GEOLOGICAL STUDY OF THE HESHBON AREA

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The application of geological research to an archaeological site is a vitally important facet of the recovery of the history of an area. Optimally, observations are made as the excavation is taking place, thereby affording analysis of the occupational sediments as they are first probed and uncovered. Unfortunately, I could not be at the site of Heshbon at the time of excavation in July and August, 1971, but did have the opportunity for field observation and study of the area in June before the excavations began. Limited investigations of the geomorphology or topographic setting, local bedrock, stratigraphy, and structure, and soils and clays of the Heshbon environment were carried out.[1]

The site of ancient Heshbon lies on the border where the highlands of the Transjordanian plateau begin to break down in the dramatic topographical descent to the low levels of the Jordan River-Dead Sea depression. This is a marked transition and may in part have been a critical factor in the historical occasion of this site as an area of occupation by man.[2]

[1] Siegfried H. Horn, director of the Heshbon expedition, graciously invited me to implement geological research of the site immediately prior to and during the early stages of the aborted 1970 expedition. That invitation was renewed for the 1971 campaign, but other commitments kept me from being present as the 1971 excavations were carried on. I wish to acknowledge the fine cooperation and assistance offered to me by Horn in providing transportation for the research and for the shipment of samples to the Cincinnati geological laboratory.

The Antiquities Department of the government of Jordan kindly provided the release of Mohammad Murshed Khadija whom the Heshbon expedition retained for my assistance and who acted as field guide. I am most grateful for this arrangement, without which only about half the actual work would have been accomplished.

[2] Friedrich Bender's (*Geologie von Jordanien* [Berlin, 1968]) *nordjordanisches Hochland ostwärts des Jordangrabens* and his *ostjordanisches*

That area of the plateau in the region of Jordan between Amman and Madeba is underlain by a series of nearly flat-lying, locally gently folded and faulted, Upper Cretaceous sediments. These deposits, ranging from the Cenomanian to the Maastrichtian in age, are composed of more resistant limestones and cherts interbedded with softer chalky limestones and marls. The resistant rock strata mark out the highest remnants of the plateau along its western margins and have not yielded to rapid weathering breakdown and erosional removal. Where the more resistant rock layers are absent and where the lithic material is dominantly marl, clay, or poorly cemented sands, topographic highs readily break down to low-lying, undulating surfaces in response to the accelerated stream erosion of the less resistant materials. The striking geomorphic differences between the plateau and the Jordan Valley slopes are immediately perceptible to anyone who has the opportunity to observe that grand vista from Mt. Nebo. The plateau highlands stand out in strong contrast to the soft, downward undulating topography of the lower valley margins.

The Transjordanian plateau is incised on the west by streams controlled in their erosional activity by the Dead Sea depression. This "geosuture" has acted as a base level (almost 1300 ft. below sea level) for the Jordan River, its tributaries, and other streams which flow into the Dead Sea or into the Arabah to the south. The deep valley extending from the Lebanon-Anti-Lebanon Mountain separation on the north through the Gulf of Aqabah to the Red Sea on the south is known as a graben or down-dropped block of the earth's crust. That the graben has had activity into relatively recent times in the crustal history of Jordan is shown by the steep gradients which the streams have, flowing like rushing torrents in the rainy season to their entrance to the Jordan plain or to the Dead Sea, where they immediately dump their sediment loads, forming alluvial fans and deltas.

Kalkplateau are, for the purpose of this discussion, considered stratigraphical and morphological continua.

Tell Ḥesbân is located on the eastern margin of the eroded area. It occupies a higher hill which is made especially prominent by a tributary of the *Wadi Ḥesbân* (see Plate XII:B) which empties into the floodplain of the Jordan River about 4 km. north of the Dead Sea. This stream has cut down from the 800 to the 500 m. level northeast of the *tell,* totally unlike the activity of any of the streams to the east or to the south in the area. The energy and erosive power of this tributary was observed in a 3-km. traverse down its valley in which tumble-polished boulders over a meter in maximum diameter occur as part of the sediment load, along with areas where the bedrock stream floor had been scoured clean. Hydrologic conditions producing these effects give rise to intensive incision and sculpturing of bordering highland areas.

The topographic setting of the site is also a response of the more resistant bedrock to the processes of weathering and erosion. The hill of ancient Heshbon stands higher than the surrounding plains on the south and on the east because of the resistance of the local limestones, some of which are quite massive (Plate XII:B). The more resistant local carbonate rocks are composed of non-porous, crystalline limestones in which much of the fossil content has been replaced by recrystallized calcite or by silica. Such durable sediments may remain as the capping rock of a plateau remnant (Plate XIII:A, arrow Z) or as a topographic shoulder on a hill above which lie rocks less resistant to erosion (Plate XII:B, arrow).

The rolling plains to the south toward Madeba and to the southeast are surfaced with virgin and transported soils partly formed in place on the less resistant strata underlying the plains and partly flushed from soils formed on the more resistant topographic highs about the area, such as the hill on which Heshbon was built.

The interaction of the atmosphere with the bedrock surface of the crust of the earth, in effect, is called weathering. This physical, chemical, and biochemical alteration of the bedrock produces soil and forms a blanket over the rock which is known as regolith. Weathering processes give rise to clays which are principal constituents of the regolith. These clays in combination with other minerals and insoluble residues from the bedrock constitute soils, the fertility and productivity of which were critical to the livelihood of man in his occupational history of the site. Thus, where down-slope erosion processes have not removed the virgin soil formed on bedrock, Arab farmers still plant grain. In much of the area to the north and west of *Ḥesbân*, surface sediment transport by mass wasting, running water, and wind has removed the soils leaving the underlying partially weathered bedrock exposed on the surface. While most of these transported soils have been lost to deposits in, and marginal to, the Jordan Valley or the Dead Sea, some remain as terraces along the sides of the *wadis* and are farmed by the present population in the area.

Historically, these weathered bedrock materials (the clays and insoluble mineral residues from the parent rock) have given rise to products considered very important to man: pottery, bricks, terra cotta articles, loom weights, blowers, ossuaries, and even small altars.

Although the study of the clays in soils of the Heshbon area is in its initial stage, X-ray diffraction analyses run on five samples from the area afford consistent evidence that the clays, in both the virgin and transported soil concentrations, are all dominantly kaolinite with a minor component of illite. These minerals together with the other insoluble residues of the transported deposits found in the terraces of the tributary system of the *Wadi Ḥesbân* provide excellent potential ceramic clay sources which may have been exploited historically by the inhabitants of Heshbon. Even without levigation, these materials would be readily usable for terra cottas. With settling of the coarse fraction, these clay sources would yield ceramic materials with excellent shrinkage and firing properties, a ceramic paste finer in its properties and surface characteristics than the palygorskite-rich clays which form in soils produced by the weathering of chalks and marls in other locations.[3]

Studies along the *wadi* system to the west of the site of Heshbon were conducted as part of a search for ceramic clay sources. Much of the terrace deposits observed contains a coarse sand-size to a fine pebble-size aggregate suspended within the clay materials. This combination of clays and coarser sediment is readily usable in the manufacture of mudbricks and may be processed with only the addition of straw and water. The study of mudbricks from west-bank sites has shown this to be a frequent mode of preparation.[4]

Interbedded with the more durable limestones described above are chalky limestones, marls (calcareous clays), cherts ("flintstones"), coquina (almost entirely composed of fossils), silicified limestones, and phosphate-rich layers. The semi-arid climate of the *Ḥesbân* area has produced an important effect in the more porous limestones and carbonate rocks which occur interbedded in this local rock sequence. Most of our experience in the United States gives us little with which to compare the solution-concentration of the relatively insoluble components of the softer parent rock material. In Jordan this calcium carbonate concentration, in part locally silicious, blankets much of the more soft and porous carbonate deposits and penetrates these bedrock units to a depth of up to three m. locally. The concentration constitutes a brittle, sometimes friable but easily workable rock mass which has lost the fabric and texture of the original rock parent. In many ways it is

[3] Clay mineral species are readily determined by a process of X-ray diffraction in which the crystal lattice dimensions of the minute clay particles are measured in Angstrom units as a function of the angle at which the X-ray beam is defracted by the atomic layers in the crystalline material. Determinations at the Cincinnati geological laboratory were made on a G.E. XRD-5 X-ray Defractometer using copper radiation.

[4] See sediment size chart in Bullard, "Geological Studies in Field Archaeology," *BA*, XXXIII (1970), 130.

analogous to the "caliche" of the semi-arid areas of the western United States. This partially weathered bedrock material, called "*nari*," as observed in the field at Heshbon, frequently takes on the appearance of a highly disturbed brecciated lithic material. As examined in the local tombs cut into it, the formation of a high concentration of insoluble components can be observed to grade downward imperceptibly into the unaltered limestone levels below.

These relatively coarse, weathered *nari* zones, and not the hard, resistant, crystalline limestone strata, are the particular rock horizons which have been exploited by the inhabitants of ancient Heshbon in the necropolis areas observed on the southwestern flanks of the hill below the modern village of *Ḥesbân*. Similar usage of this particular kind of bedrock expression was also observed in a great number of tombs cut into the rock immediately northwest of the site of Heshbon (Plate XIII: A, arrow X). In this latter instance, tombs were cut through a more resistant carbonate layer above into the highly weathered *nari* compositions below where enlargement of chambers occurred laterally, accompanied by the drilling of burial loculi into the adjacent bedrock. In a Byzantine tomb in a topographic rise east of the *tell*, newly excavated by the Antiquities Department of Jordan, fine plaster surfacing covered the porous *nari* walls of the chambers in which sarcophagi were found.

The geological survey of the sedimentary strata of the immediate neighborhood of the Heshbon area revealed the presence of certain lithic varieties in the fields, along the gentle hillslopes, and in the canyon walls of the tributaries of the *Wadi Ḥesbân*. These local rock occurrences provided the working raw materials for the inhabitants of Heshbon for the manufacture of the buildings in which they lived, the walls of fortification of the city, many of the utensils and tools essential to their way of life, and the paving materials of streets and roads in instances where they were in fact surfaced. In a very special sense these lithic materials constituted an essential component in the ecology of the inhabitants of Heshbon.

A limited but intensive survey was made of all the rock materials occurring as surface float on the slopes of *Tell Ḥesbân*, as piles of constructional materials removed from the 1968 excavations, as structures, and as the balk surfaces of the Squares exposed by excavation during that campaign. Samples of these materials were collected and, based upon a cursory field examination, a catalog of the rock species was tentatively made. These observations served as a basis for differentiating local from the exotic materials (non-local lithic objects carried to the city of Heshbon from other places). While certain definite limitations exist in the rapid field determinations made during the short visit to Jordan, many of these will be eliminated in intensive laboratory study and analysis of those materials now available for research at Cincinnati. At this present state of the investigation, certain meaningful observations can be made.

The rock material available for constructional purposes in the structures undergoing excavation at *Tell Ḥesbân* consists of two dominant lithic entities which appear most frequently in construction phases and in the surface float. *Nari* occurs as the stone used as facing and as backing in walls and structures still intact; more than half the surface float consisted of this material as well. Quarrying sites abound for this material principally on the shoulders of the hills of the neighborhood.

Typical methods of quarrying were observed on the hill to the northwest of *Tell Ḥesbân* in an area where several tons of the material had been removed. Quarrying efforts were observed in numerous places typical of that shown in Plate XIII:B. Here the attempt to remove the block was not complete, although the channeling about it is evident on the right side where a remnant was left after the rest of the stone was lifted away. The effects of weathering have softened considerably the chisel marks along the sides, but the high incidence of the sunlight heightens the remnant cuttings.

Many instances of channel quarrying techniques were recorded. Remnants of channel cutting and step-wise excavation and removal were seen in the area along the horizon in the view of Plate XIII:A. It was interesting to observe that the houses of the modern village of *Ḥesbân* also contain *nari* as the principal building material in their structures. Other building material of considerable importance consists of the hard, resistant, crystalline, fossiliferous limestone which crops out in certain strata along the slopes of the area.

By far the most "noble" building stone in the locality of ancient Heshbon is the material observed in the church building exposed in Area A on the *tell*. The exquisiteness of this lithic material is immediately evident even to the casual observer, but the petrologic reason for this clearly illustrates the basis for the merits of this material as attractive masonry. This particular limestone was recorded in its closest proximity to the site on the northwestern slopes of the hill immediately below. The arrow in Plate XII:B shows the most striking outcrop exposure of this particular rock material. Everywhere along the face to the right (southwest) of the point of the arrow in the illustration, massive quarry markings were in evidence. This undoubtedly is one of the principal sites, if not the principal quarrying site, for the lithic material of the church structure. Initial petrographic study indicates that the material sampled at the building site and at the quarry site—both were sampled *in situ*—reveals very closely matching petrographic affinities.

An example of this material is shown in Plate XIV:B. The fossil content of the material is evident, suspended in a fine carbonate mud matrix. This lithic material is properly known as a pelecypodal biomicrite, the microscopic characteristics of which may be observed in Plate XIV:C. The fossil materials are manifestly Upper Cretaceous in geologic affinity and characterize the fauna of the local geologic strata exposed in the upper parts of the canyon walls of the tributary system of the *Wadi Ḥesbân*. The microphotograph (Plate XIV:C) shows two characteristic fossil constituents which dominate the fabric of this rock material: mostly pelecypods (various varieties of clams)—both free-moving and sessile forms (such as the rudistid fragment observable in the upper left of Plate XIV:C), and gastropod shells (such as the nearly circular form in Plate XIV:C, lower right). All these forms are evident in the polished section of Plate XIV:B. This section undoubtedly represents the "marble-like" appearance of the surface of the church building, even in its newly excavated state.

This elegant building material was also used in the columns and column bases of the church building. Whether or not that column remnant observed in the field about .5 km. southwest of the Heshbon site on the northwestern flanks of the hill (Plate XIV:A) was intended for the church building or not, one cannot say. The rock material which is exposed in this area is of identical composition. This material, although some distance away from the outcrop shown in Plate XII:B, is in stratigraphic continuum with that carbonate deposit. All along the strike of this outcrop, similar quarrying activity was observed with numerous cuttings, excavations, and channelings which marked a vigorous activity on the part of quarrymen and masons in securing the lithic materials for construction purposes. It was interesting to note at least two futile attempts to cut tombs into this material where typical Roman facades were chiseled in the rock together with the initial cutting of entrances, both of which were aborted. One could speculate that the tomb-cutters may have found this rock material far more resistant to this kind of exploitation than the *nari* in which most of the tomb chambers occur.

Additional confirmation of the hypothesis of the local quarrying sites is seen in the abrupt step-like outcrop characteristic of the resistant limestone shown in Plate XII:B, arrow. Such abrupt steps on the hillslopes are produced by natural processes only in cases where the bedrock is faulted or joints in directions parallel to the strike (compass-bearing of the surface outcrop direction) of the rock bedding. No such joints or faulting were anywhere apparent along the exposures studied. This, along with the quarry marks, is considered strong evidence for the contention that this constitutes the source of the building material. One may compare and contrast the appearance of surface outcrops in the illustrations shown in Plates XII:B and XIII:A, where the principal difference in abrupt change of slope gradient in Plate XII:B has been caused by the activities of man in his quarrying operations.

Other examples of the use of this "noble" stone were noted on the northwest slopes of the acropolis area of the *tell*. In addition to numerous instances of surface float of this composition, there was one row of large boulder-size blocks exposed through the debris which were "in place." The historical context was not explored in the excavations up to this time, but this serves as evidence of other use (or perhaps reuse) of this lithic material. The Wall 17 in Area B:1 on the *tell* was constructed mostly of weathered field stones, only partly trimmed, of the same resistant carbonate rock.

While the previous discussion has related directly to structures *in situ* in the archaeological site itself, the following discussion is designed to afford an introductory consideration of the potential contribution of geologic study of the lithic tools, utensils, and weapons characteristic of the historical periods under archaeological excavation. Five very hard millstone materials were observed in the surface float of the *tell* and a sixth was observed on top of the bedrock strata in an area where there had been intensive quarrying and possible construction at an earlier time on top of the hill to the northwest of the site (the crest of the hill shown in Plate XIII:A). One of the hardest substances used and different from the other five observed was composed of a highly silicious, phosphatic, lithic material from the north slope of the *tell*. This material, having the hardness of chert but not possessing its typical brittle quality, is shown in Plate XV:A. Originally a marine sediment composed of phosphatic fish bone and teeth detritis in a carbonate matrix, the calcite material has undergone complete replacement by silica in the form of chert. Silica-replaced lithic material with fish remains were not observed in any of the outcrops in the *Ḥesbân* area. The implication is that this choice millstone material is probably exotic to the locality.

Another lithic material found to abound on the *tell* was basalt. Basaltic fragments of millstones, bowls, and possibly loom weights were observed in the surface float on all sides of the *tell.* A number of the basaltic materials were sampled and a representative portion sent to Cincinnati for additional analysis. Thin-sections of two different basalts are shown in Plates XV:B and XVI:A. Basaltic materials were observed in the field to the northwest at the site of *Umm el-Jamal* near the Syrian border where an entire ancient town built of basalt stones remains in a considerable state of preservation. This "ghost town" from the late Roman and early Byzantine period is built of raw material immediately available to the inhabitants of that community. An example of building material from that city is shown in Plate XV:B. The large crystals of olivine and plagioclase are clearly evident in the microphotograph.

Basalt artifacts from the Heshbon site were observed to have mineral content similar to that of the *Umm el-Jamal* area, but they exhibited a crystalline fabric that gave evidence of a lava with much more rapid cooling rate. The fine crystals of the basalt bowl fragment are typical of this difference. A much higher calcite content was observed in nearly all of the basalt collected at Heshbon. It is a reasonable assumption that this material used by the inhabitants of the ancient city came from outcrops far closer than the remote Syrian border.

The geologic map of the area of Heshbon (Plate XII:A) shows two surface expressions of basalt and basaltic materials. They form deposits on the eastern slopes of the valley immediately above the Dead Sea. The southernmost of these basaltic occurrences is a lava flow from a cinder cone which arises just below the 700 m. contour west-southwest of

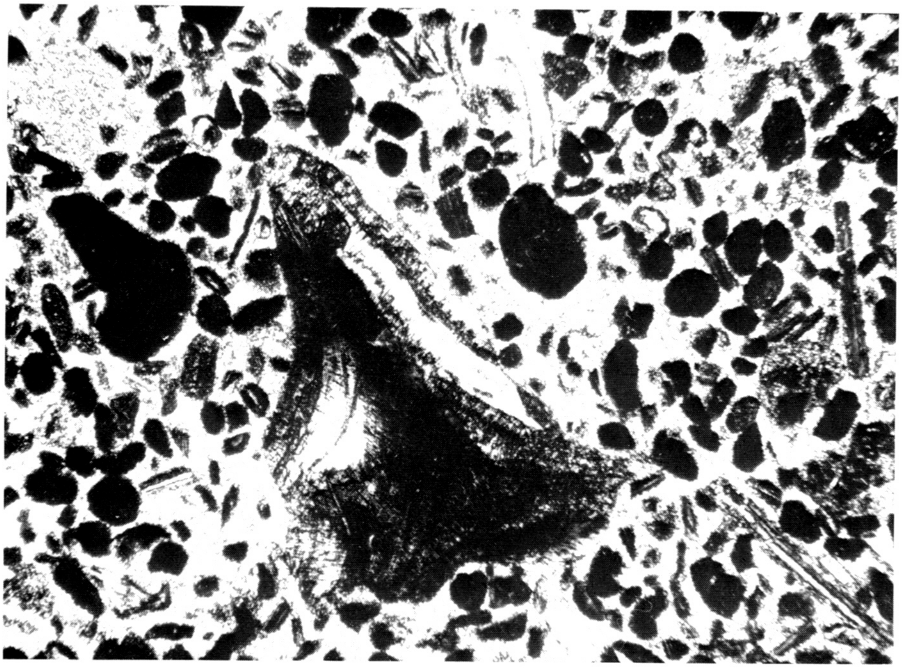
Madeba. Another occurrence exists about 5 km. to the north of the former, mostly on the sloping surface below mean sea level, but above the level of the Dead Sea. Inasmuch as both of these outcrops were in areas absolutely restricted by the military, I could make no observations nor obtain samples for comparative study from these potential sources. It is, nevertheless, important to try to differentiate on the basis of subtle mineral or trace element differences or on the basis of obvious petrologic affinity the main basaltic raw material sources in this area of Jordan. These examples are noted here to illustrate the direction that such a study should take. Other accessible occurrences of basalt were observed and sampled in the south along the *Wadi Mujib* and along a Roman road about ten miles north of *Shaubak* along the King's Highway route to Petra. These and other igneous basaltic materials are under study.

Another example of the interesting lithic suite from Heshbon is the ichthial biosparite illustrated in Plate XVI:B. This fossiliferous limestone has abundant fish part remains and is somewhat carbonaceous. The example shown in the microphotograph is a cross-section of a fish vertebra in a matrix of sparry (crystalline) calcite, fish bone, and crab carapace remains. This is a rather distinctive lithic material and was observed as having been used as the raw material for some of the sculptured images (idols) in the Archaeological Museum in Amman. The locality of the surface outcrop of this material was not discovered in the field studies but it is a sufficiently unique material that one may hypothesize that it is confined to one or two strata within a limited vertical distribution and along the aerial outcrop pattern of the formation(s) involved.

The initial work of G. S. Blake, *The Stratigraphy of Palestine and its Building Stones* (Jerusalem, 1936), was a start in the study of the natural resources which have played so prominent a role in the history of the Near East. While Blake's study largely constitutes a commentary on materials which were in use in structures before and up to 1935, it is the kind of research which should continue in the study of archaeological remains. This is important for reconstruction of the vital activities of the people who historically made an archaeological site significant. Such studies, however, should not be limited merely to the lithic materials which constitute the domestic and industrial makeup of an historic site, but should also include the ceramic, gemstone, metal, and mineral resource wealth of an occupational area.

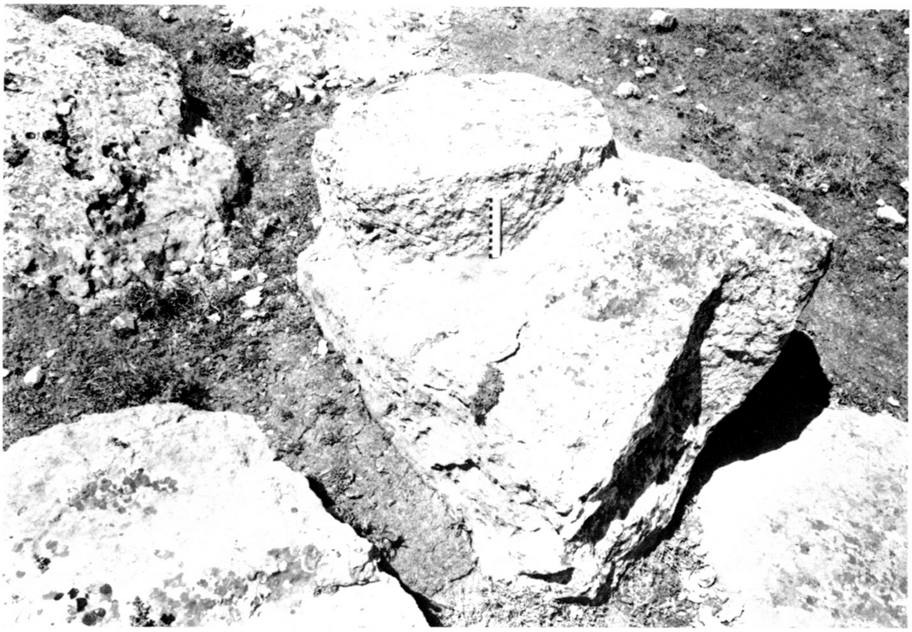
Additionally, aside from merely perfunctory analytical chores of a petrographic nature, I see a special role for the geologist in archaeological studies contributing to the historical elucidation of the archaeological record. Even as he pursues the genetic significance of sedimentary rock bodies in their natural context in his traditional vocation, the geologist may also find application for insights in the genesis of the sediment of a *tell.* Certain sedimentary environments of *Tell Ḥesbân* lend themselves well to that sort of analysis which has yielded fruitful results in earth science. The sedimentological study of the stratigraphic phases of occupational accretion has much to contribute to the historical understanding of the successive deposits which exist on the site.

The distinct dependence of man on his local environment is evident from the economic exploitation of the local geology. His needs were met from materials quarried within the hill upon which Heshbon was built and rebuilt, from the soils, clays, and sediments of the fields and the *wadis* nearby, and from the rocks of volcanic origin of the region. The structures he erected, the artifacts he designed, and the commodities he consumed were nearly all critically determined by the geological context of his way of life. The cities of *Tell Ḥesbân* flourished and left sedimentary records of their prosperity, their worship, their defensive measures, and their tragic destruction: a story written boldly in the stratigraphic account.

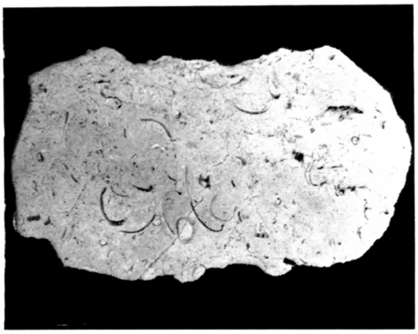


A. Microphotograph of a very hard millstone from the surface float on the north slope of *Tell Ḥesbân*. Fish tooth (center) with phosphatic grains in a chert matrix. (40 ×)

B. Microphotograph of a coarsely crystalline basalt from *Umm al-Jamal*. Mineralogy: olivine (large angular crystals), plagioclase (elongate lathes), pyroxene (inter-crystalline area). (40 ×)

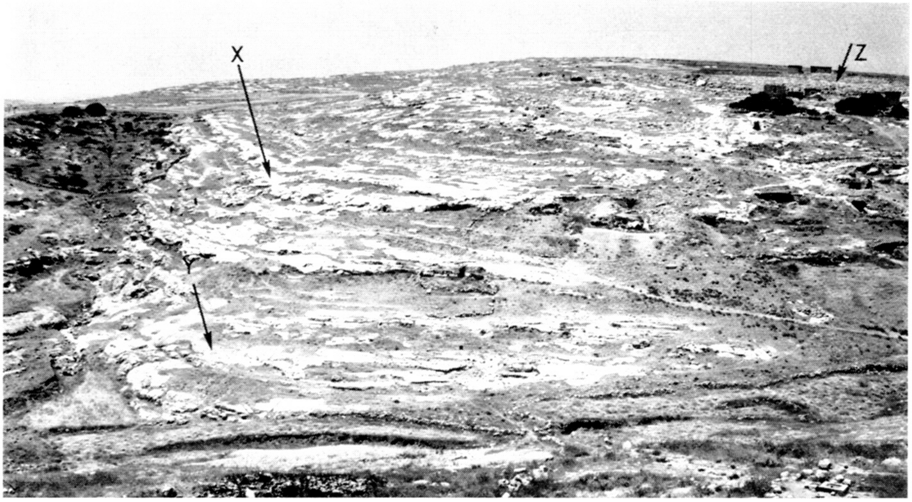


A. Partially quarried columnar section from the same lithic material as shown in Plate XII:B, but at an outcrop location about .5 km. to the west (right) of that view.

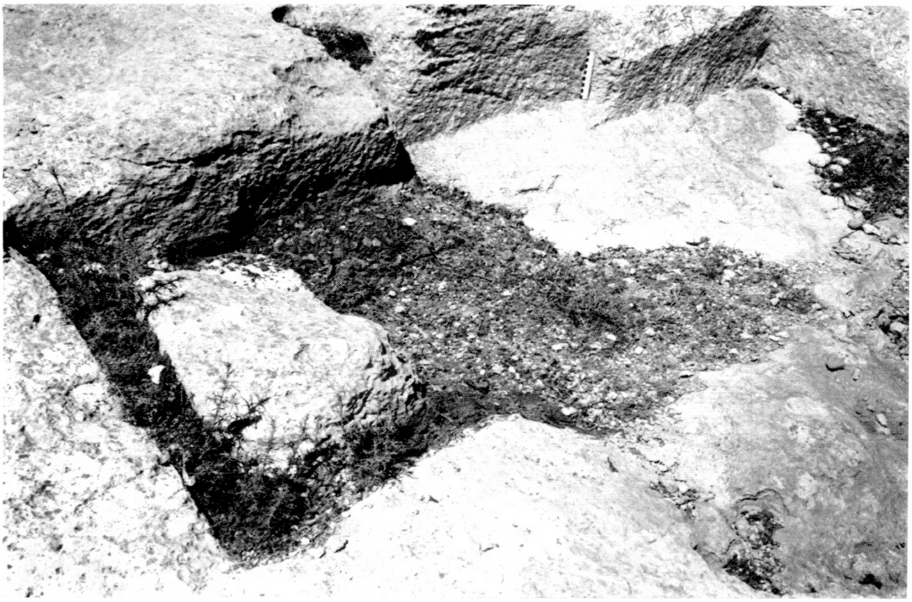


B. Polished section of the fossiliferous limestone (pelecypodal biomicrite) from a column base of the church in Area A at *Tell Ḥesbân*.

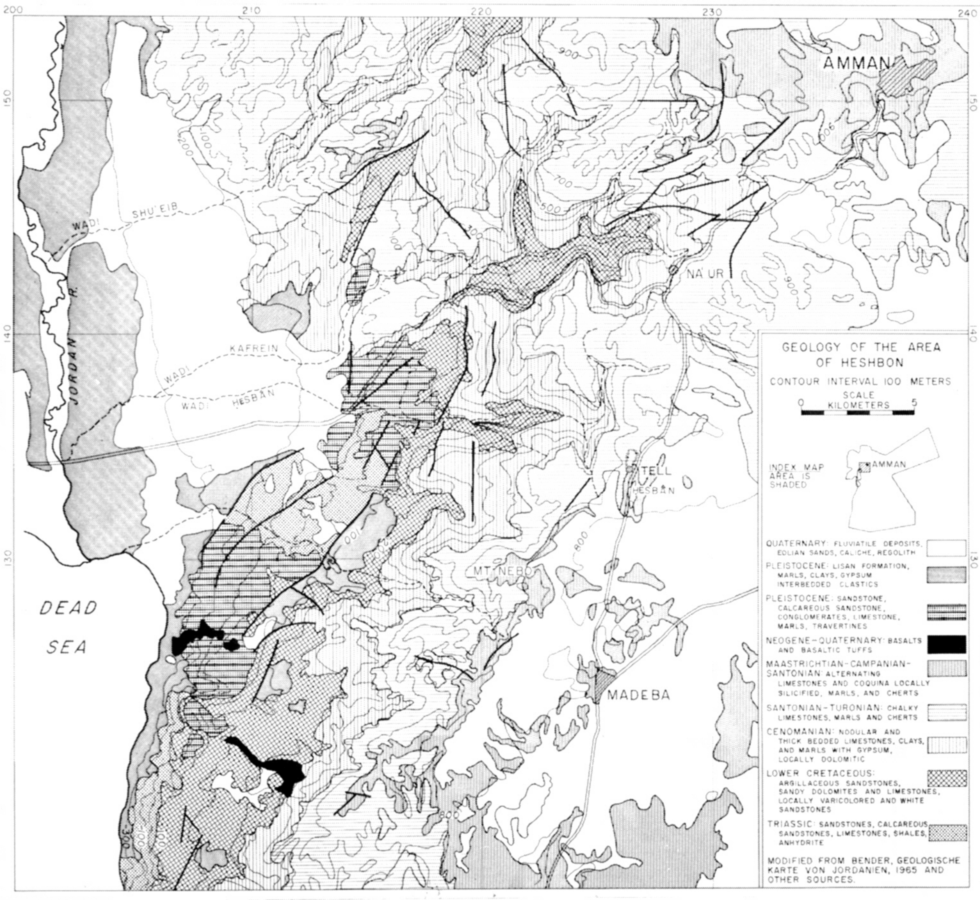
C. Microphotograph of the fossiliferous limestone shown in B, showing pelecypod (upper left) and gastropod (lower right) in a matrix of broken shell fragments, mostly replaced with sparry calcite. (20 ×)



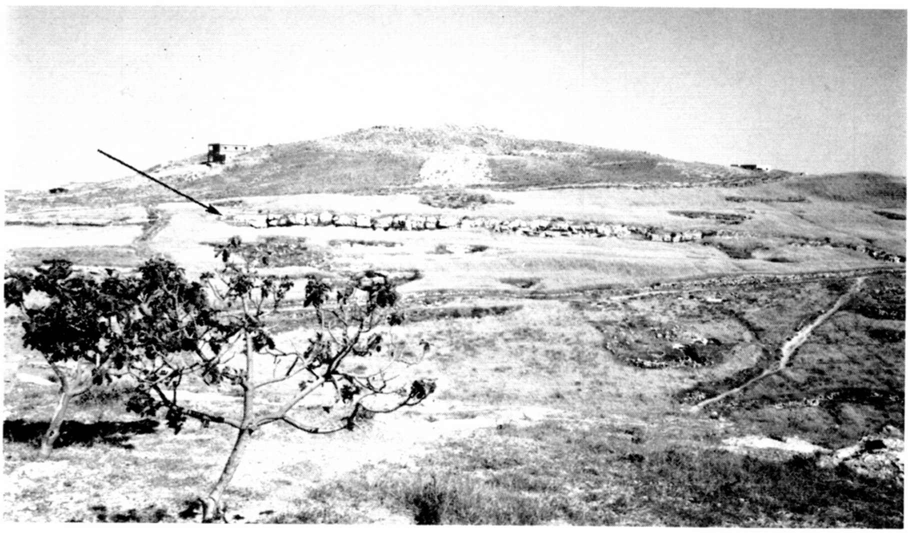
A. Lithic outcrop pattern on the hill across the *Wadi Ḥesbân* tributary immediately northwest of *Tell Ḥesbân*. Alternating Turonian limestone and chalky limestone occur above and below X. Thick-bedded Cenomanian nodular limestone occurs at and below Y. A massive, hard, fossiliferous cherty limestone occurs on top of the hill at Z.



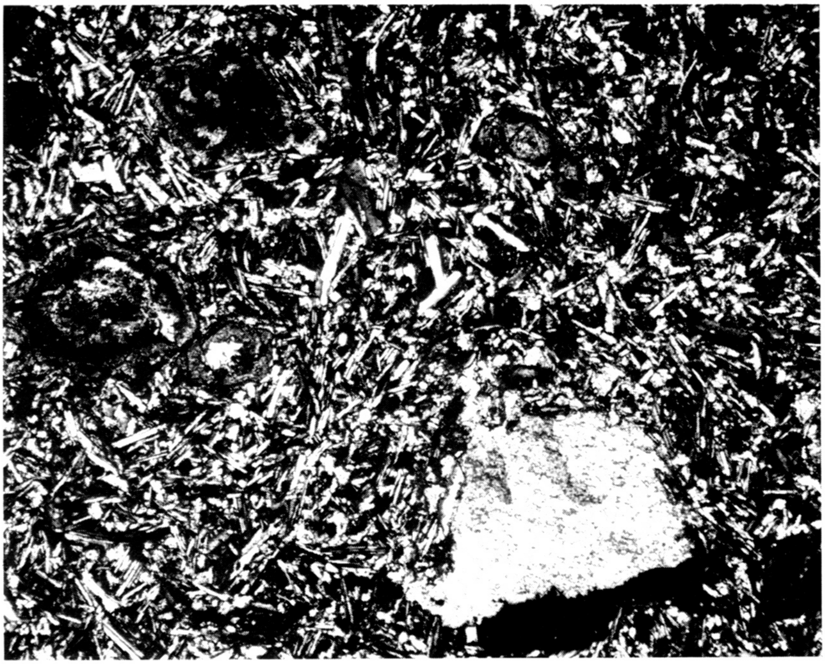
B. Stone block quarry site on the hill northwest of *Tell Ḥesbân* (At X on Plate XIII:A). The chisel marks are quite distinct, but the block was not successfully quarried in its entirety. (Scale 15 cm.)



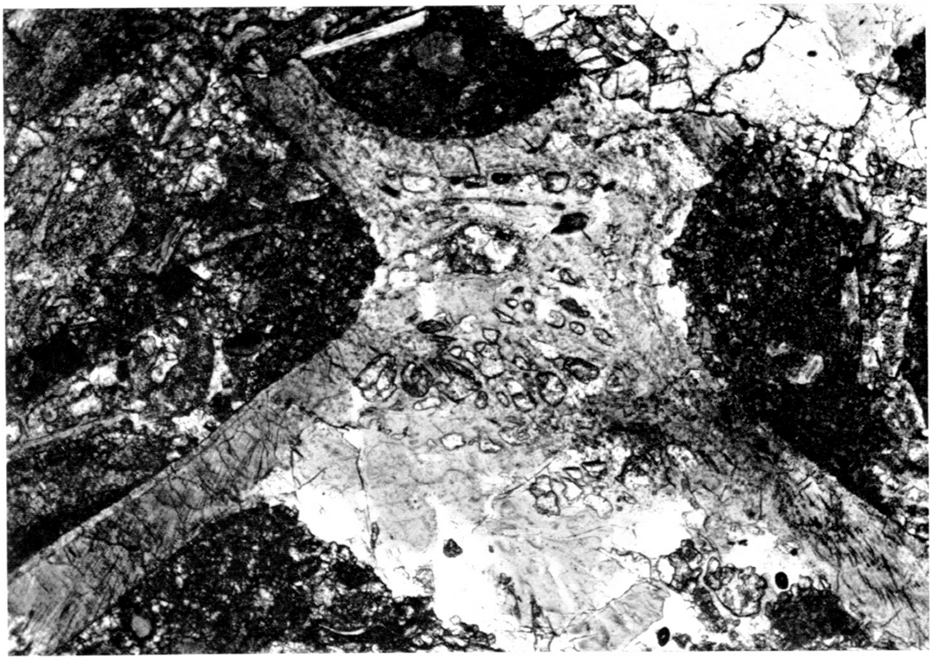
A. Geological Map of the Heshbon Area.



B. *Tell Ḥesbân* from the northwest. A massive, thick-bedded fossiliferous limestone forms a significant outcrop belt along the slope (arrow).



A. Microphotograph of a fragment of a basalt bowl with legs, found at *Tell Ḥesbân*. Light mass, lower right, calcite vesicle filling, altered olivine (angular crystals, upper left) in a ground mass of plagioclase lathes. (40 ×)



B. Microphotograph of a fossiliferous limestone, back fill debris from the north side of the apse, Area A of *Tell Ḥesbân*. Cross-section of a fish vertebra in a matrix of sparry calcite. (40 ×)