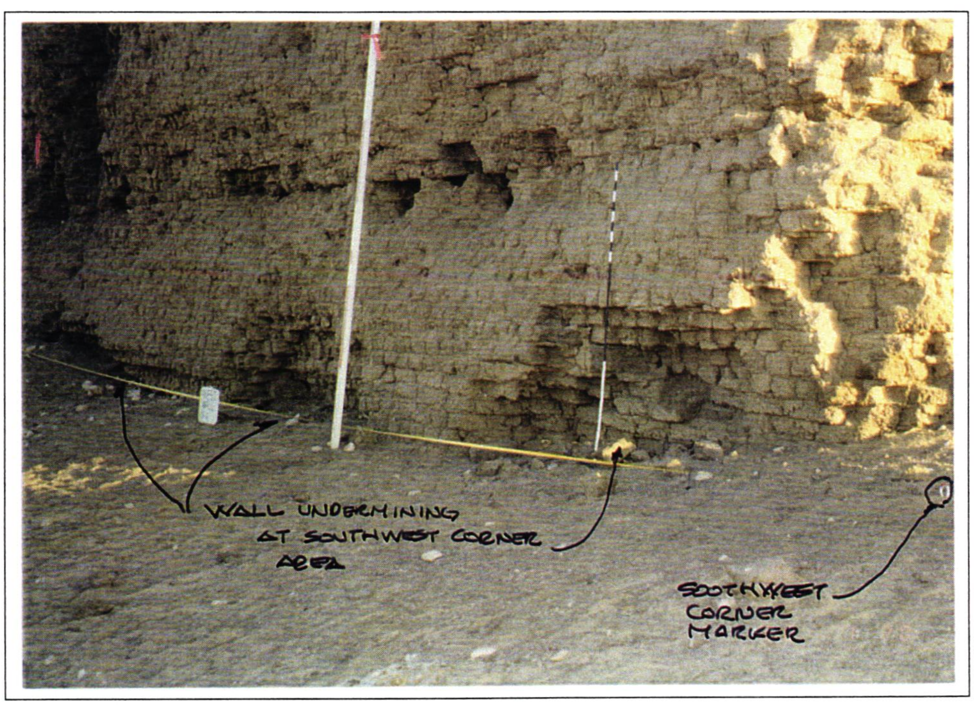
Photograph No. 65 West Main Enclosure Wall South End



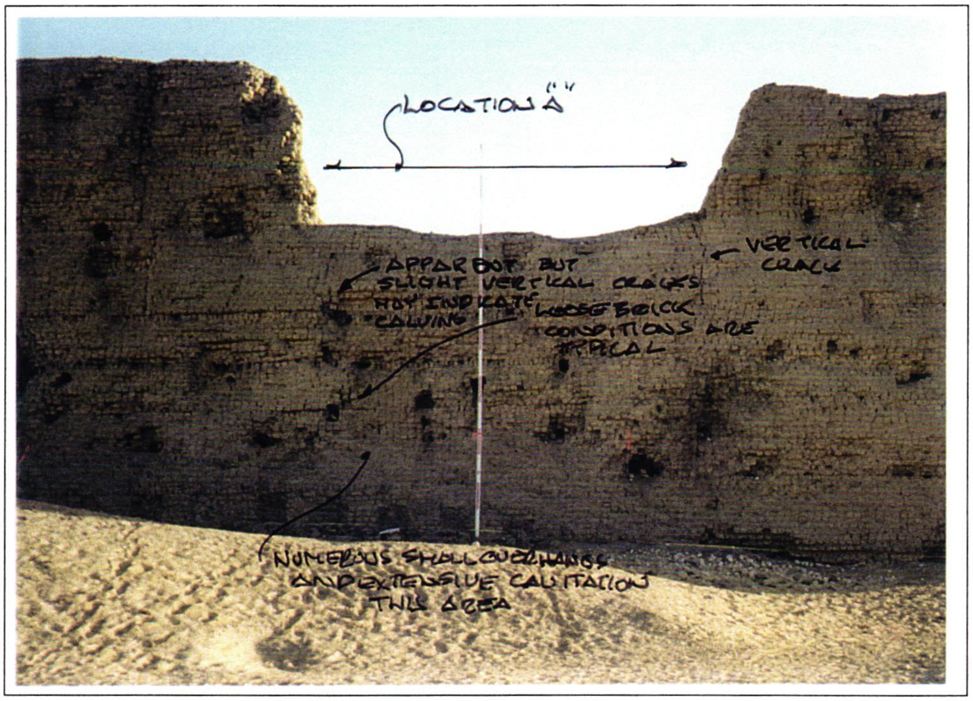
Photograph No. 66 West Main Enclosure Wall South End



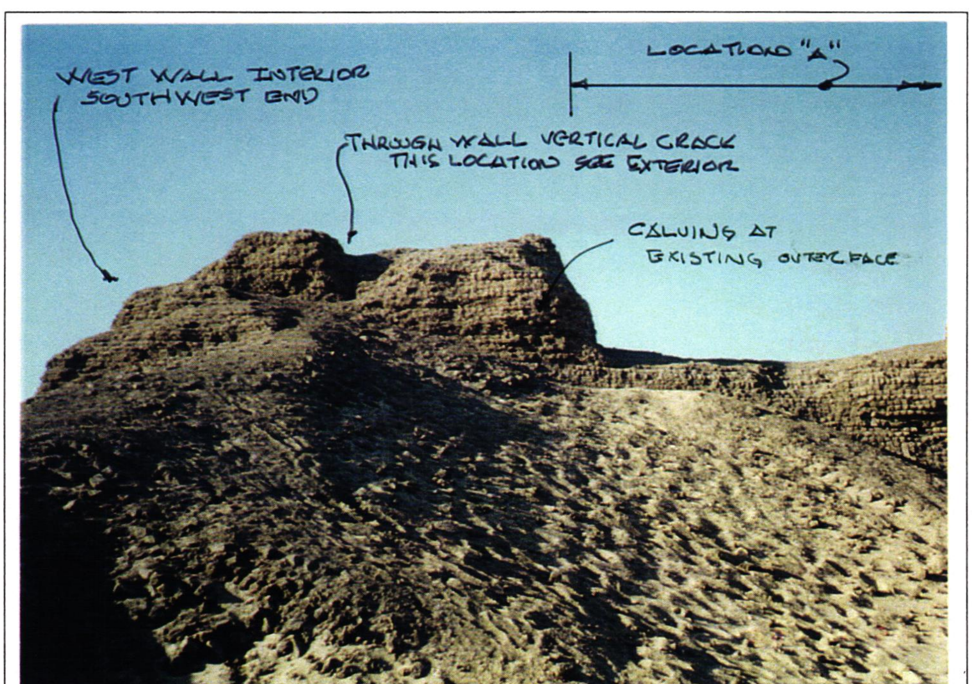
Photograph No. 67 West Main Enclosure Wall South End Upper Surface



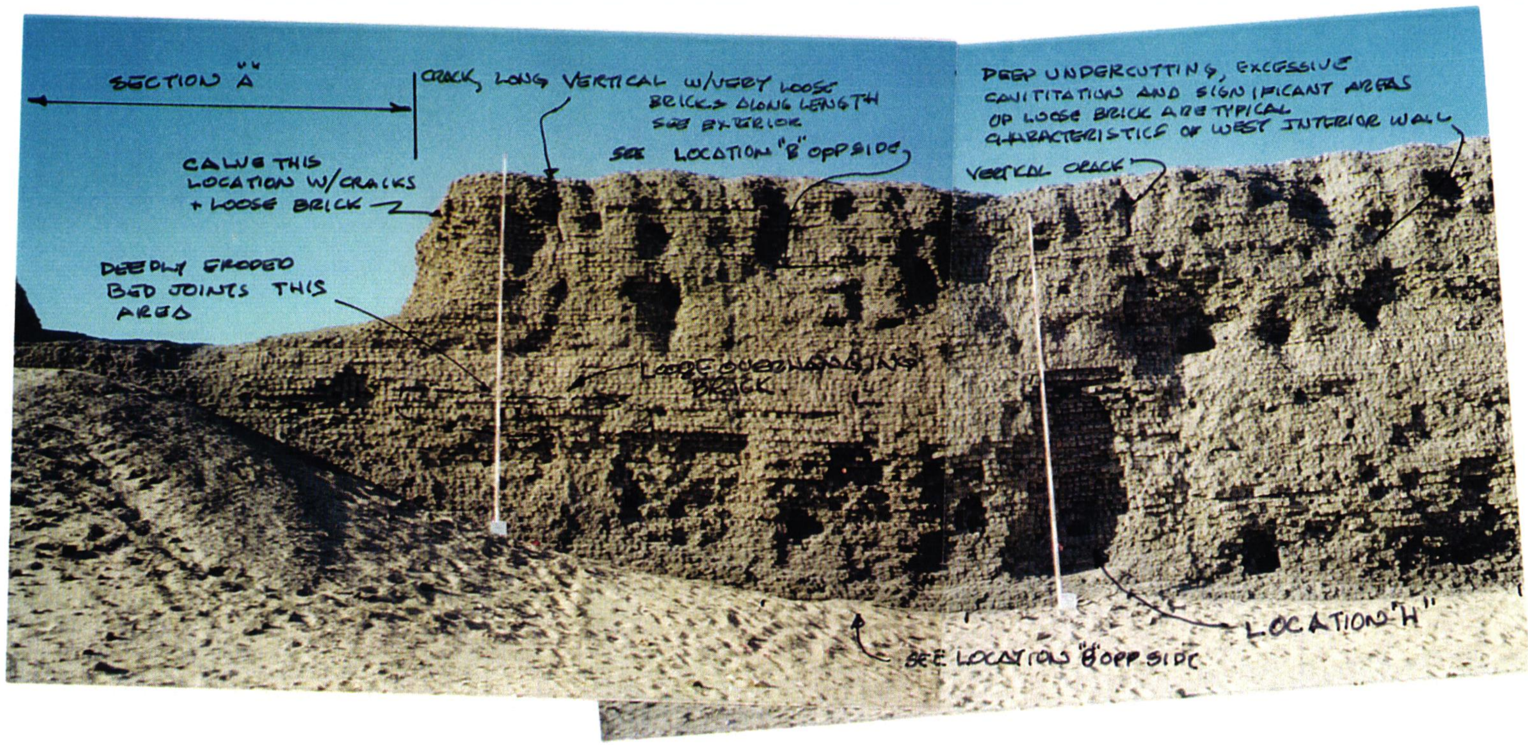
Photograph No. 68 West Main Enclosure Wall South End Lower Surface



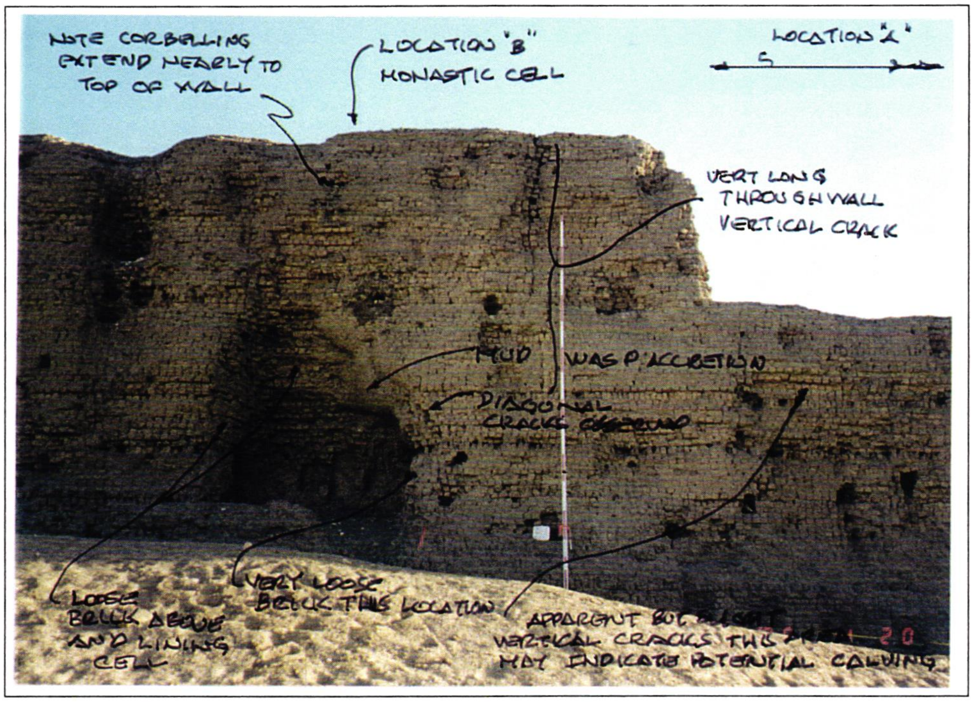
Photograph No. 69 Location "A" West Main Enclosure Wall



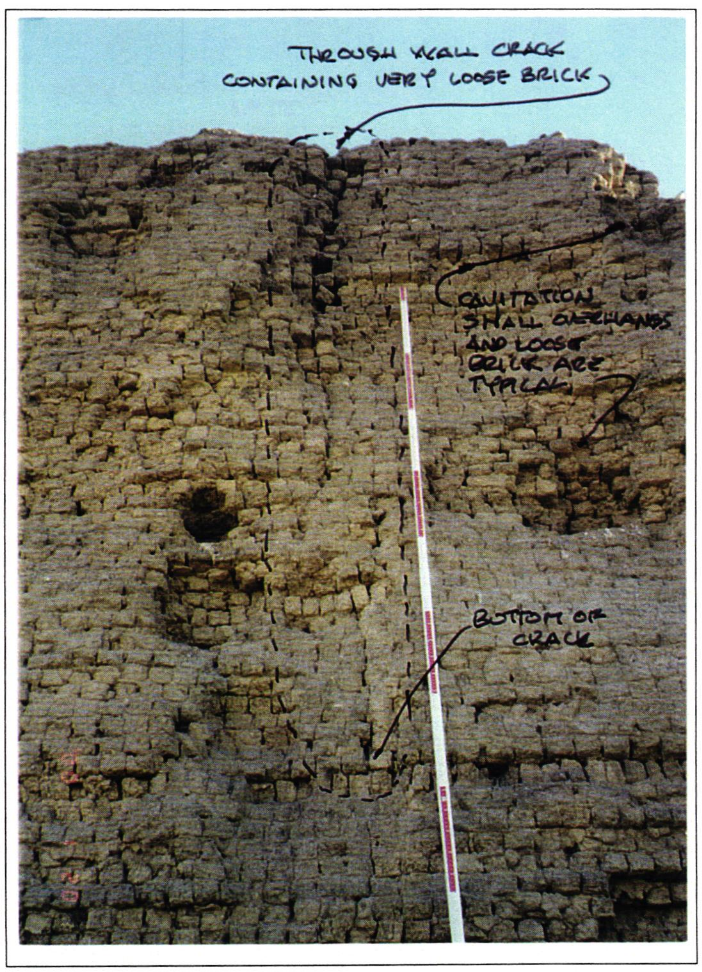
Photograph No. 70 Interior Southwest Corner West Main Enclosure Wall



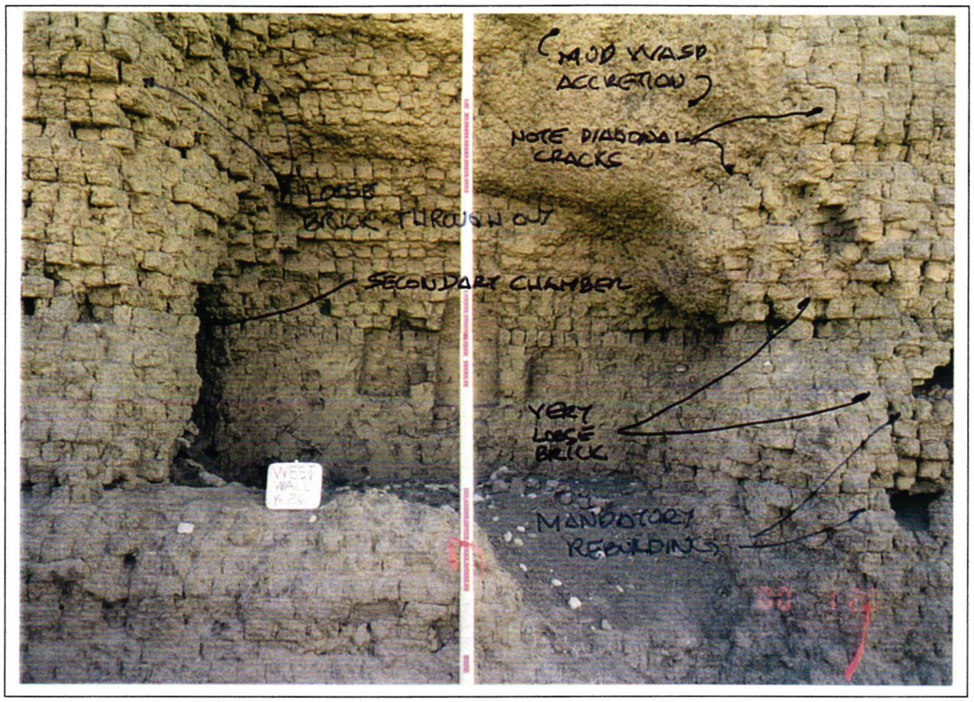
Composite Photograph No. 71 West Main Enclosure Wall, Interior View Adjacent to Location "A"



Photograph No. 72 Location “B” Monastic Cell

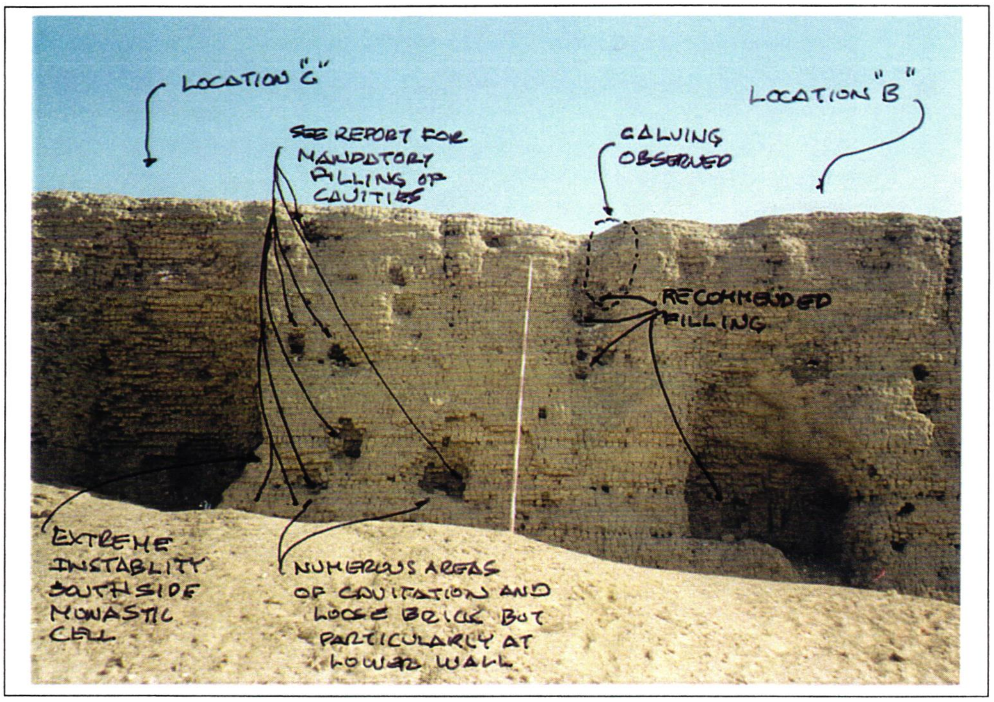


Photograph No. 73 Vertical Cracking Near Location “B”



Photograph No. 74 Location "B" Monastic Cell

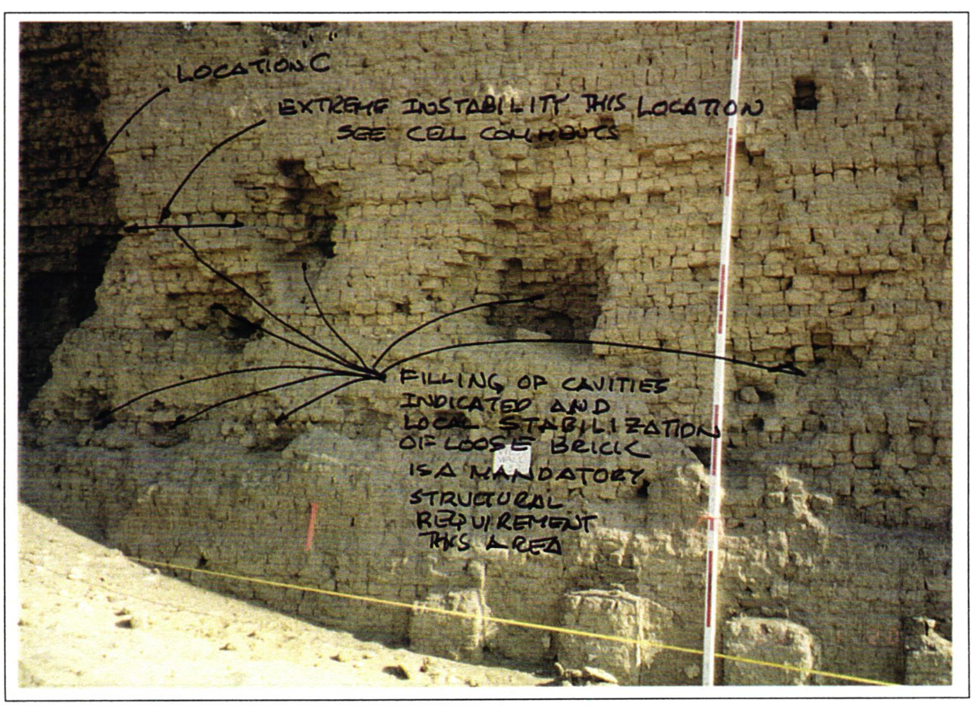
Photograph No. 75 Location "B" Monastic Cell Brick Instability



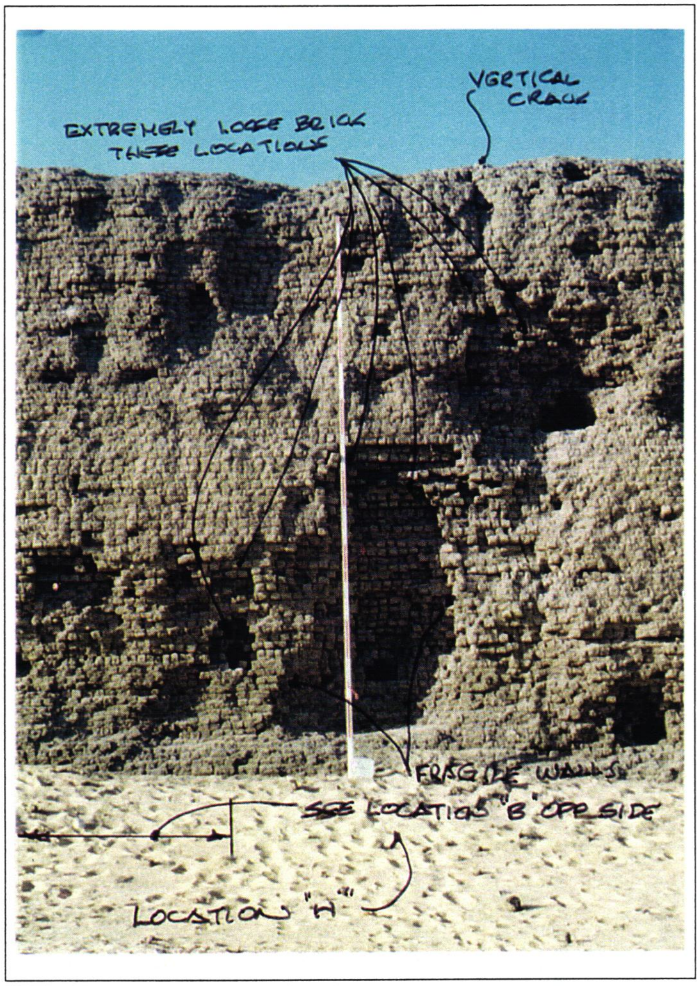
Photograph No. 76 Monastic Cells at West Main Enclosure Walls

Photograph No. 77 Location "C" Monastic Cell

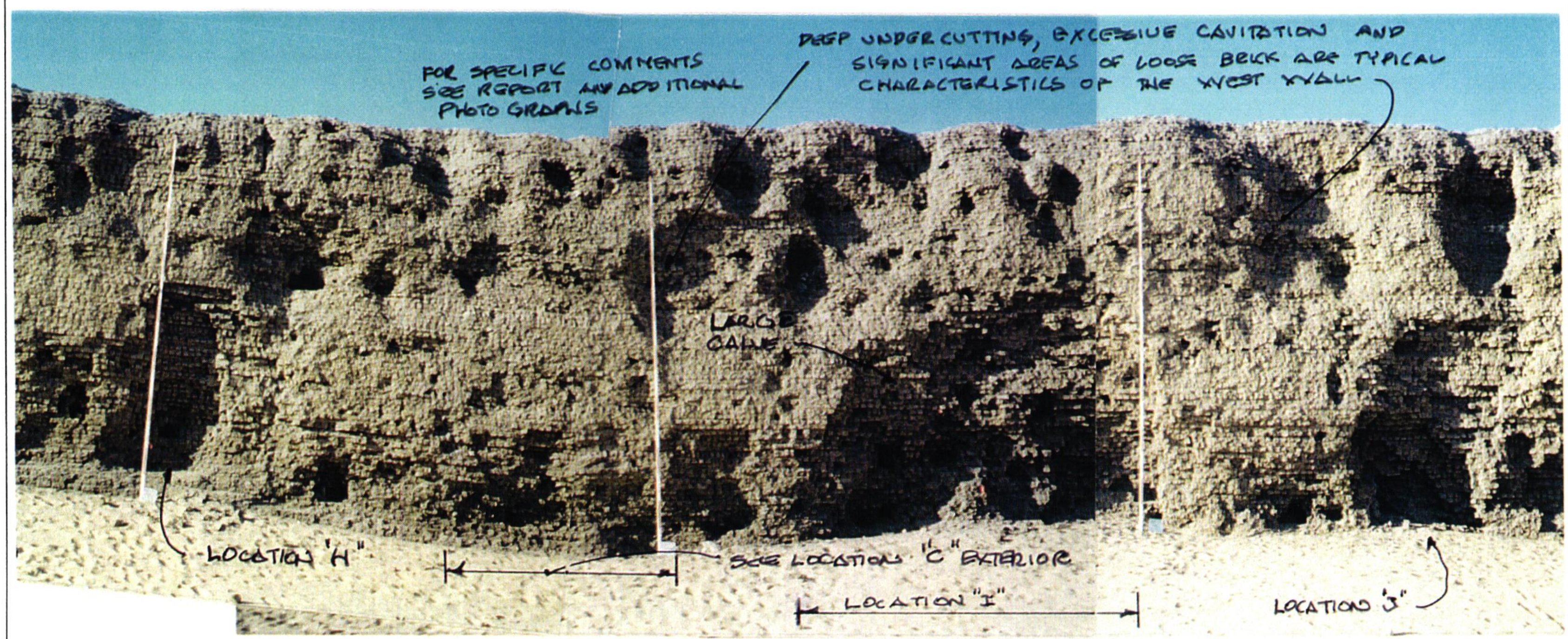
Photograph No. 78 Location "C" Monastic Cell



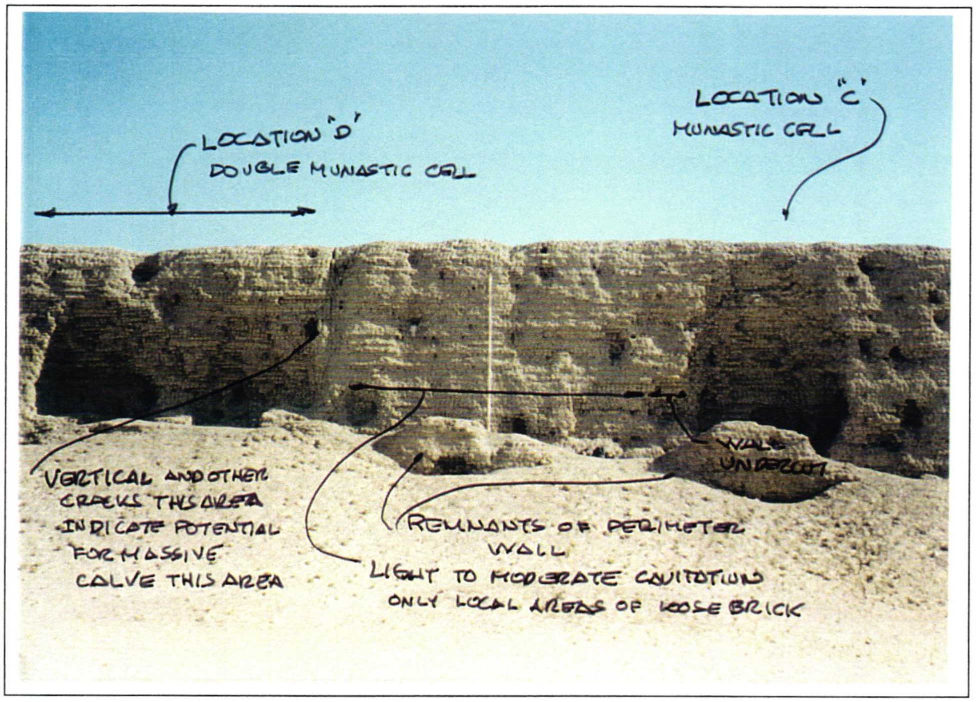
Photograph No. 79 Wall Instability Adjacent to Location "C"



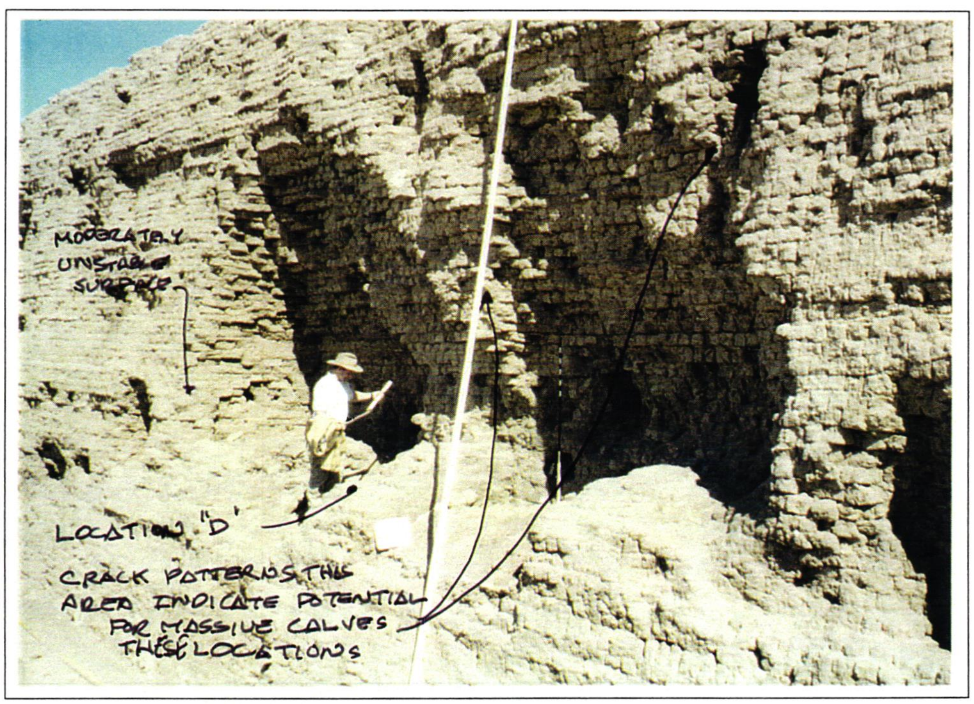
Photograph No. 80 Location "H" West Main Enclosure Wall Interior View



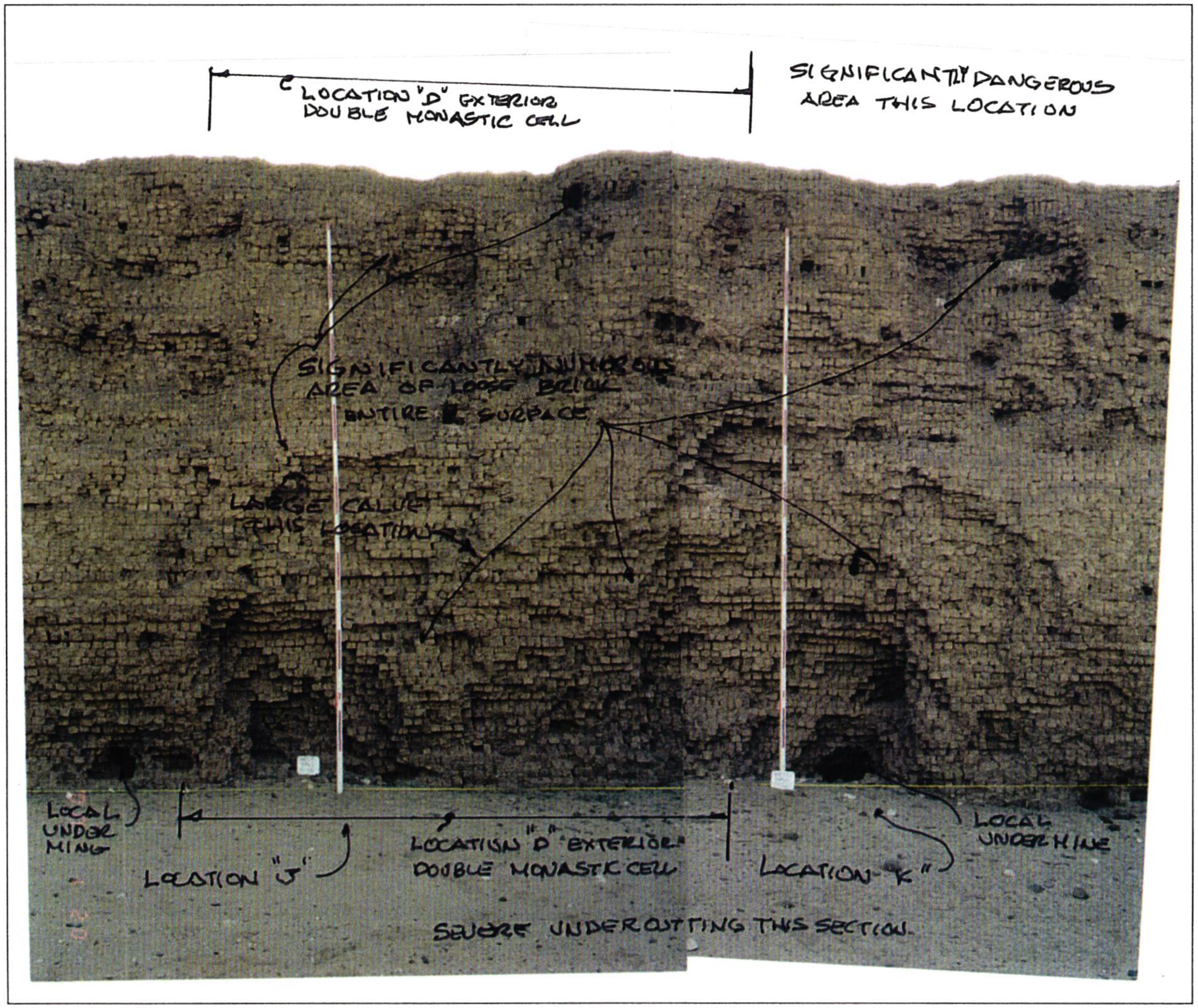
Composite Photograph No. 81 Locations "H","I" and "J" Interior West Main Enclosure Wall



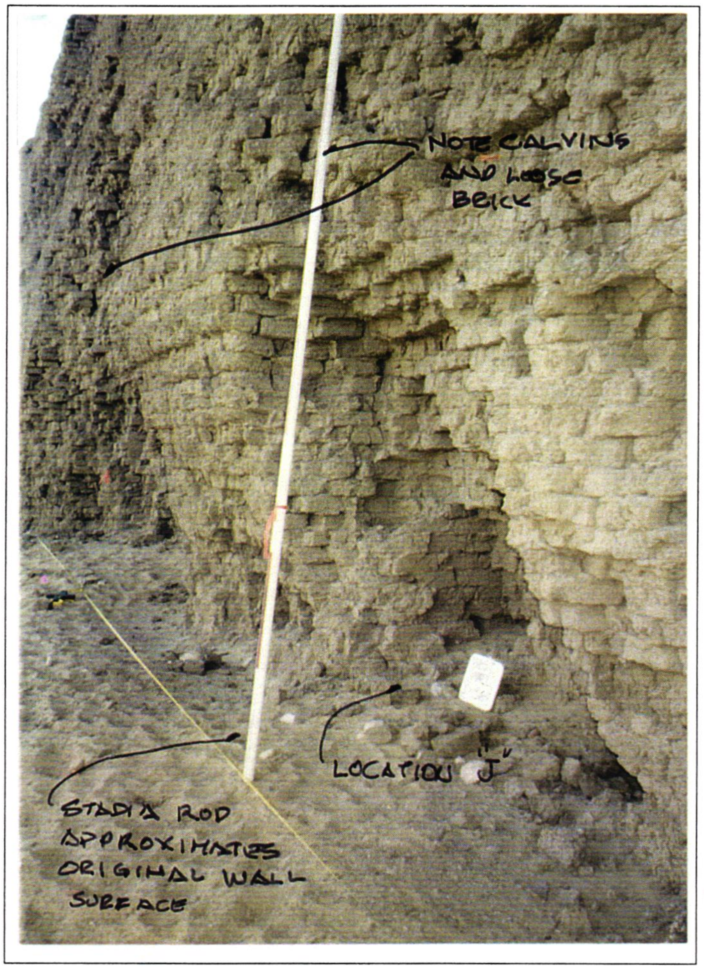
Photograph No. 82 Monastic Cells West Main Enclosure Wall



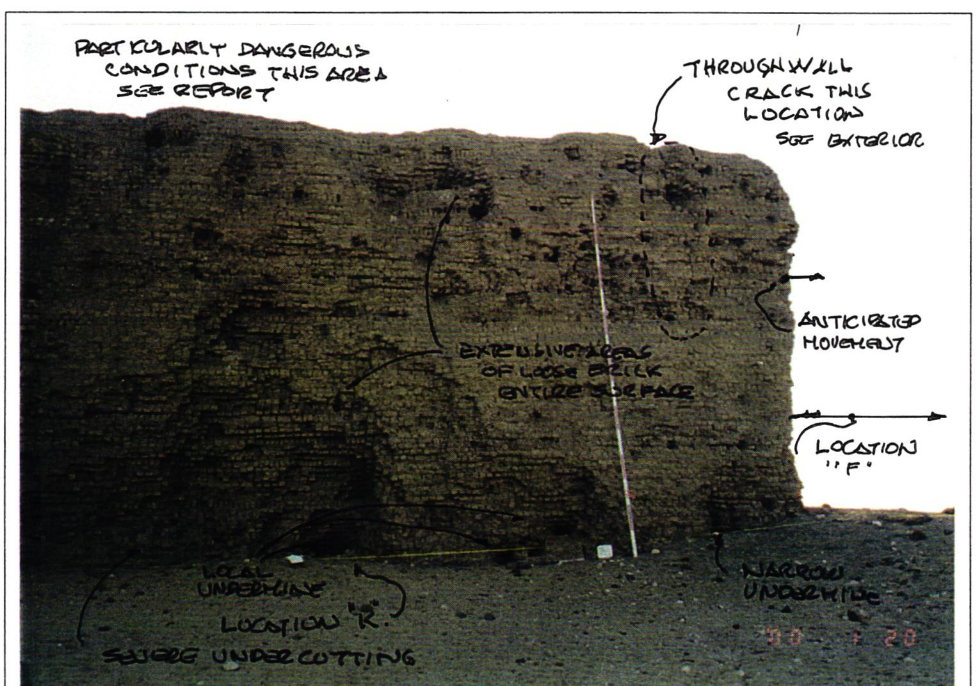
Photograph No. 83 Monastic Cell Location "D" West Main Enclosure Wall



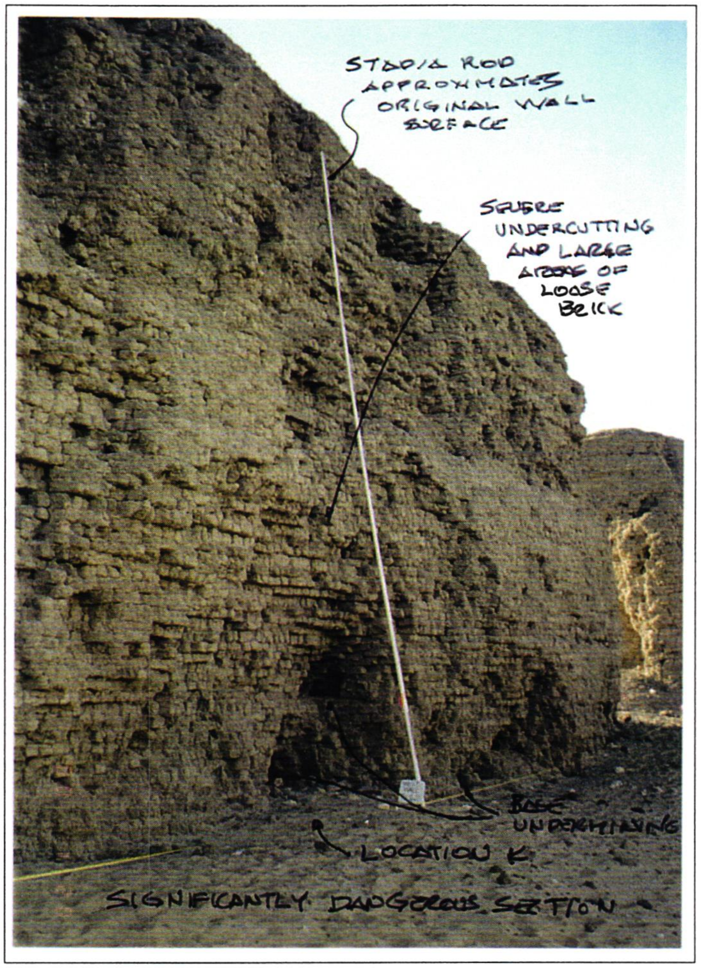
Composite Photograph No. 84 Locations "J" and "K" Interior West Main Enclosure Wall



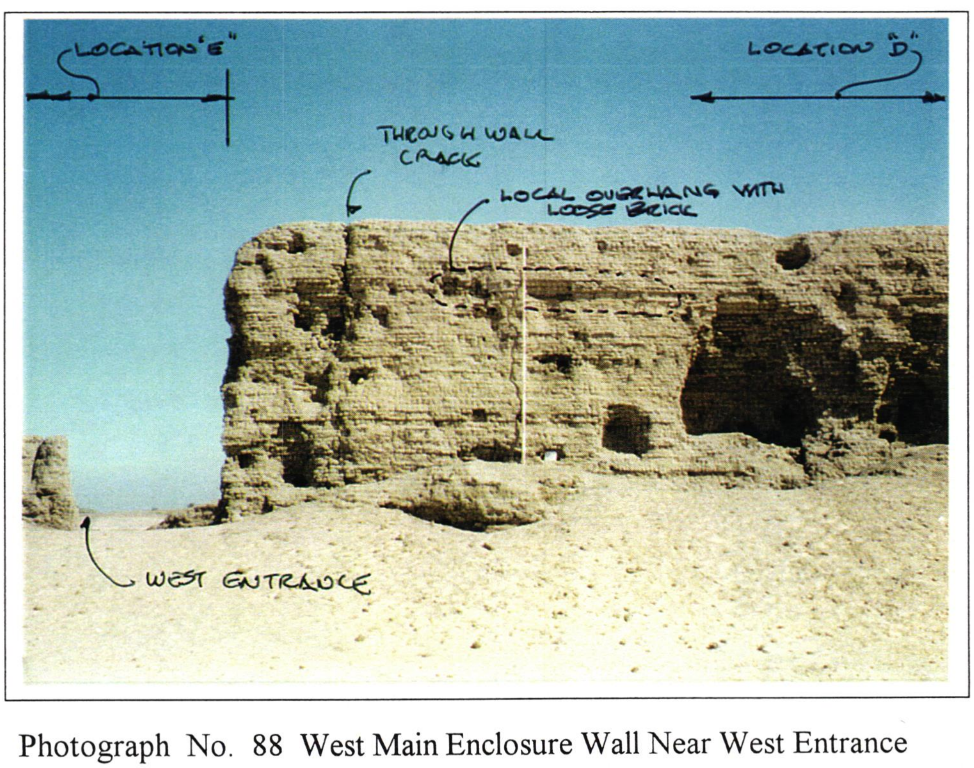
Photograph No. 85 Wall Undercutting West Main Enclosure Wall



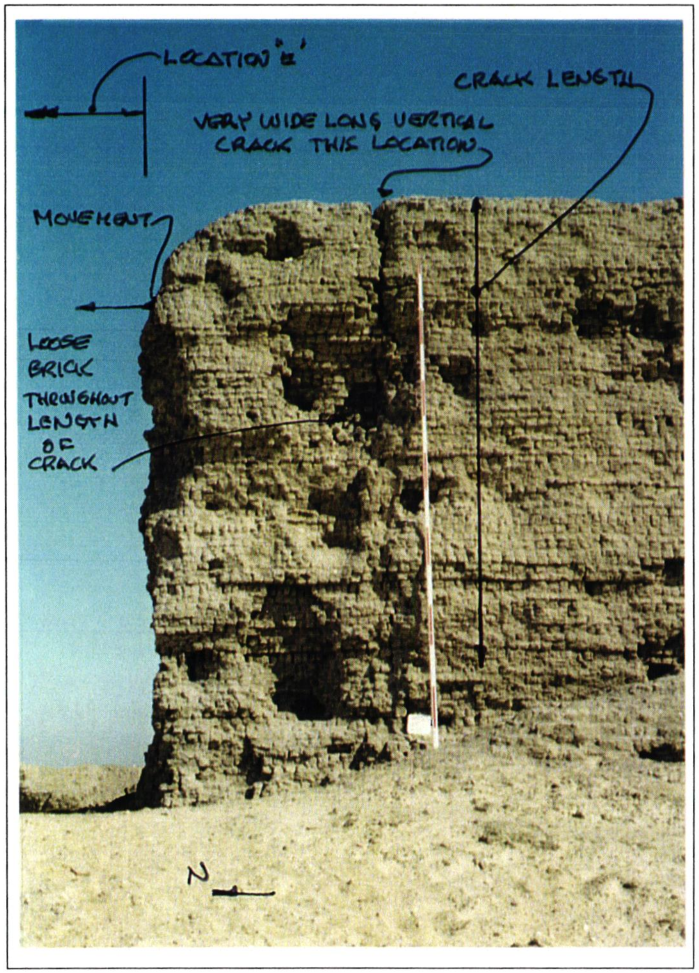
Photograph No. 86 West Main Enclosure Wall Near West Entrance



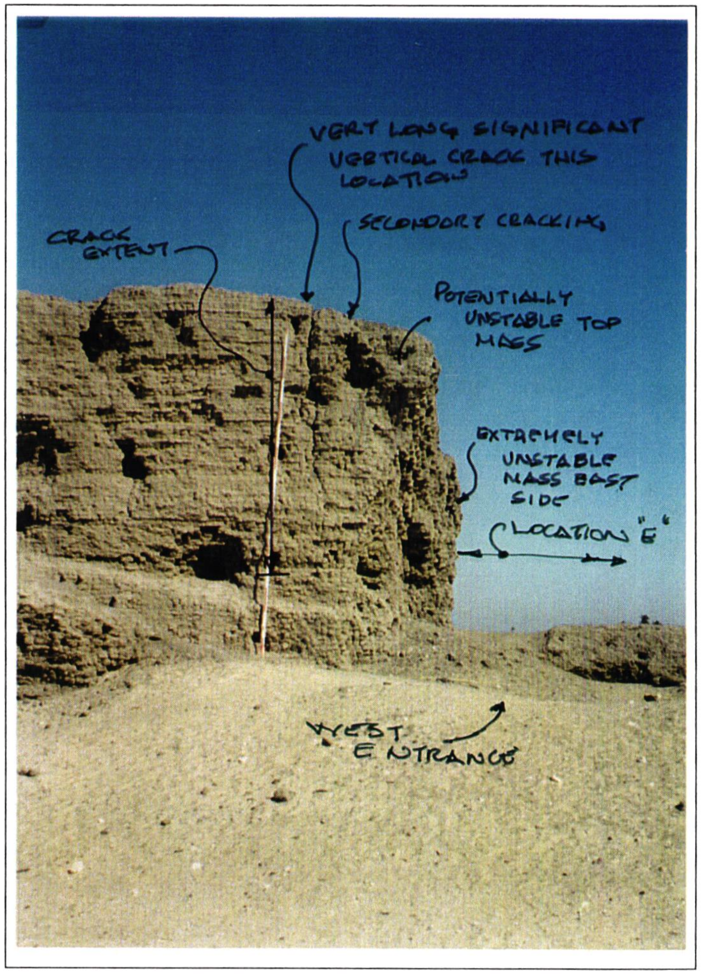
Photograph No. 87 Wall Undercutting West Main Enclosure Wall



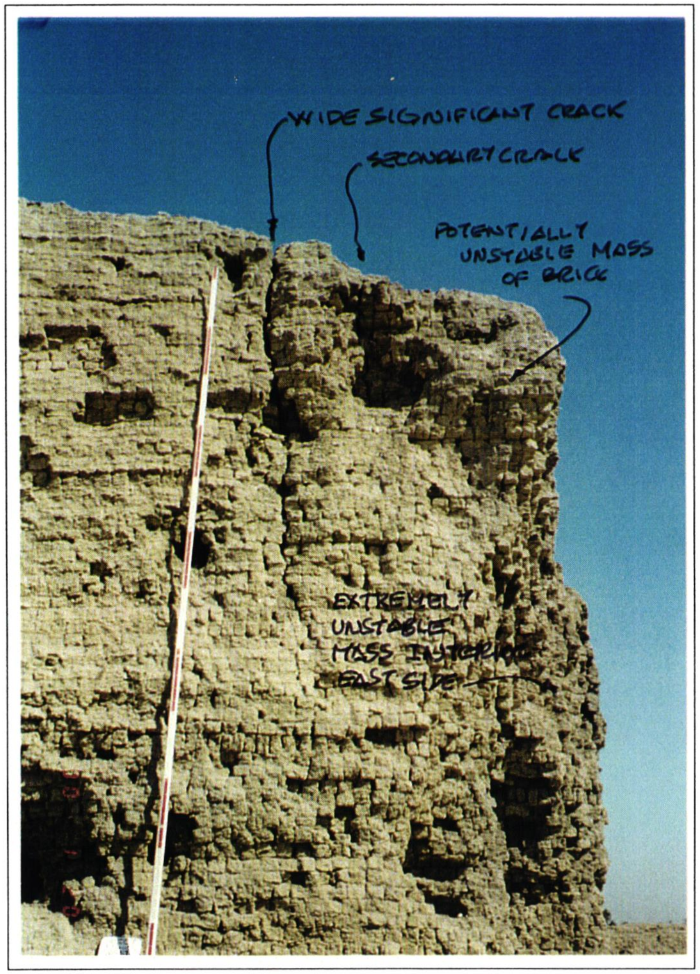
Photograph No. 88 West Main Enclosure Wall Near West Entrance



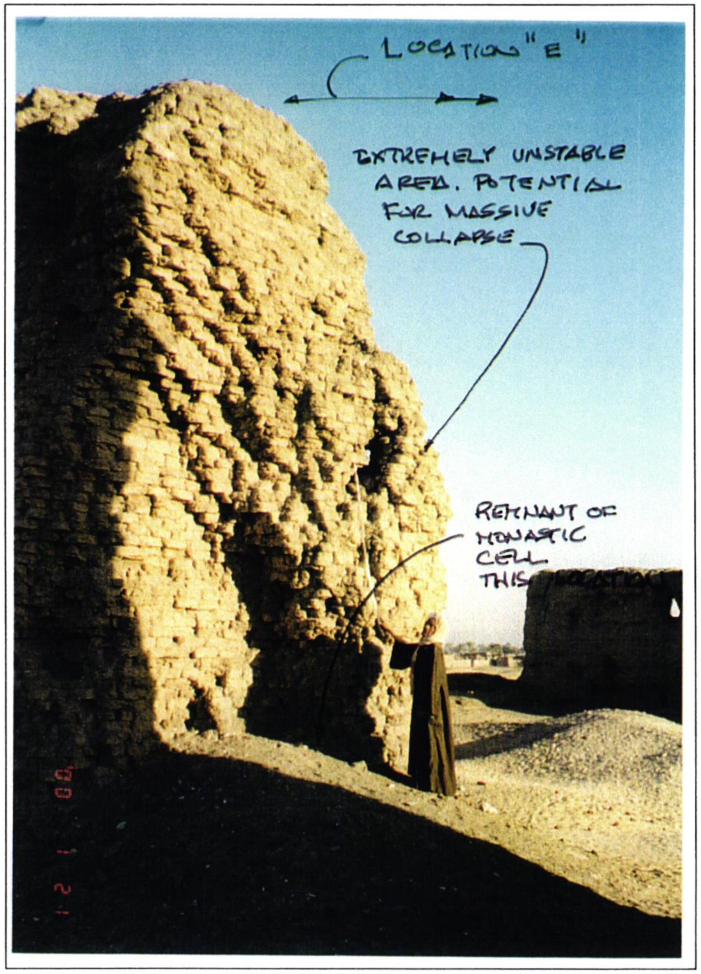
Photograph No. 89 Main Enclosure Wall at West Entrance



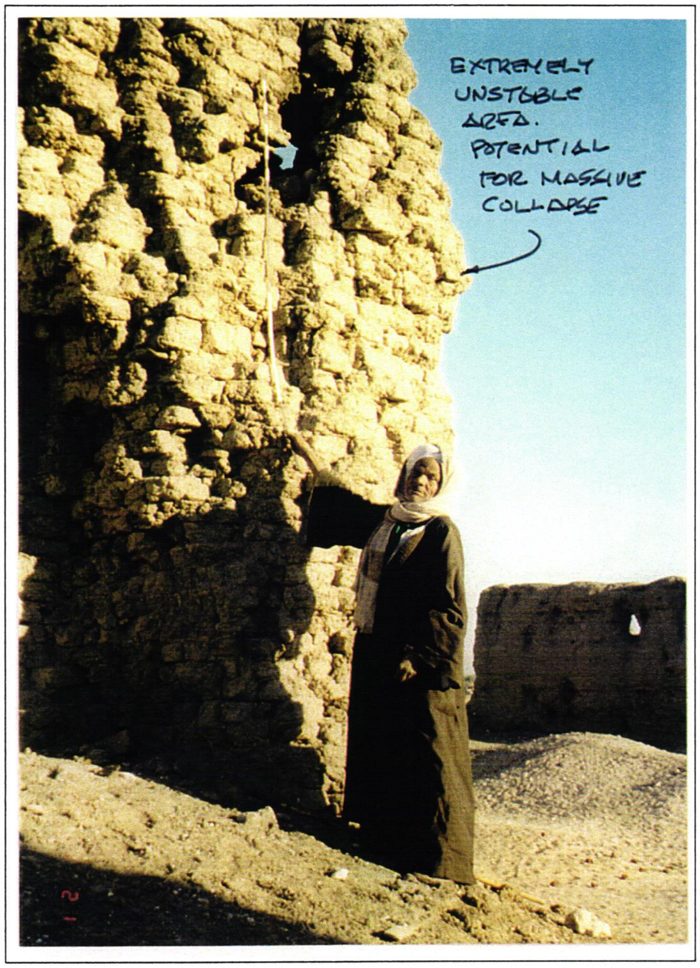
Photograph No. 90 West Main Enclosure Wall at West Entrance



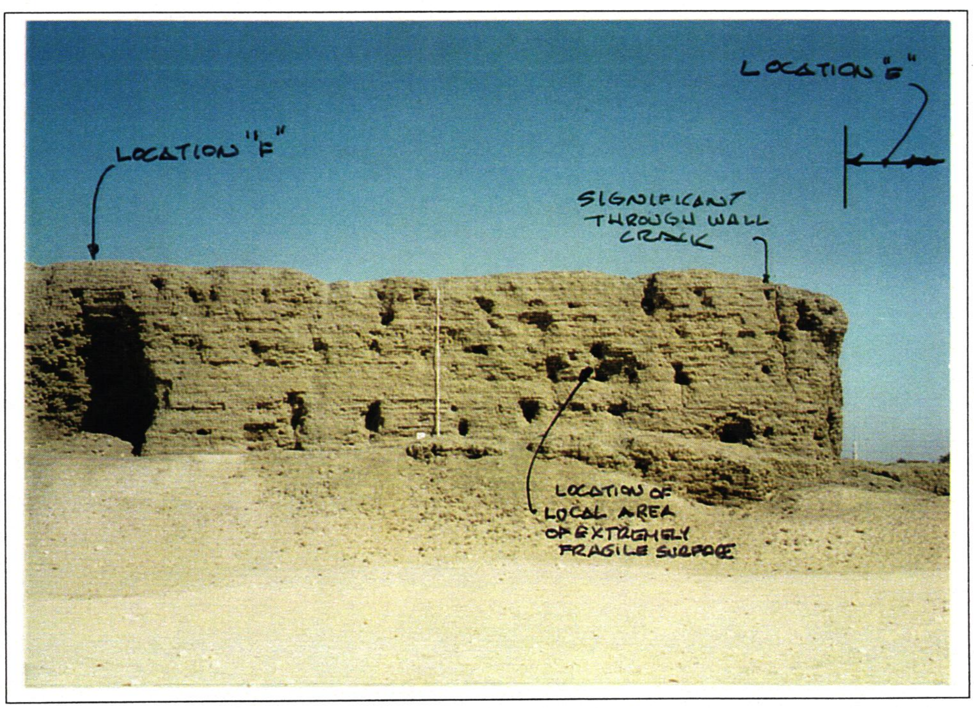
Photograph No. 91 Instability at North Side West Entrance



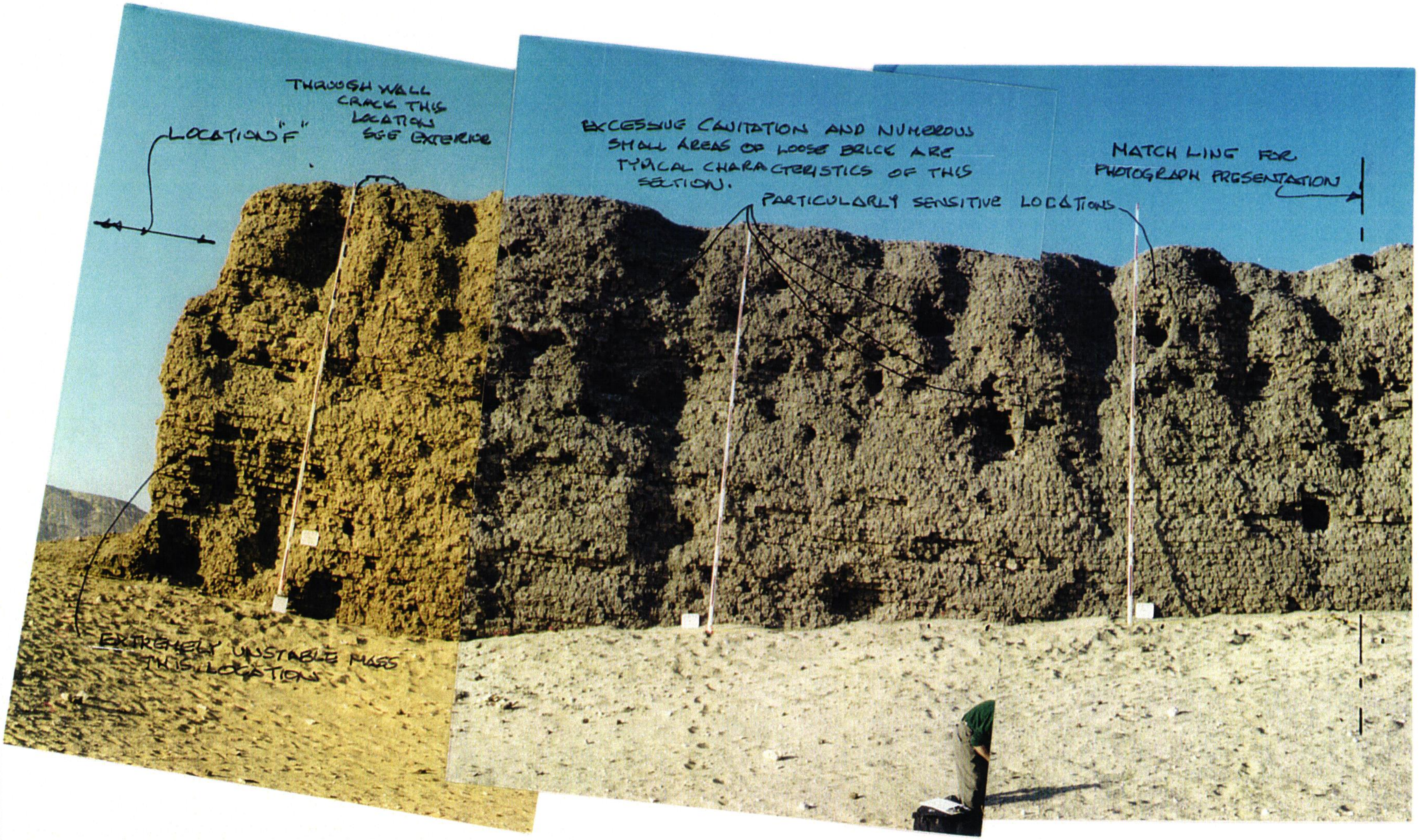
Photograph No. 92 Potential Failure Location at West Entrance



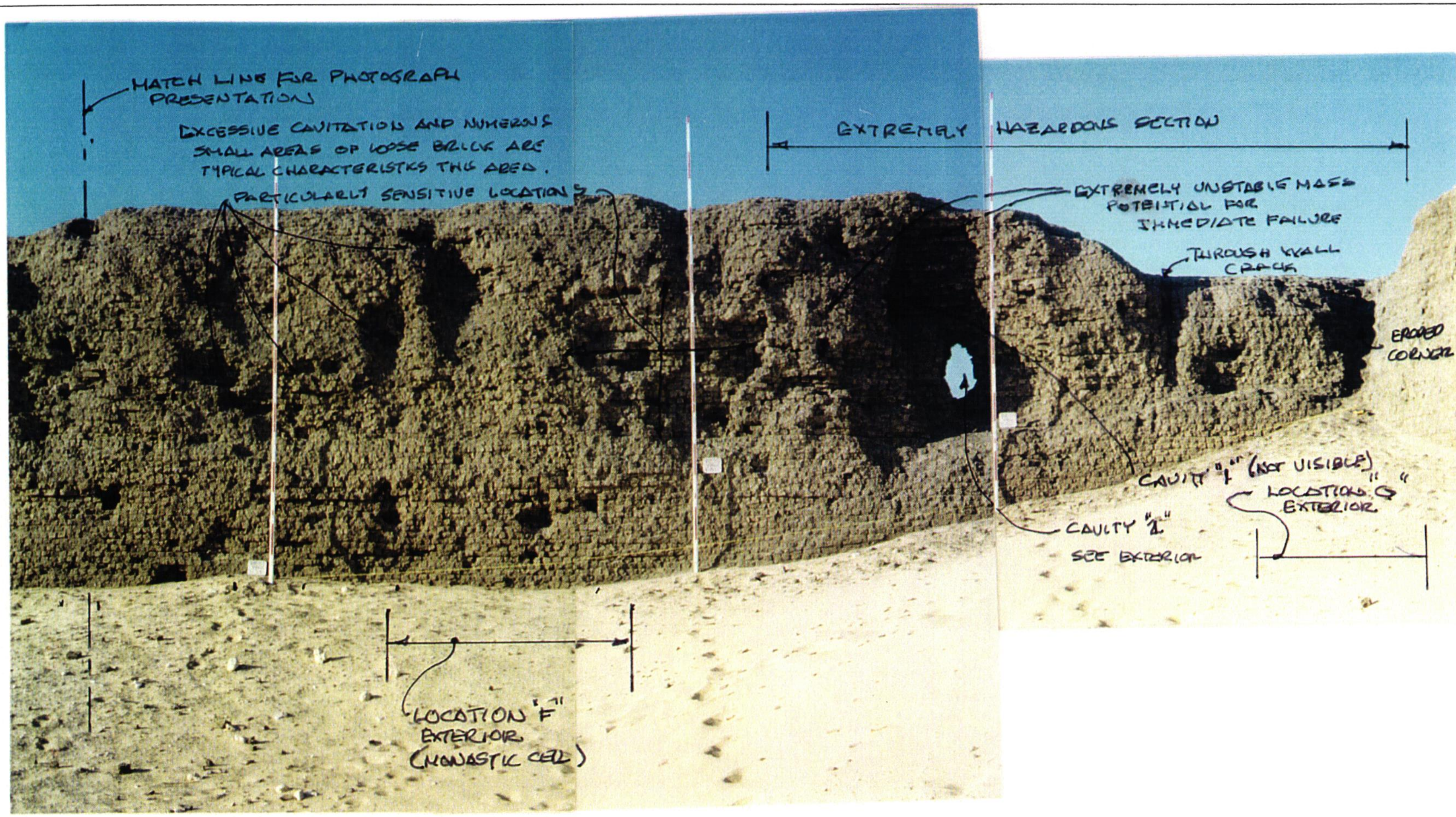
Photograph No. 93 Potential Failure Location at West Entrance



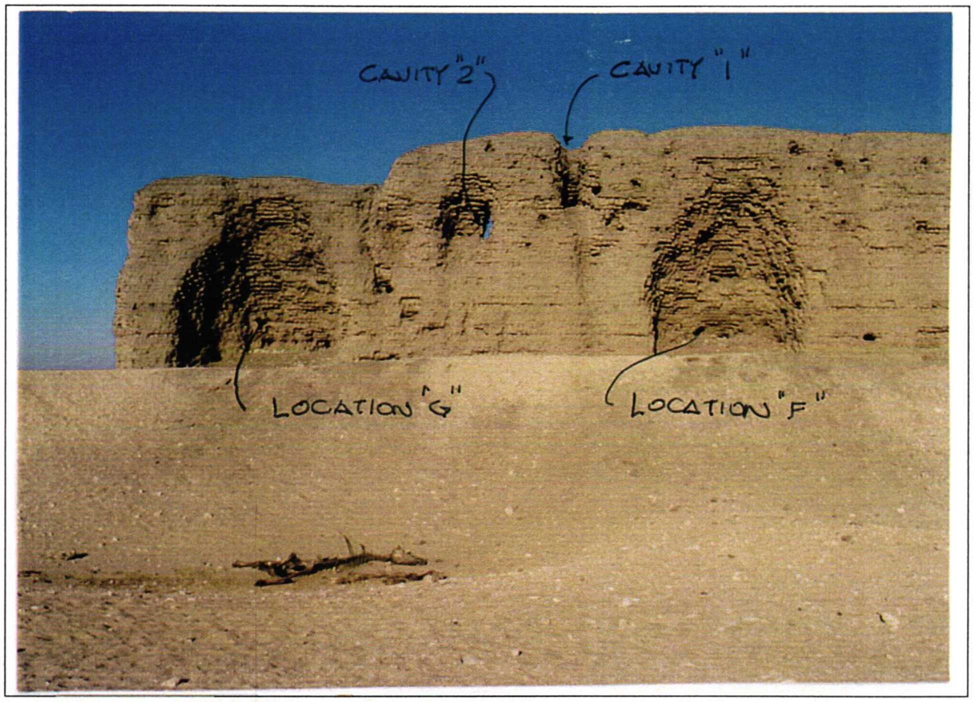
Photograph No. 94 West Main Enclosure Wall North Area



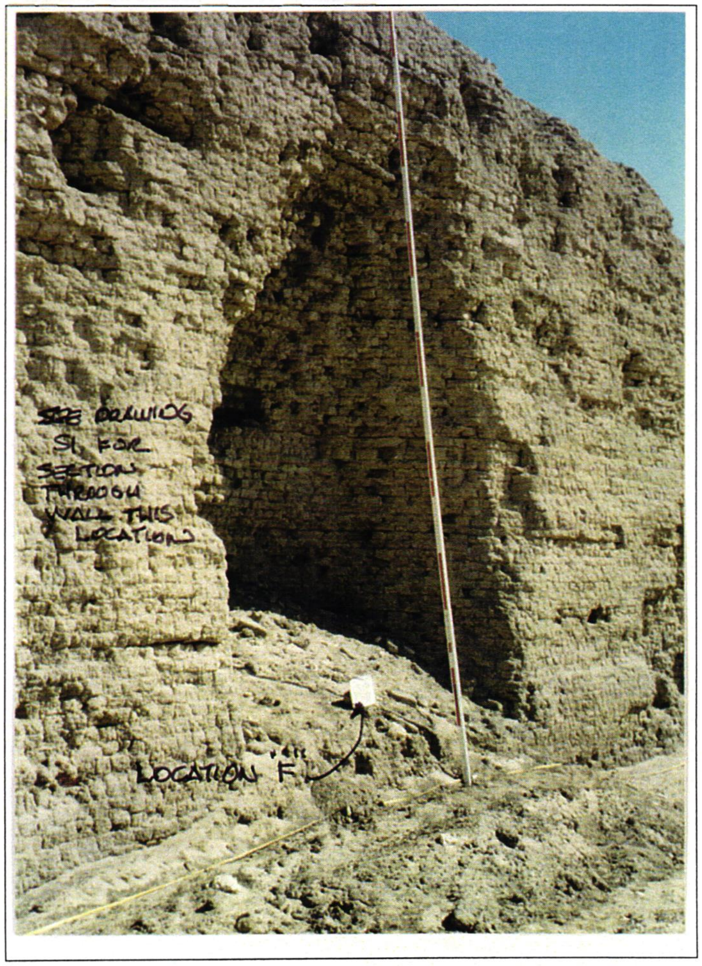
Composite Photograph No. 95 North Interior End West Main Enclosure Wall (1 of 2 Photographs)



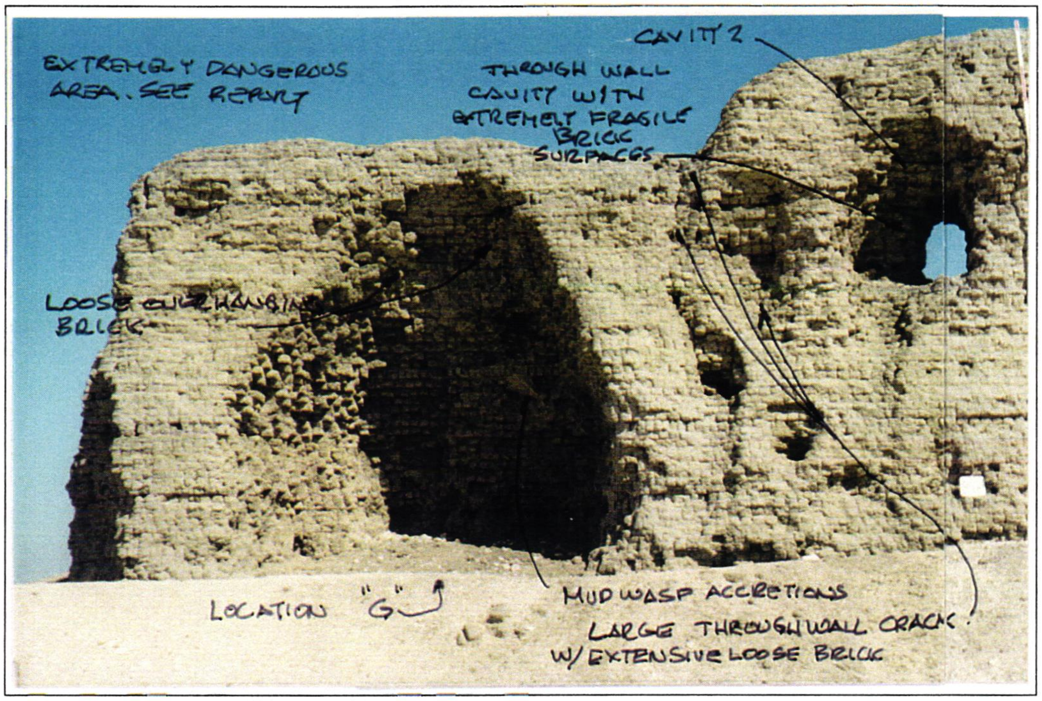
Composite Photograph No. 96 North Interior End West Main Enclosure Wall (2 of 2 Photographs)



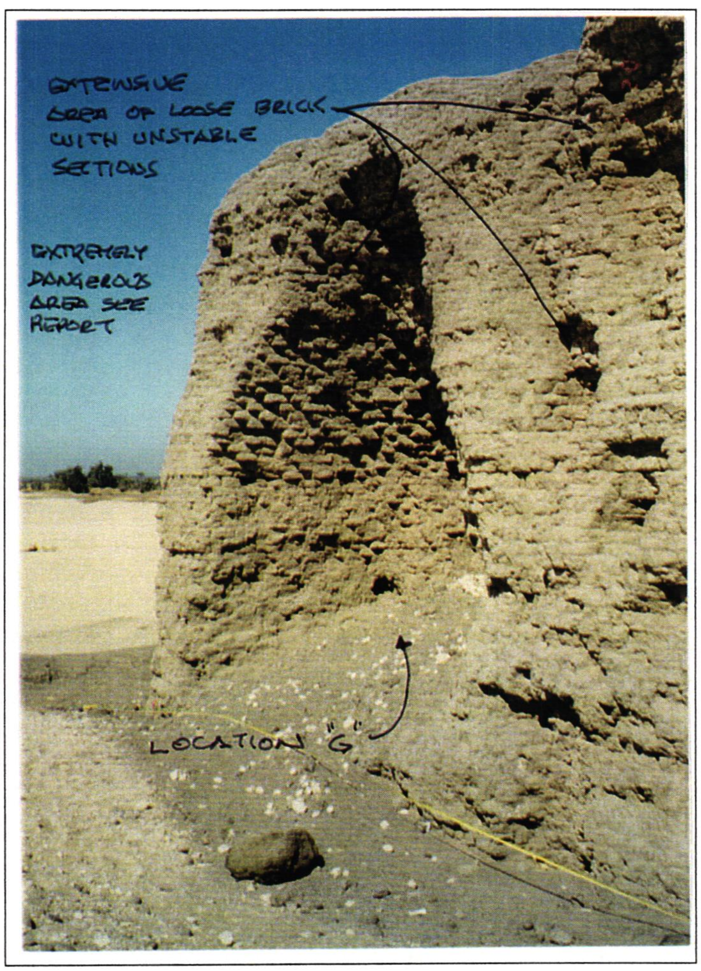
Photograph No. 97 West Main Enclosure Wall North End Exterior



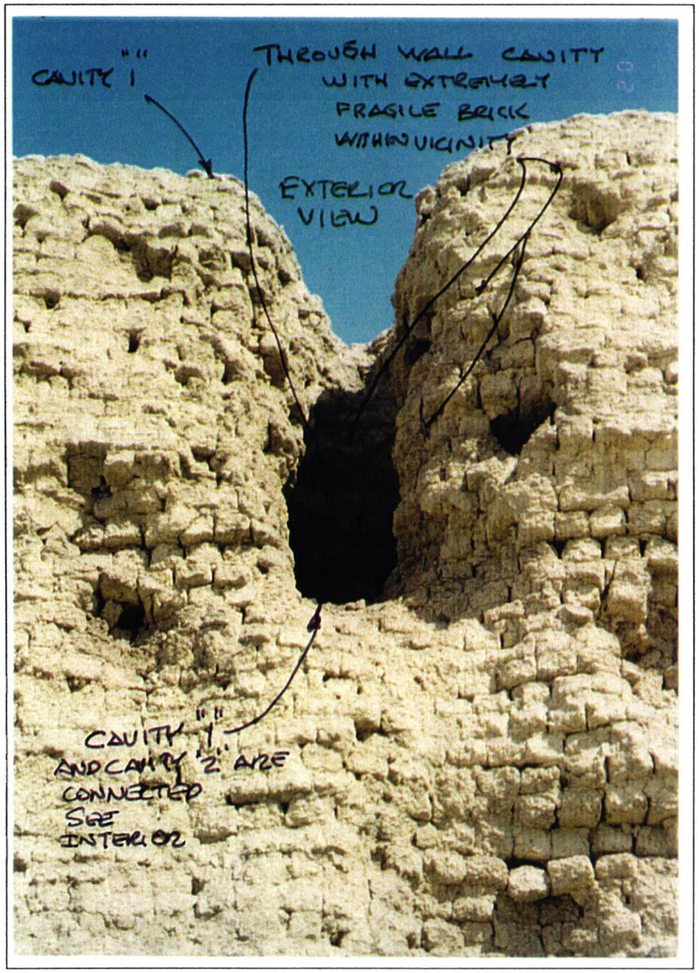
Photograph No. 98 Location "F" West Main Enclosure Wall



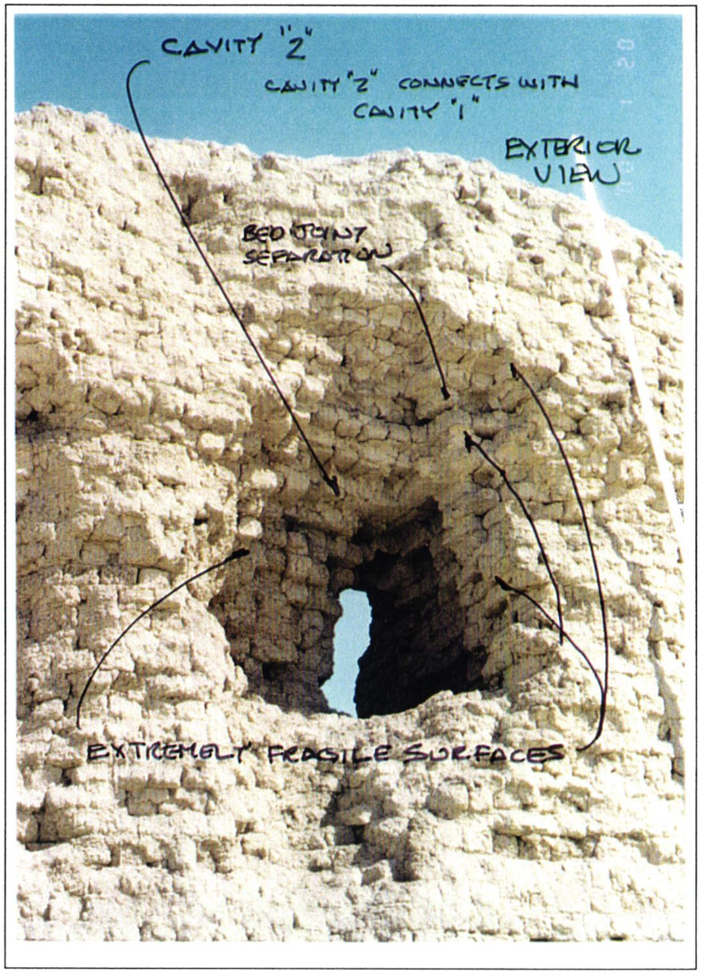
Photograph No. 99 West Main Enclosure Wall, North End, Exterior



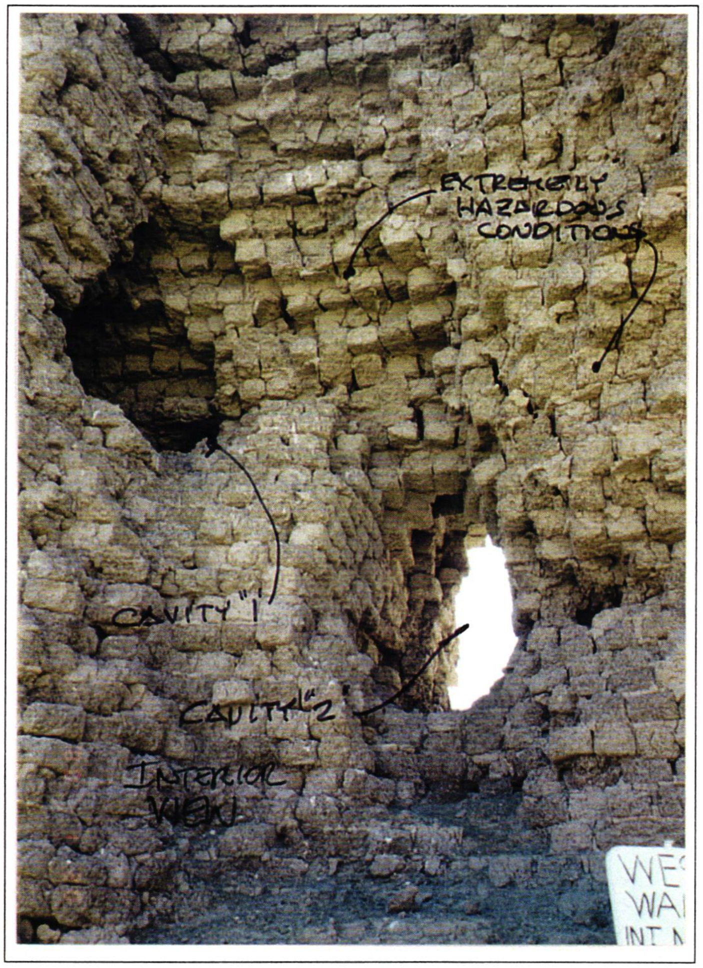
Photograph No. 100 Location "G" West Main Enclosure Wall



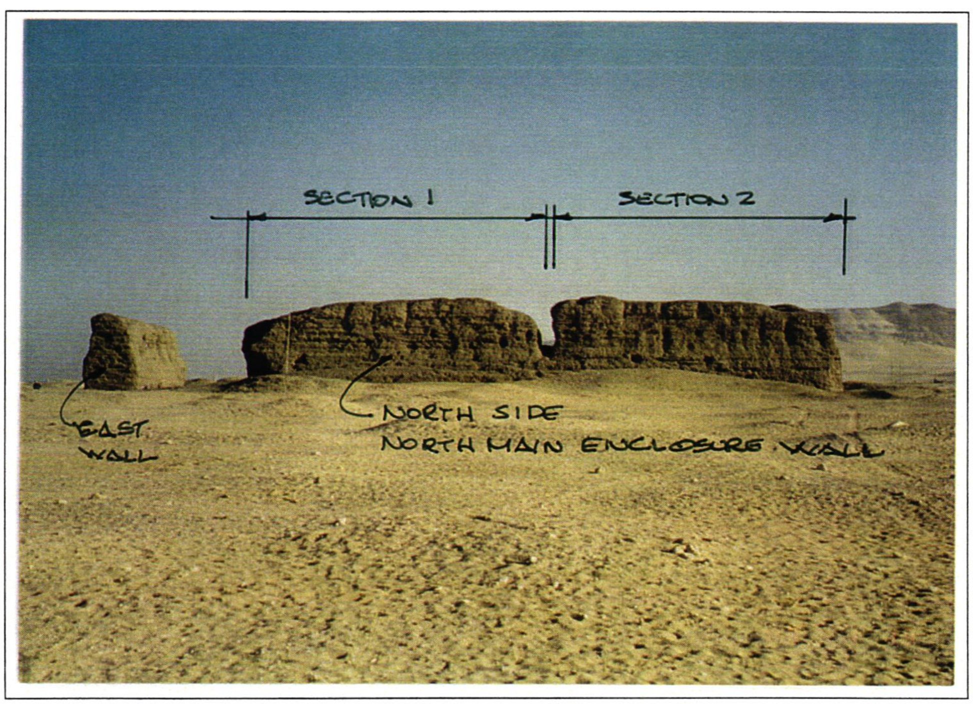
Photograph No. 101 Cavity 1 West Main Enclosure Wall



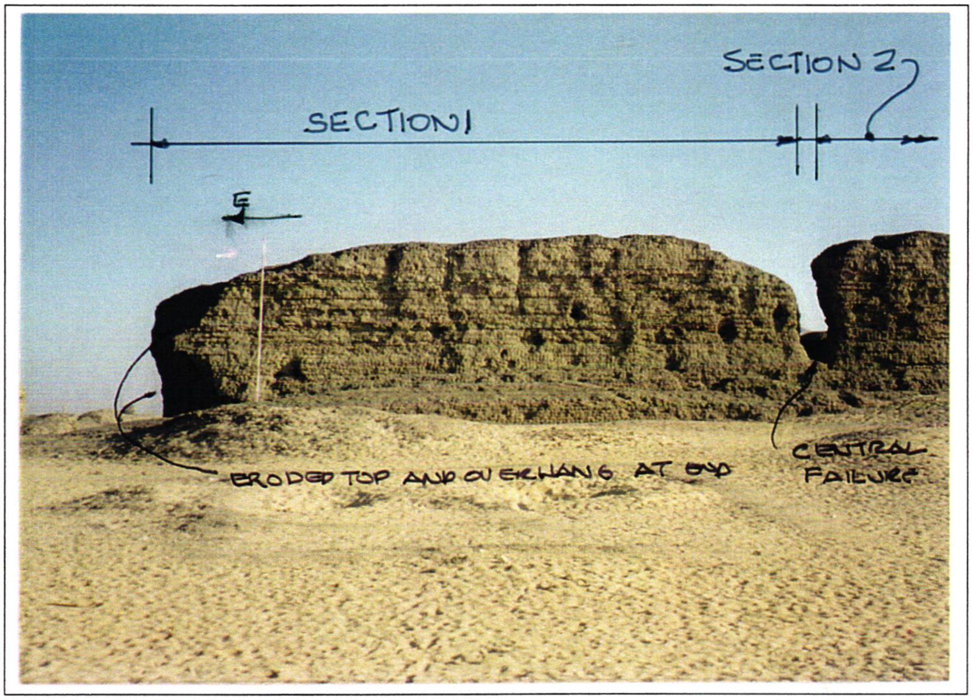
Photograph No. 102 Cavity 2 West Main Enclosure Wall



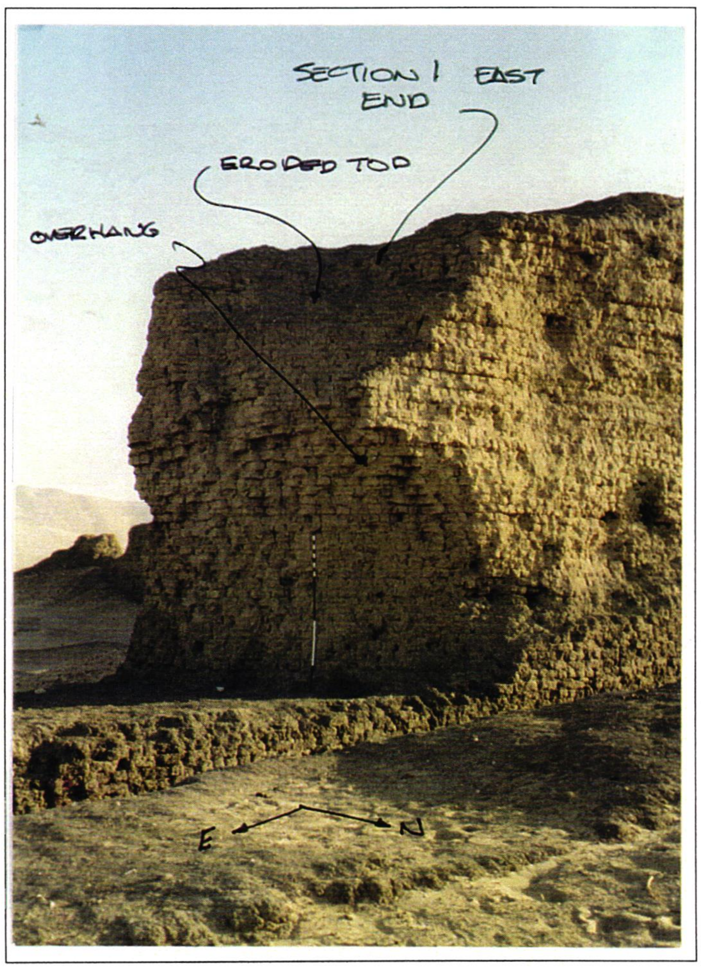
Photograph No. 103 Cavity 1 and Cavity 2 Interconnection, Interior View



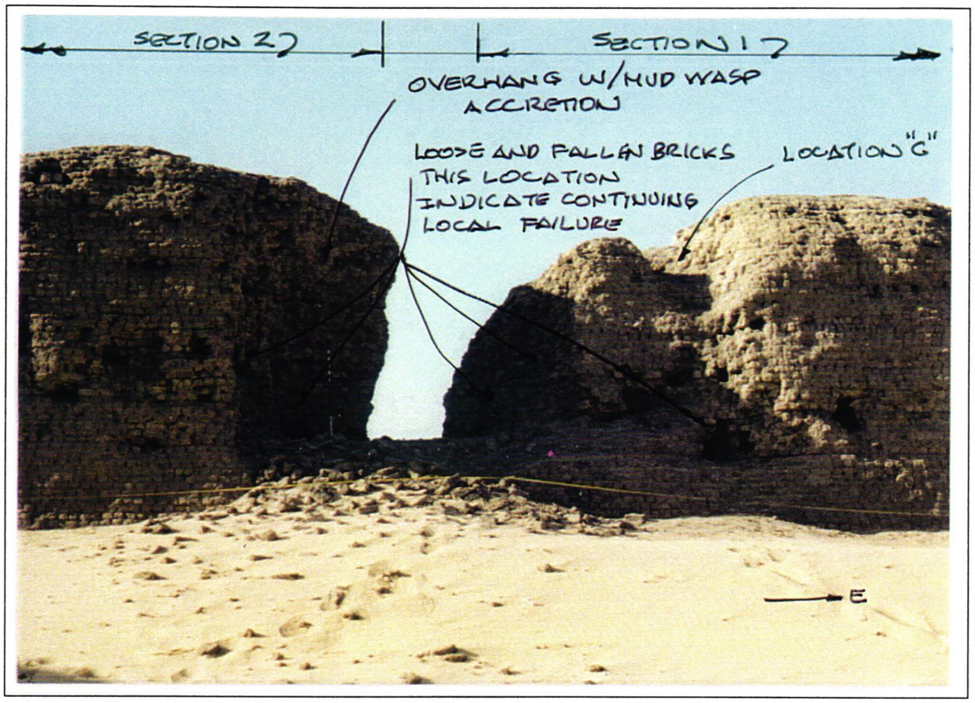
Photograph No. 104 North Main Enclosure Wall



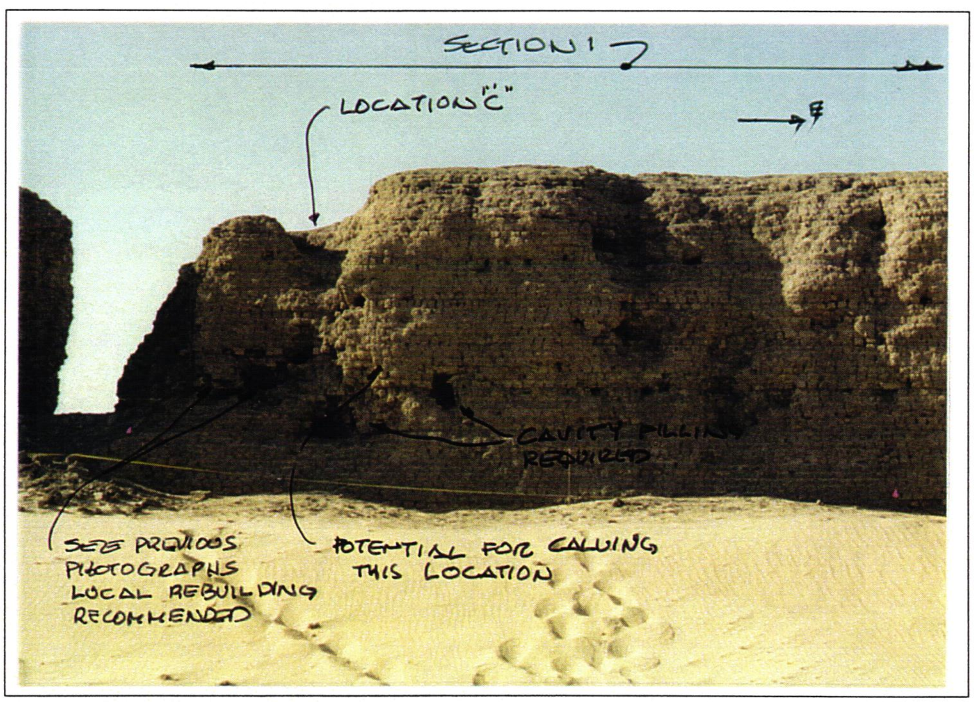
Photograph No. 105 Section 1 North Main Enclosure Wall



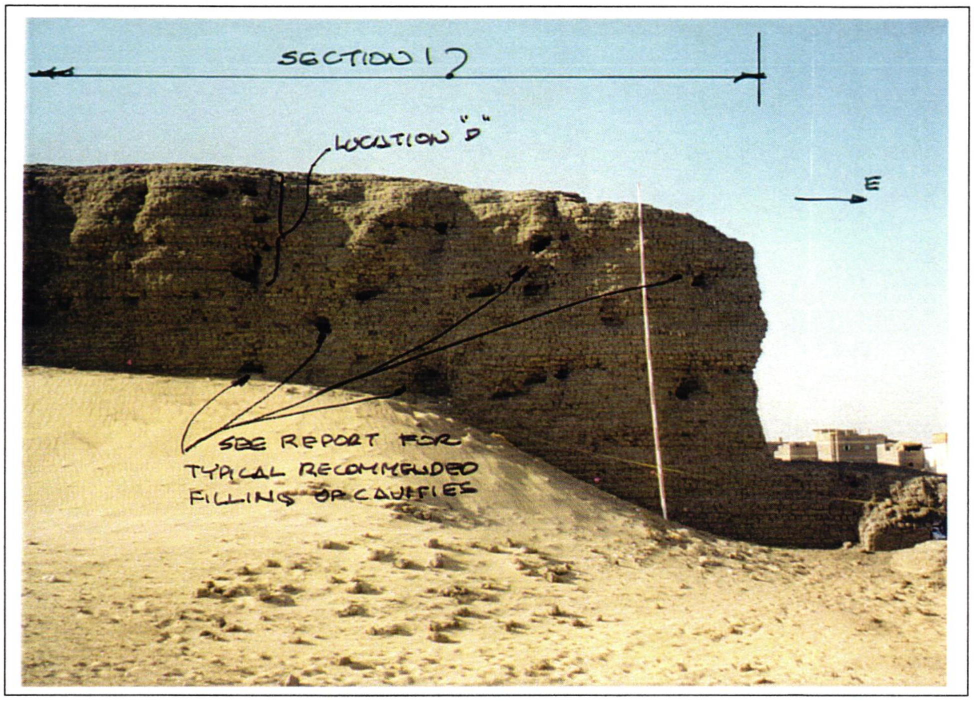
Photograph No. 106 East End North Main Enclosure Wall



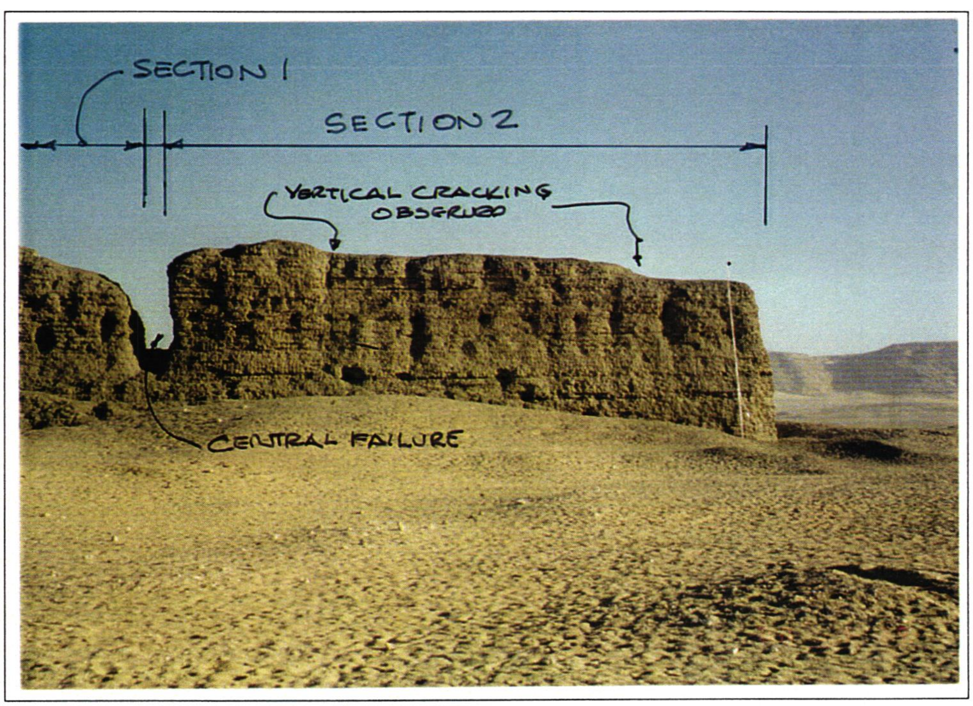
Photograph No. 107 Central Failure North Main Enclosure Wall



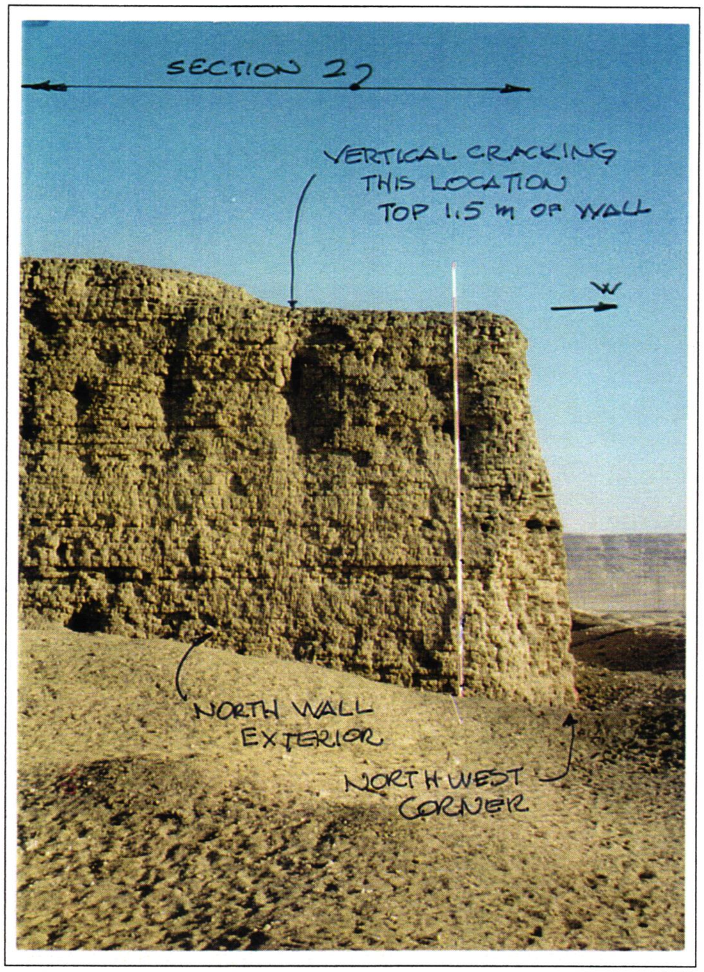
Photograph No. 108 Conditions Near Central Failure North Main Enclosure Wall



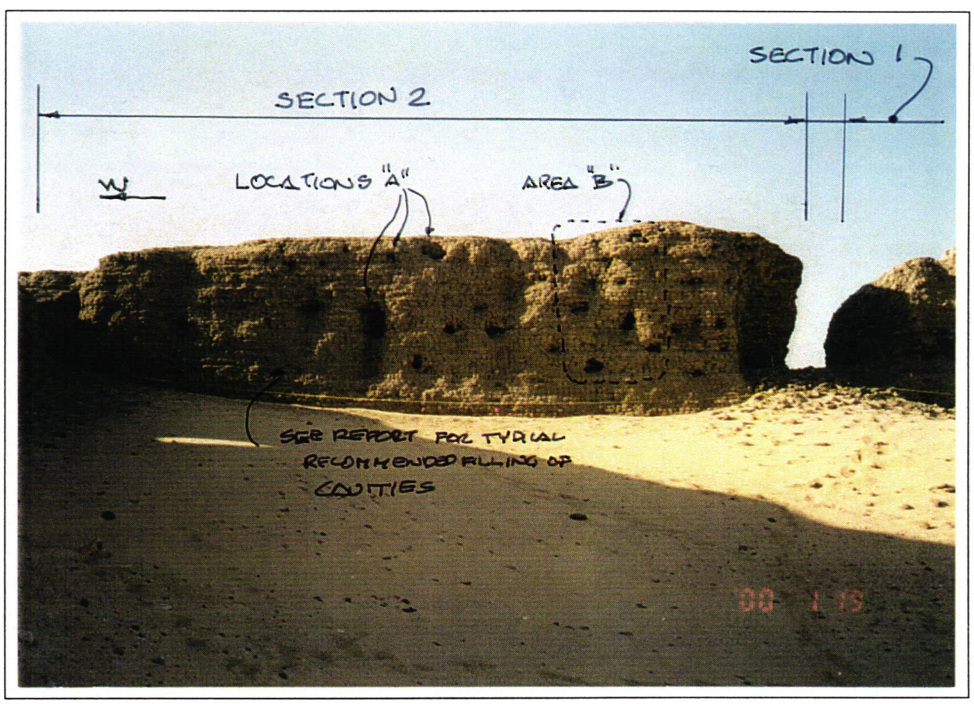
Photograph No. 109 North Main Enclosure Wall East End Interior View



Photograph No. 110 Section 2 North Main Enclosure Wall

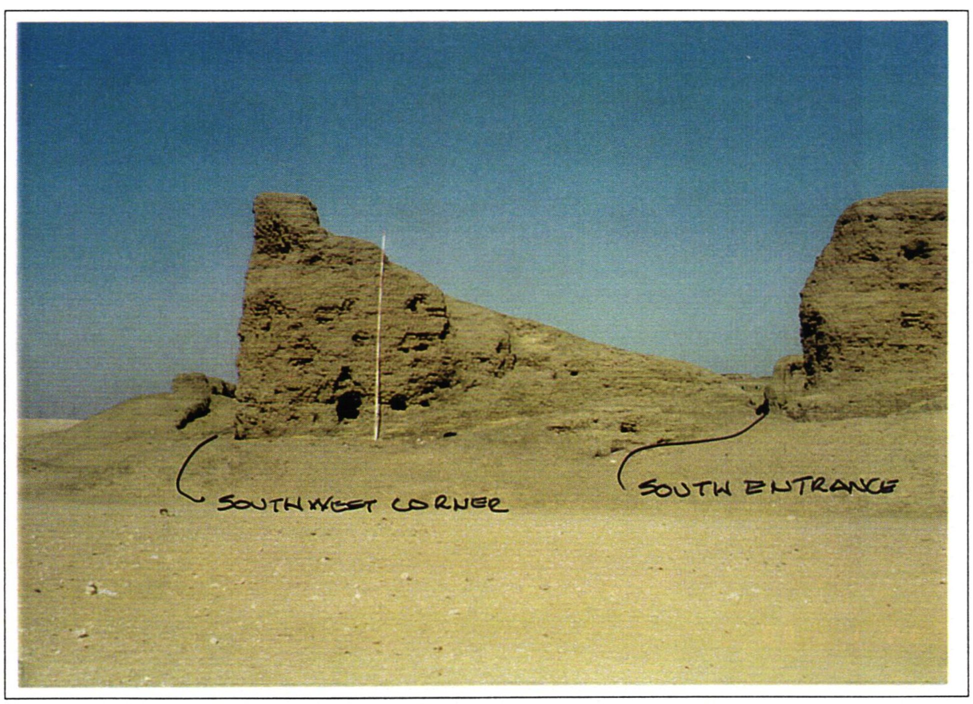


Photograph No. 111 North Main Enclosure Wall West End Exterior View

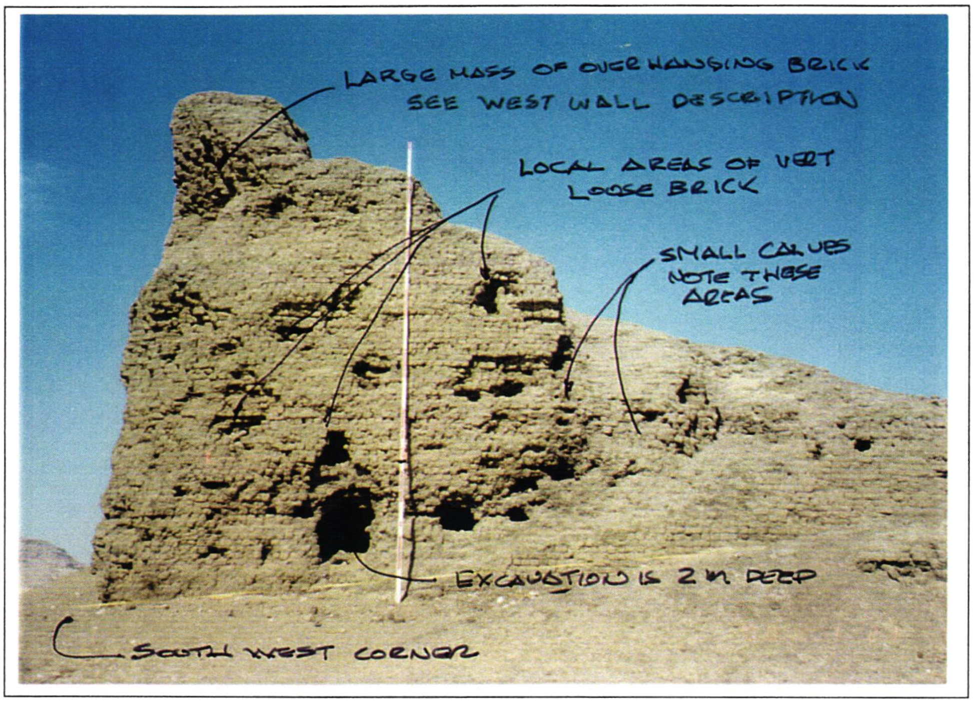


Photograph No. 112 Section 2 North Main Enclosure Wall, Interior View

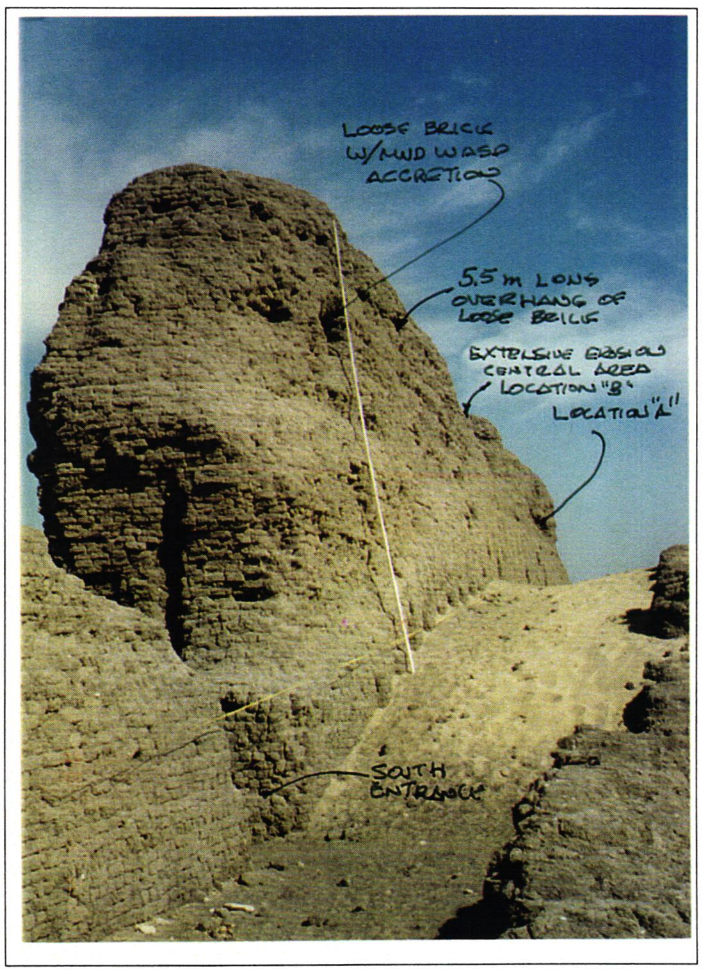
Photograph No. 113 South Main Enclosure Wall



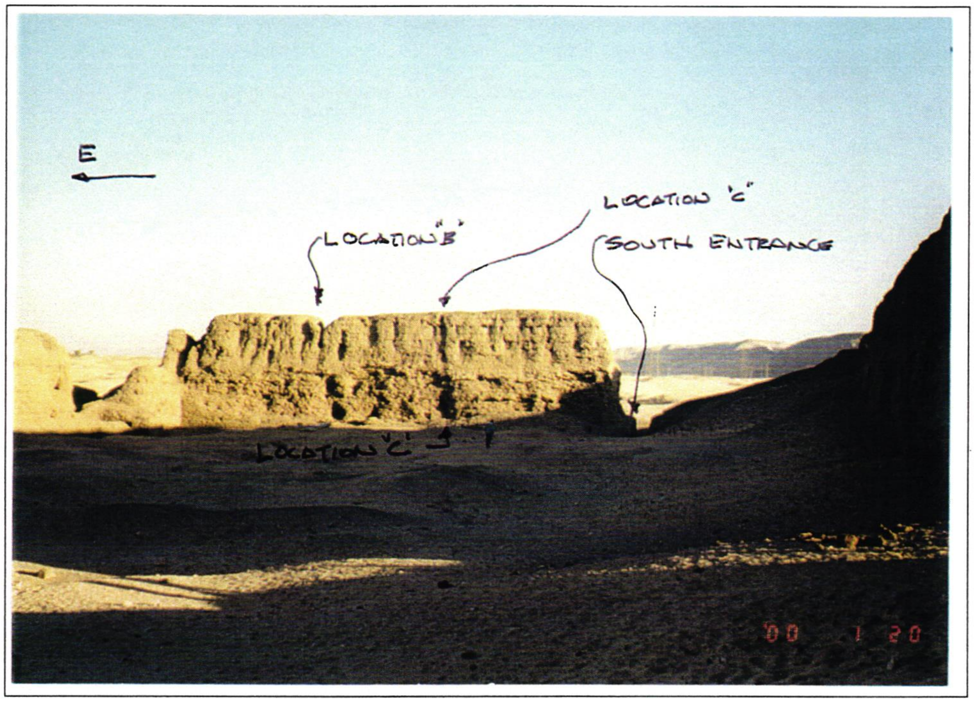
Photograph No. 114 South Main Enclosure Wall, West End



Photograph No. 115 West Main Enclosure Wall, West End



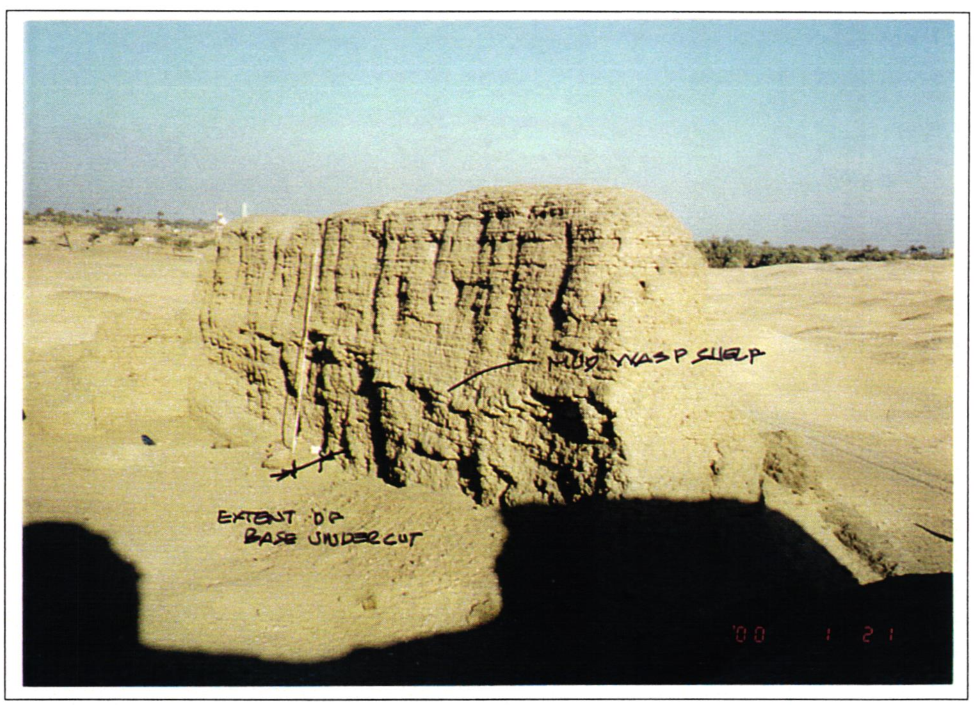
Photograph No. 116 South Main Enclosure Wall



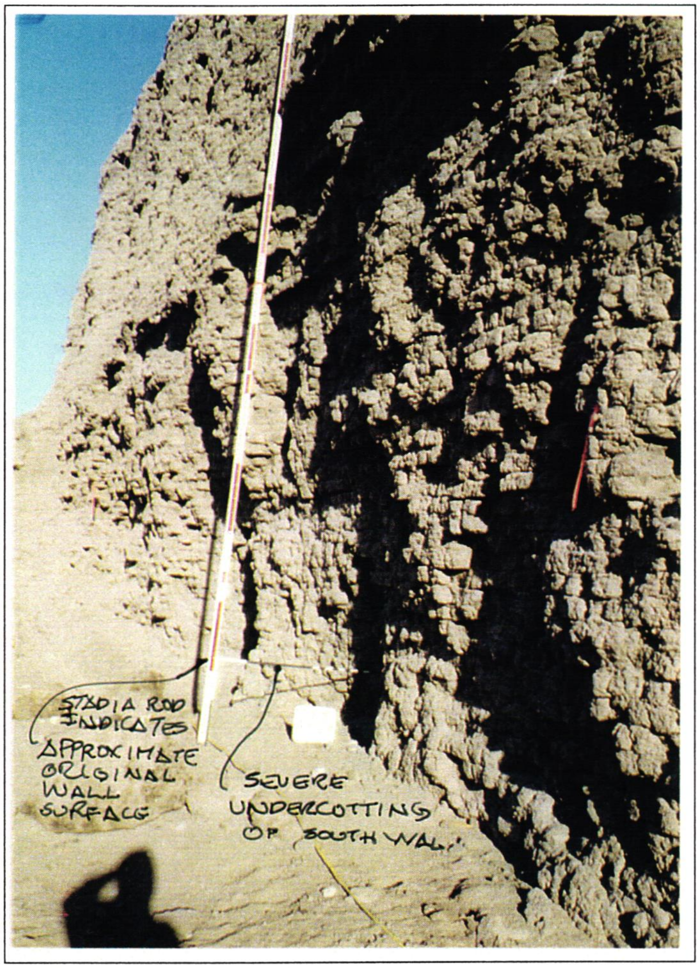
Photograph No. 117 South Main Enclosure Wall, Interior View

Photograph No. 118 South Main Enclosure Wall, Southwest View

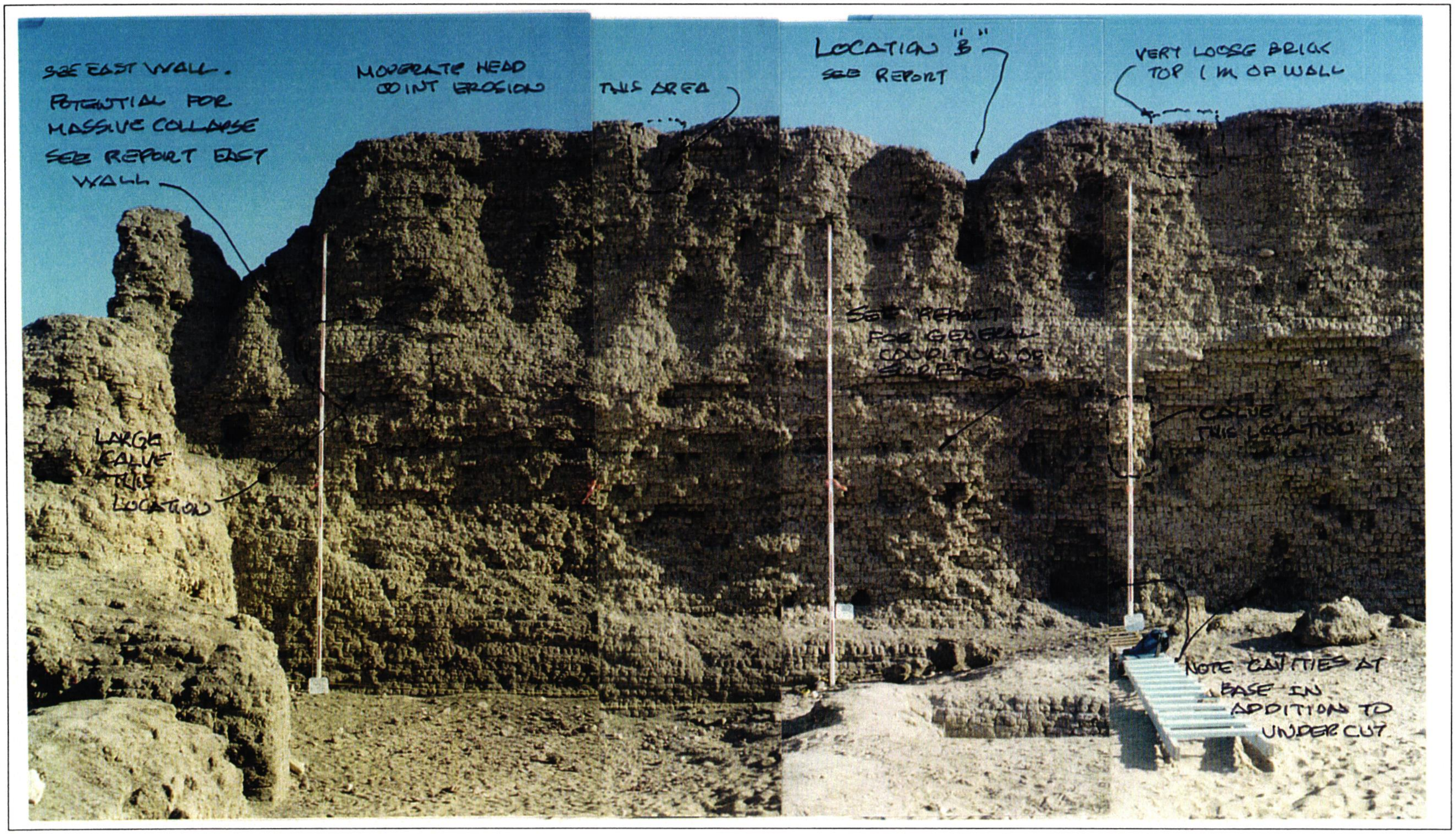
Photograph No. 119 South Main Enclosure Wall, Interior View



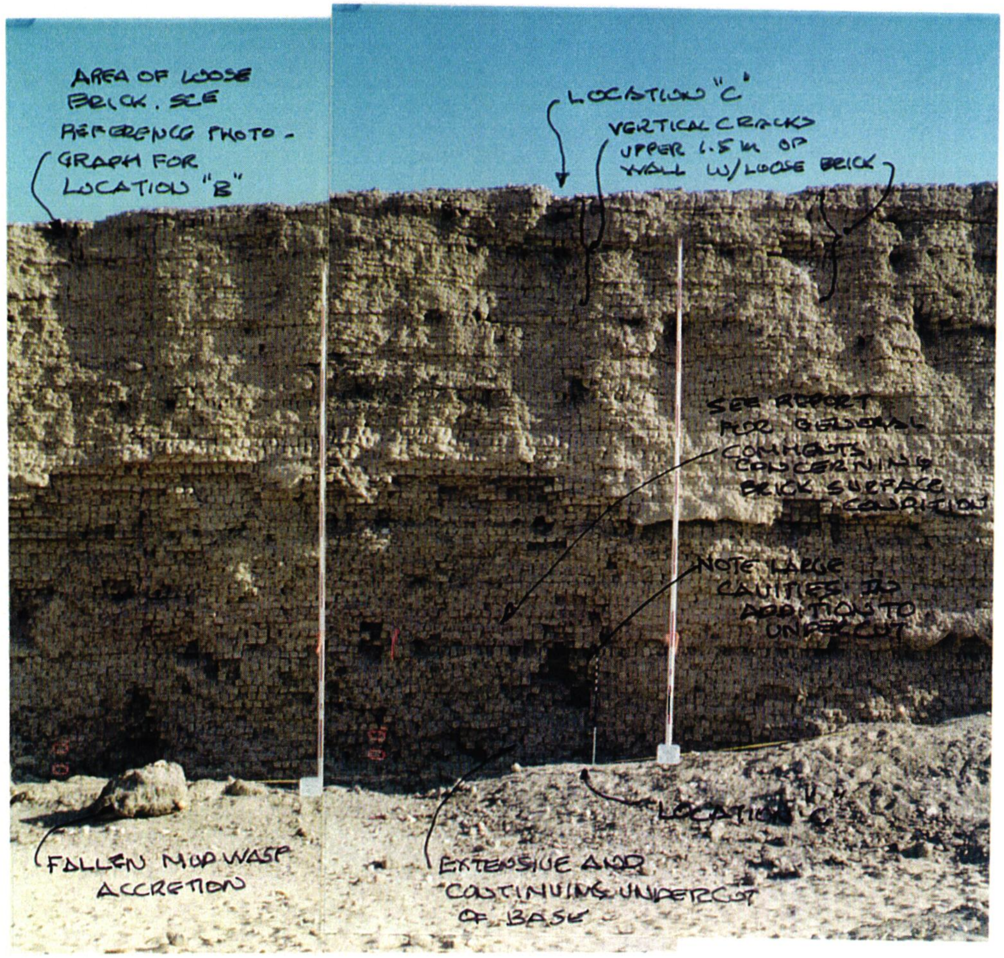
Photograph No. 120 Undercutting of South Main Enclosure Wall



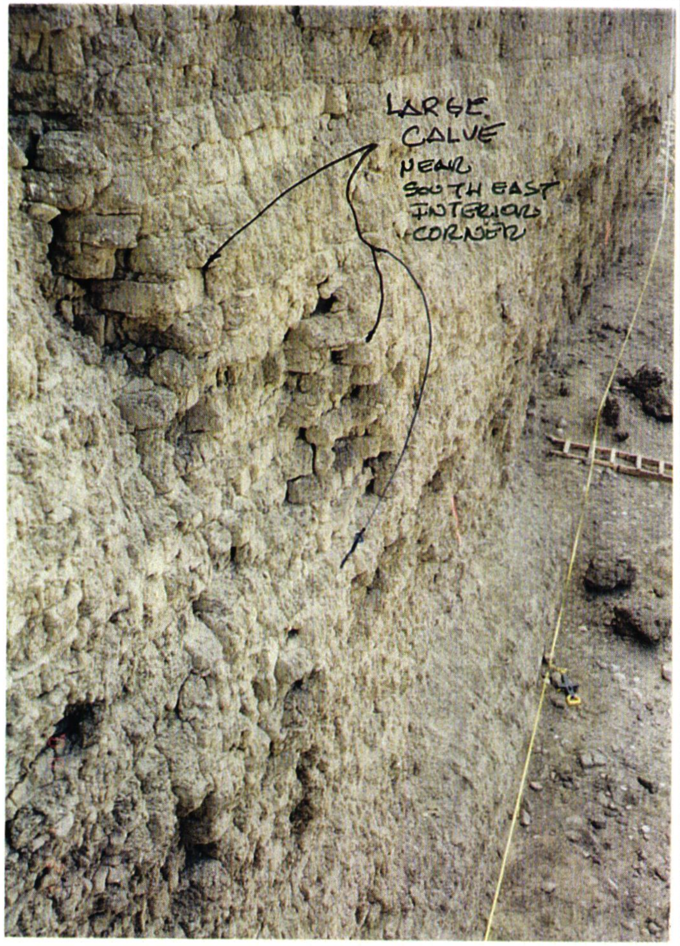
Photograph No. 121 Wall Undercutting at South Main Enclosure Wall



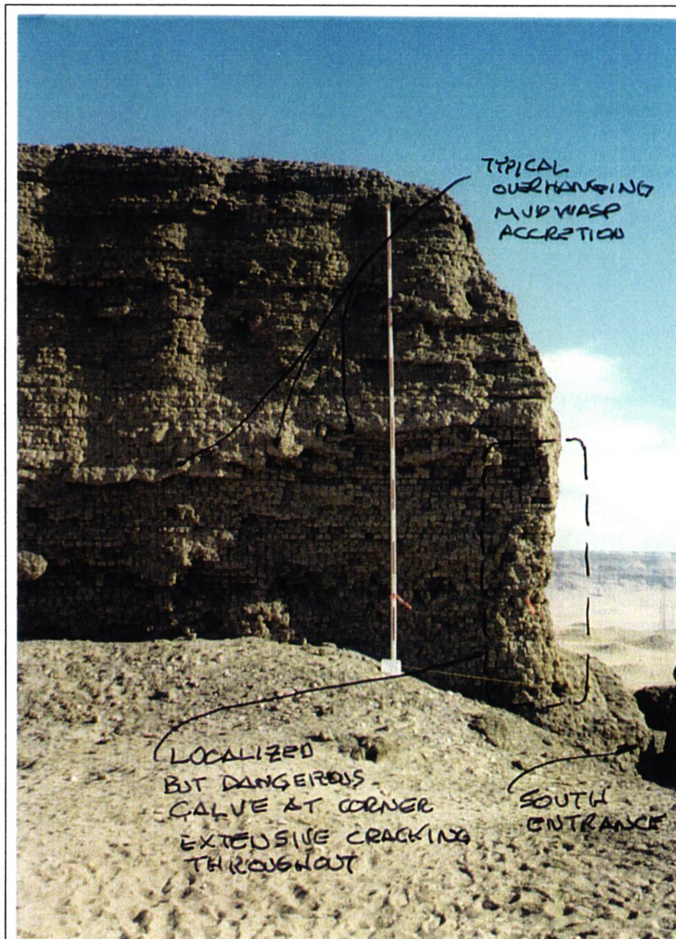
Composite Photograph No. 122 South Main Enclosure Wall



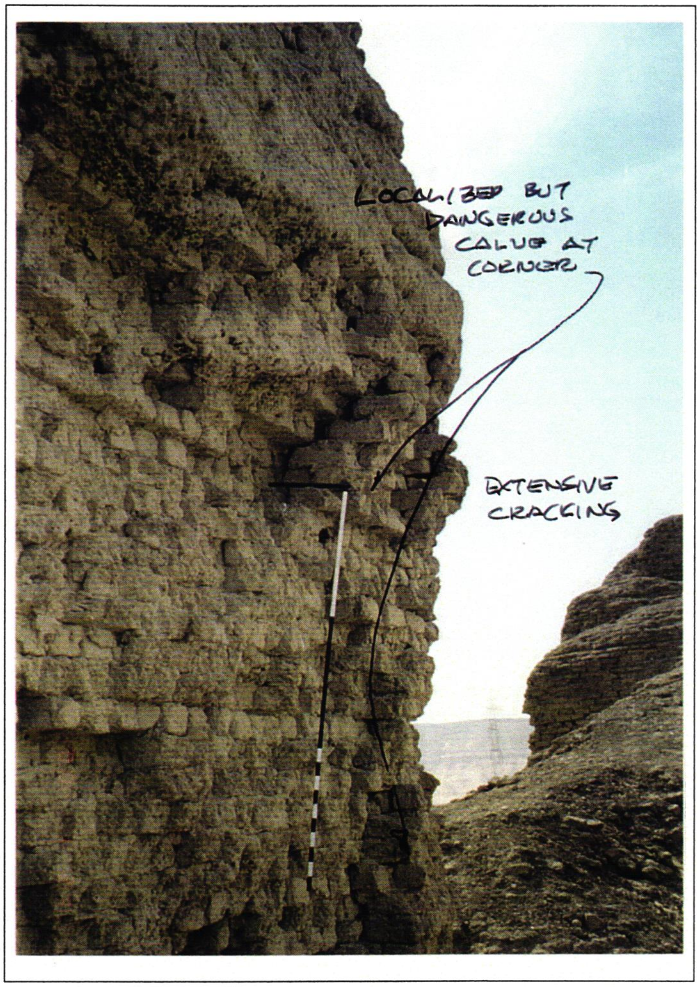
Composite Photograph No. 123 South Main Enclosure Wall



Photograph No. 124 Large Calve Near Southwest Corner



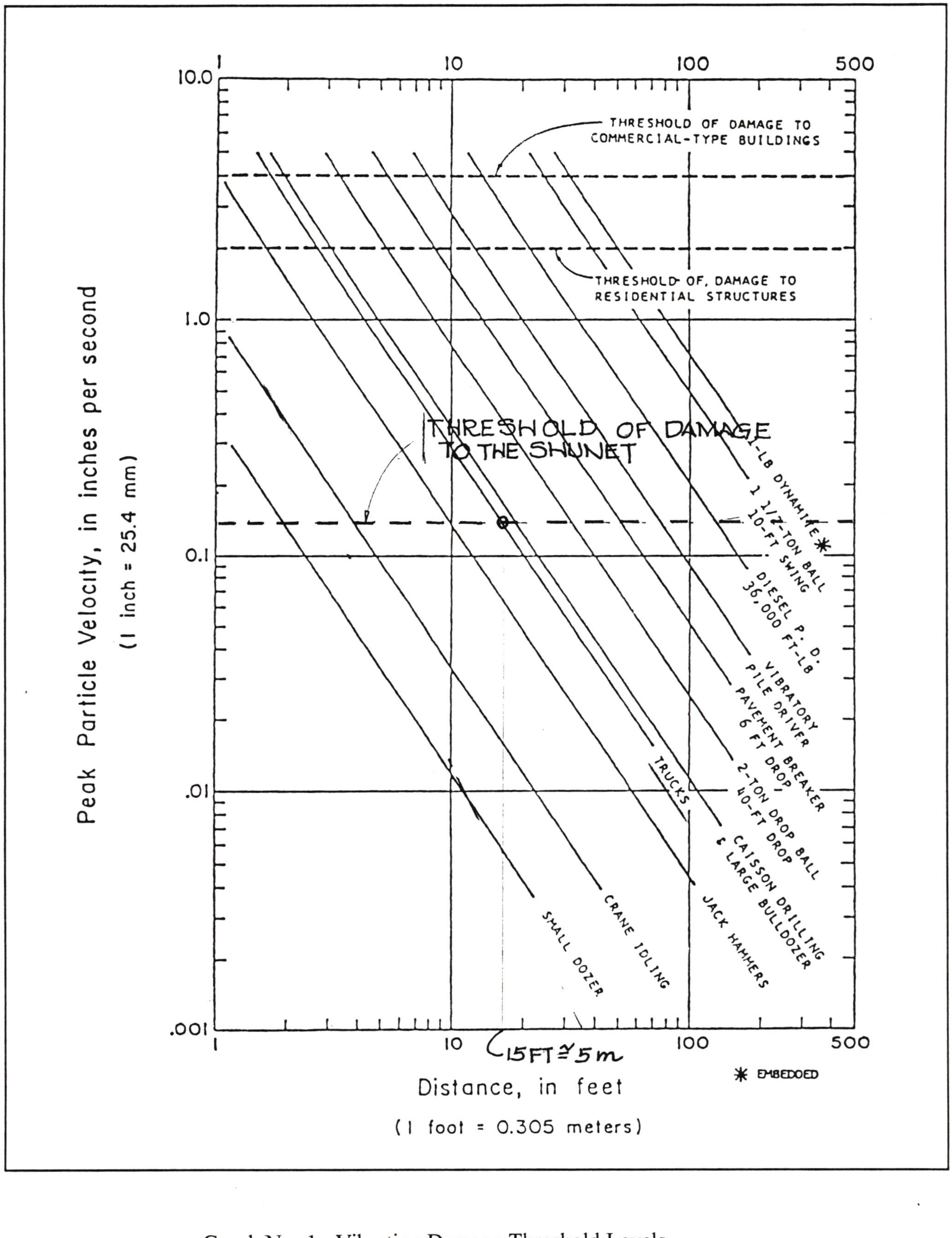
Photograph No. 125 Unstable Corner Near South Entrance



Photograph No. 126 Detail View of Dangerous Corner Near South Entrance, South Main Enclosure Wall

Appendix *B* - Drawing S1

Appendix *C* - Graph No. 1



Graph No. 1. Vibration Damage Threshold Levels.

From "Construction Vibrations: State of the Art", 1981 ASCE *Journal of the Geotechnical Engineering Division*, John Wiss

Appendix D - Scaffolding Catalogs