Quarry Technique in the Early Bronze Age in the Southern Levant, *Hirbet ez-Zeraqōn*: A Case Study*

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1. Introduction

The Early Bronze Age in the Southern Levant was characterized by the emergence of fortified cities. These cities were pre-planned and many of them were established on virgin soil or bare rock surfaces. Most scholars agree that the choice of the city location was determined by several important factors. For example, the defensive and strategic positions of the city were carefully chosen by the builders of these towns. Cities were primarily situated on a hilly area to make use of the natural landscape. Natural landscape features were cliffs and steep slopes. These strategic locations were utilized to partially protect the town. The cities were to be located on main ancient trade routes. The availability of having natural resources like water, fertile land, vegetation and construction materials close to the site is another significant decisive factor in choosing the site.

The availability of resources led naturally to regional differences of structural materials. Due to the plentiful presence of stone, the inhabitants of Jordanian highlands used it intensively as construction material during the Early Bronze Age. While in other parts, for example in the Jordan Valley, sun-dried mud-bricks were predominantly used. Consequently, our research will focus on the proper understanding of the landscape and the availability of raw construction materials.

The way in which humans made use of available resources more efficiently and more easily in their natural context is a key answer to understanding ancient quarrying techniques. Therefore, the place of the quarry, the availability of materials close to the site, setting up workshops and other facilities, were all determined by landscape topography and the geology of the resources. According to Zipf’s principle of least efforts and security\(^1\), humans chose the least consuming place in terms of effort and time.

Decisions regarding the size of the city and its borders, about the inner divisions of the different quarters of the city, and about the quantity and the quality of structural materials needed to be taken into consideration before the construction of these Early Bronze Age cities could begin.

In the case of *Hirbet ez-Zeraqōn* the available construction material included both stone and mud-brick material. Buildings inside the city were made from mud-bricks on stone foundations, while the entire fortifications were made from stone. The large quantity of stone blocks and gravels used in massive fortification walls at the site led us to look for available

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* The authors are grateful to the directors of the excavations at *Hirbet ez-Zeraqōn* Prof. Dr. S. Mittmann and Prof. Dr. M. Ibrahim for their permissions to work on this subject.

\(^1\) Zipf 1949, 19.
quarrying places close to the site. The inhabitants of Ḥirbet ez-Zaraqūn could not have collected them solely from the surface.

Archaeologists studying the architecture of the Early Bronze Age city rarely focus their studies on the sources of stones and the quarrying techniques. Therefore, this paper attempts to shed light on the quarry techniques of the Early Bronze Age by studying and analyzing the available sources of stone blocks that were used to build the fortifications of Ḥirbet ez-Zaraqūn.

Ḥirbet ez-Zaraqūn is located on the Eastern slope of a flat hilltop on the western edge of Wādī es-Sellāl ca. 13 km Northeast of Irbid (figs. 1–3). The excavations between 1984 and 1994 were concentrated in two major areas in the lower and the upper parts of the city. As a result Ḥirbet ez-Zaraqūn was identified as ‘one major period site’ that was fortified during the Early Bronze Age II and developed into a major city towards the end of Early Bronze Age II and during Early Bronze Age III. Sometime during the Early Bronze Age III the site was abandoned completely and reoccupied as an open seasonal settlement in the Early Bronze Age IV. The fortification wall, which was either eroded on the side of Wādī es-Sellāl or might have never been built on that side, enclosed an area of ca. 8 hectares. A temple and a palace complex were excavated in the upper city. Domestic structures separated by streets

Fig. 1. Early Bronze Age sites mentioned in the text.

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Fig. 2. Topographic map of Ḥirbet ez-Zeraqūn.
Fig. 3. Digital terrain model of *Hirbet ez-Zeraqôn* plateau dipping towards *Wádi eš-Sellâle*.

Fig. 4. General geology of the area in the vicinity of *Hirbet ez-Zeraqôn*.
were excavated in the lower city. Building complexes in both the upper and the lower city were built mostly from mud-bricks on stone foundations. The fortification wall was built with either large (110 × 60 – 60 × 30 cm) or medium (40 × 30 – 20 × 20 cm) limestone blocks. The stones were laid in the so called ‘dry-construction method’, in which loose earth functions as a kind of mortar. The fortification wall was ca. 800 m in length and 4 m in width while the expected original height of the wall was between 5 and 7 m. Thus a rough estimate of the quantity of stones that had been used alone in the fortifications, including the large bastions around the main city gates, comes to some 25,000 m³. The stones used for the foundations of the structures inside the city amounted to no less than 10,000 m³.

2. Geology and Geomorphology of Hirbet ez-Zeraqön

The study of the geology and the rock types exposed in the area is of great importance, as the purpose of this research is to determine the construction characteristics and prevalence of the raw materials used in the construction of the ancient settlement.

The ez-Zeraqön plateau and its surroundings are geologically characterized by general stratigraphy ranging from the Umm Rįgim chert limestone formation, surrounded by the Muwaqqar chalk marl formation in the North and Northeast, soil covered basalt on the Northwest and basalt in the far Northwest (fig. 4). The tertiary and cretaceous limestones are exposed with more than 200 m of thick rock successions of wide carbonate deposits. The limestone is overlain by thin, discontinuous upper Pliocene and lower Pleistocene calcarenites, deposited within the dissolution cavities of the upper layers. According to Bender, the geology of the area is made of chalk – a marl member rests on the phosphorite member and it is composed of soft chalk, marl, bituminous limestone and marly limestone of the Meastrichtian-Paleocene Age. The total thickness of the limestone formation occurring on the site is not known but it exceeds 200 m in the Northern vicinity of Hirbet ez-Zeraqön.

The main chalky limestone series underlies the entire archaeological site and the surrounding country (fig. 4). It is present on both slopes of Wāḍî eš-Šella and continues beyond the limits of the study area to the upstream portion of the Wāḍî gorge.

Basalt outcrops within the upstream portion of Wāḍî eš-Šellāţe gorge area belong to the Yarmūk basalt, which is considered to be the Northwestern extension of Harret el-Ǧabbān. The basalt occurs on the Northeastern side of the site as small inliers in the limestone formation, which unconformably overlies the limestone. Farther to the East beyond the limits of the study area, it forms a continuous outcrop at the base of the escarpment bordering the site.

Both the lithography and the material in the archaeological site indicate a formation consisting of alternating strata of massive, firm to hard, white to gray crystalline limestone and softer, gray, thinly-bedded, dense, marly limestone interbedded with some thin beds of

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3 Excluding the Eastern side of the settlement where no remains of fortifications have been found.
4 DOUGLAS 2007, 4.
5 Two large rectangular bastions close to the city gates in the upper and lower city gates were found. The one in the upper city measured 30 × 8 m. The bastion of the lower city is 8 m in width, while its total length was not completely excavated.
6 MOH’D 2000, 7.
7 BENDER 1968, 230.
8 BENDER 1974, 196.
marl and clay. Some thin beds of flint are also present. The strata range from 4 m to over 25 m in thickness (fig. 5).

Geomorphologically, the present landform is the result of the underlying limestone structures of bedding, interbedding, joint systematizing, and karst processes (fig. 9), which represent a peculiar hydrogeological domain. In fact, the hydraulic base level of groundwater circulation corresponds to the fluctuations in the rainfall and the discharge of the several springs draining groundwater along preferential path flows along Wādī eš-Šellāl. The upper beds have been weakened by weathering and some parts of it have been removed by erosion.

The morphology of the rocky plateau is the result of the interaction of numerous natural and anthropogenic processes. These included the physical and mechanical properties of the rock formations, the sedimentation structures and patterns, the degree of weathering of rock masses, tectonics, groundwater, hydrology and climate, seismicity and last but not least, the human activities at ez-Zeraqōn. They play an important role in the assessment of the occupation process and the location of sites.

3. Stone Quarry

A peculiar joint system occurs in the limestone of the ez-Zeraqōn plateau. The joint system reflects the major trending and history of the structural deformation in the Jordan rift valley, Yarmūk fault, and Wādī eš-Šellāl. Two repeated joint lineaments are found on the exposed limestone plateau. The following rose-diagram of the structural deformation of the limestone shows two major trends of the joint lineaments; the first is at 0°/180° degree North/South, and represents about 40% of the total readings, and varies at horizontal intervals ranging from 50 cm to 3 m. The second set of lineaments trending at 130°/310° degrees Northwest represents about 45% of the total readings (fig. 6). The resultant joint system produced a different main master joint system cut diagonally by another secondary joint system. This joint system created joint networks with two perpendicular sides that were used by the Early Bronze Age masons to easily detach the stone blocks (fig. 7). The average thickness of the exposed upper strata of the limestone mostly vary from 24 cm to 45 cm, which corresponds with the average thickness of the stone blocks used in the construction of fortification walls.

Reflecting the local geology of the site, the Early Bronze Age inhabitants of Hirbet ez-Zeraqōn used the structural deformation of the joint system to choose certain zones as quarry areas. Different quarry areas can be observed in the upper and lower part of the city. Although no impression of tools such as picks, hammers, wedges or chisels were recorded on the rock surfaces at the different quarry areas, close examination of some of these quarry spots proved that simple tools were used to detach the blocks through their vertical and horizontal joints to extract large stones. Some of them fit the size of the blocks which were used for the two main gates of ez-Zeraqōn upper and lower city (fig. 8). Moreover, the thickness of the quarried blocks was generally determined by the thickness of the beds and the existing dissolution cavities, which allowed for easy detachment of the blocks due to karst weathering of the limestone through its joints and bedding planes (fig. 9). Tools, such as chisels and hammers could have been used to groove and channel the vertically demarcated natural lineaments of the limestone joint system to split them as desired. Once the detachment was executed, hammered wedges (e.g. wood, bronze?) were inserted into the joints and grooves to split the marked blocks. The absence of major tooling marks at these spots may indicate the easy detachments of the stone blocks.
Fig. 5. Site general geological stratigraphy.

Fig. 6. Rose diagram showing the two diagonally cutting joint systems of the limestone bedrock of Hirbet ez-Zeraqön.
Fig. 7. Limestone block detachment through the diagonally cutting joint system seen in the lower city.

Fig. 8. Quarry spot at the Northeastern part of the Hirbet ez-Zeraqon plateau showing the detachment of stone blocks based on their joint system.
The rough and unsmoothed surfaces or sides of some of the extracted blocks indicate that they were extracted and transported in the form of roughly-hewn limestone blocks. The absence of debris at all the suggested quarry spots supports the hypothesis that final dressing for some blocks may have been carried out somewhere near the construction destinations. The byproduct stone materials would then have been used in the filling of the building walls, floors, as well as in the fortification wall. Earth mixed with ashes may have also been used to bond some of the uneven and irregular surfaces of the foundation blocks.

The masonry blocks of the upper city temple and of some parts of the fortifications are said to have been quarried from the cherty limestone located in the upper layers of the Northwestern part of the ancient city.

The best location for the quarry would be close to the site or on the site itself. This would save a lot of effort regarding transport. In the case of Ḥirbet ez-Zeraqōn the area of the site itself was used for quarrying the stone. The builders of the city could profit from several factors when constructing their quarry:

1. The area of the site was rich in different types of limestone⁹.
2. The natural limestone layers were directly on the surface or at least very close to the surface.

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⁹ Most recently the local inhabitants of the villages close to the site like el-Muğaiyir, Sāl and Bušrā were using the area for quarrying the lime for construction purposes.
3. The thickness of the natural limestone layers was appropriate for the fortifications.
4. The structural joint system of crossed vertical joints made the detachment of the stone blocks easy.
5. Quarrying the stones from the surface of the site created the opportunity to construct some buildings on a bedrock foundation\textsuperscript{10}.

4. Geoarchaeological Analysis of the Stone Blocks

Although rocks are abundant in the study area, not all deposits were acceptable and easily available for construction purposes. Some deposits were unusable because of their weak physical properties (e.g., low strength and hardness, high degree of weather wear of the rock) or inaccessibility. However, the strength and hardness of the rock are clearly significant for the building of fortification walls, floors, foundations, walks, staircases, towers and other superstructures. The characteristics of the rock have a powerful influence on the building styles, the stone’s workability and the use of the stone material within the different installations. The selection of stone blocks for a special purpose depends also on a number of additional factors, like the mineral constituents of the stones, the degree and rate of their weathering, their degree of compression and load stress, the block geometry and finally on their mode of quarrying and construction. The parameters of these factors, in turn, depend on the micro- and macroscopic structural forms such as texture, sorting, compactness, porosity, bedding planes, vertical and inclined joints, grains, pores size and shape, and the morphology of the weathered products.

Four stone blocks were selected by macro investigation to represent the major rock types which were used in the building of ez-Zeraqôn city. The stone blocks’ dimensions and their hand-specimen macro-physical properties have been summarized in Table 1. Properties such as elastic modulus, tensile or flexural strength, shear strength, stress-strain relationships and bond strength were measured in terms of uniaxial compressive strength of a $10 \times 10$ mm cube, moist cured for 5 days. Compressive strength is the common basis for building and designing structures. A Universal Testing Machine (Model Ti-FMC-3000) was used for the measurement of the compression and tensile tests of the stone samples. The terms “strength” and “compressive strength” are used interchangeably; they were expressed in graphic form.

\textsuperscript{10} In different parts of the city, bedrock was used as the foundation for many buildings such as the palace, temple and various domestic buildings.
Quarry Technique in the Early Bronze Age in the Southern Levant, Ḥirbet ez-Zeraqūn

<table>
<thead>
<tr>
<th>Stone no.</th>
<th>Type of rock</th>
<th>Dimensions in cm</th>
<th>Macro-characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cherty limestone</td>
<td>18 × 27</td>
<td>Showing rectangular fractures on two sides and natural break in the other sides. Bed thickness is 21 cm. The sample shows weathering on its top and in the lower parts, which indicates a free hanging or easily detached bedrock. The lower part has calcareous encrustations. The beds show about 11° dipping into the formation and 14° out of the formation.</td>
</tr>
<tr>
<td>2</td>
<td>Chalky limestone</td>
<td>24 × 26</td>
<td>Showing some degree of dissolution weathering and structural weakness. The sample shows rectangular working on two sides. One side is along vertical joints of 74° West of the formation line. The thickness of the bed is 18 cm with 21° dipping out of the formation.</td>
</tr>
<tr>
<td>3</td>
<td>Bituminous chalky limestone</td>
<td>34 × 23</td>
<td>The sample shows ancient and old massive weathering forms. The chalky thickness of the bed is 24 cm in average. The block shows a rectangular joint system with diagonal vertical joint trending towards one of the block sides. This indicates a triangular joint system corresponding to the site’s bedrock.</td>
</tr>
<tr>
<td>4</td>
<td>Interbedded crystalline limestone</td>
<td>27 × 19</td>
<td>The sample is compact showing paleo-hydro activities (deposition of calcareous encrustations on the upper and lower sides of the sample). The bed’s thickness is 19 cm. Vertical joints of 90° cross with bedding plain dipping 19°.</td>
</tr>
</tbody>
</table>

Table 1. The main characteristics of the selected rock samples from the site.

Studies of the physical properties of the exposed limestone indicating specific gravity and unconfined compressive strength were made on 4 samples. They show results varying from 7725 to 3620 p.s.i. (73 to 60 kg/cm²).

<table>
<thead>
<tr>
<th>Stone no.</th>
<th>Type of rock</th>
<th>Specific gravity (dry)</th>
<th>Compressive strength kg/cm²</th>
<th>Compressive strength p.s.i.</th>
<th>Porosity n (%)</th>
<th>Water absorption wa (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Marly limestone</td>
<td>1.68</td>
<td>253.40</td>
<td>3620</td>
<td>42.96</td>
<td>36.49</td>
</tr>
<tr>
<td>2</td>
<td>Cherty limestone</td>
<td>2.05</td>
<td>540.75</td>
<td>7725</td>
<td>49.63</td>
<td>27.90</td>
</tr>
<tr>
<td>3</td>
<td>Chalky limestone</td>
<td>1.50</td>
<td>416.50</td>
<td>5950</td>
<td>44.76</td>
<td>34.54</td>
</tr>
<tr>
<td>4</td>
<td>Bituminous limestone</td>
<td>1.67</td>
<td>395.58</td>
<td>5655</td>
<td>46.93</td>
<td>32.84</td>
</tr>
</tbody>
</table>

Table 2. The different physical properties of the tested limestone samples.
The analysis shows that limestone material can be classified into weak marly and bituminous limestones, and strong cherty and chalky limestones. The Early Bronze Age masons of ez-Zeraqūn recognized the diverse engineering characteristics of this material and utilized it for different architectural installations.

Large strong, compact cherty limestone blocks quarried from the upper formation were extracted and used to protect the gates and corners of the fortification walls (figs. 10–11). It is generally assumed that the measured compressive strength of stone blocks increases with the increasing rate of loading. Similar building techniques were also observed on other Early Bronze Age fortified sites such as Hirbet el-Batrāwī (fig. 12) and Hirbet Iskander (fig. 13). Usually the quoins were made of hard stone material. Their function was to carry and distribute the load and stress of the building.

5. Conclusion

The wide distribution and the varieties of archaeological sites and installations throughout the highland of North Jordan provide us with strong evidence that stone was used as the most substantial and locally available material for the construction of public and domestic buildings, towns and cities and their fortifications throughout the ages. The easily available massive component of the Umm Riḥim chert limestone outcrop, which is surrounded by the Muwaqqar chalk marl formation in North Jordan, provided the main building material which was used for the majority of the buildings of the Early Bronze Age city of Hirbet ez-Zeraqūn and its fortification walls.

Studying the Early Bronze Age city of Hirbet ez-Zeraqūn quarry and construction techniques, a few general conclusions can be drawn. The builders of Hirbet ez-Zeraqūn not only demonstrate a good knowledge of the local geology but also made skillful, creative use of simple indigenous quarry techniques. Apart from the geo-strategic factor, several decisive factors were considered by Hirbet ez-Zeraqūn’s city builders when they chose the location of the site:

1. the richness of the area in limestone, which did not require transportation efforts;
2. the physical properties and structural features of the limestone as a building material;
3. the natural layering of the limestone, which was directly on the surface or close to it;
4. the thickness of the natural limestone layers, and finally
5. the removal of unwanted surface slopes in some parts of the site in order to get a stable foundation ground for the construction of the buildings.

In the absence of documentary records or written evidence, it was not easy to give a decisive or even a narrow range dating for the quarry spots. However, their location within the Early Bronze Age site and the presence of excavated typologically dated evidence on the surface and between the structures could help to give a relative dating. After comparing the quarried or exploited bedrock elements at the quarry areas with the masonry building stones of the fortification wall and other different installations, the close similarities suggest a date parallel to the Early Bronze Age settlement in Hirbet ez-Zeraqūn.

In conclusion, it must be said that more analytical comparisons with other sites in the Southern Levant are needed, where there is valuable information regarding the quarrying techniques in order to support our understanding of the fortification systems of the Early Bronze Age in the Southern Levant.

For the pottery study from Hirbet ez-Zeraqūn see Genz 2002.
Fig. 10. Hirbet ez-Zeraqôn lower city gate with cherty limestone blocks used in the gate corners.

Fig. 11. Hirbet ez-Zeraqôn upper city gate with cherty limestone blocks used in the gate corners.
Fig. 12. Cherty limestone blocks at the corners of the main gate at Ḫirbet el-Batrāwī.

Fig. 13. Cherty limestone blocks at the corners of the main gate at Ḫirbet Iskander.
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