A Proposed GIS-Based Documentation System for Historical Limestone Quarries in Amman/Jordan

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Abstract: *This paper explores the distribution and variety of stone quarries throughout the central region of Jordan, especially the area of Amman (Ancient Philadelphia). Such spatial distribution of these installations provides strong evidence that stone at this region has been the most usable material in construction activities particularly in the Roman era. The selected quarries supplied limestone of the same given component; essentially composed of sedimental dense grain cemented oyster shell. Different elements of masonry were quarried up to the standards and transported, as ashlar blocks or roughly hewn dressed rounded unfluted columns and drums, to be finally finished and smoothed at the construction destination. Transportation techniques to transfer the material are also discussed. The comparison of the embedded or exploited elements at the quarries with the masonry of different neighboring monuments contributes to the narrowing of the absolute dating for such quarries. The paper proposes a GIS-based documentation system for mapping and georeferencing all quarries on digital maps. The proposed system is simple, robust, well-structured and interfaced to contain all basic GIS modules and functions' application in the field of archaeology. This proposal includes preparing digital GIS maps that show accurately the location of the quarries> architectural elements, the uses of GPS technology, and detailed maps for each quarry.*

Introduction

Archaeological investigation which includes survey and excavation on the east and north-east of Amman (Fig. 1), the capital of Jordan and very close to Abu sayag village, reveals the presence of several historical occupations dating back to different periods, from Neolithic till recent days (Conder 1889; Glueck 1930's; Parker 1976, 1982, 1983). This is clear in many locations such as Wadi Al-Qattar and Wadi al-'Ish where several buildings and monuments (including a set of historical Castles) are still standing. This heritage is part of the great cities of the Decapolis, with all the forts and legionary camps of the Roman Limes Arabicus in Jordan that presents the Roman distinguished construction strategies in the region with the stone being the primary building material. Little or almost no effort in the literature is directed toward investigating the historical quarries in Jordan as part of the existing valuable heritage. This results in lack of information about such treasure especially with many of such quarries being destroyed by modern construction projects.

This work focuses on exploring, analyzing and documenting the landscape and the structure of the quarries under consideration near the city of Amman, the southernmost Decapolis city in the Graeco-Roman periods (Ghawanmeh 1979; Parker 1982). Part of this investigation emphasizes the role of stone in the construction activities at these locations, in addition to studying the site formulation of such quarries. Studying such system of quarries in the specified spatiotemporal

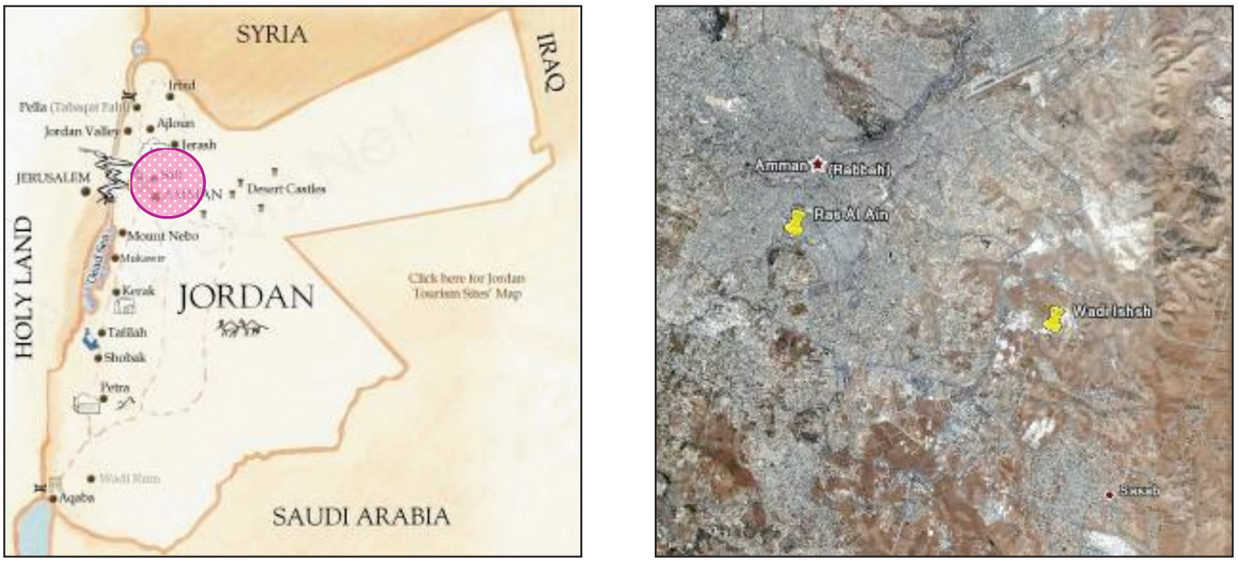

Fig. 1: Jordan map (Left) showing the study area (Right) (source: http://www.atlastours.net/jordan/islamic_map.jpg and Google Earth, 2007)

domain is very important to understanding the adapted building construction technologies. The investigation covers the quarrying process for stone extraction, modes of transporting, construction materials, and the development of tools and equipment (Ward-Perkins 1971). The paper proposes as well a complete framework for utilizing Geographic Information Systems (GIS), a digital mapping technology, as supported by other spatial technologies such as Remote Sensing and Global Positioning System (GPS) to document and map the remains within the quarries under investigation. Remotely sensed satellite imagery is useful to prepare land use change maps for the area after being processed, rectified and classified. GPS will be used in geo-referencing and documenting the accurate position coordinates for different monuments and structural components of the quarry system. Finally, the proposed GIS system is anticipated to integrate all spatial information layers in one capable geodatabase ready to allow further investigation and analysis of historical Limestone Quarries in Amman, Jordan.

Location and Geological Characteristics of the Quarries System

The study area, near the city of Amman, contains a number of valuable historical quarries. Of these, three are the most significant sites; namely: Wãdi al-'Ish quarry; Rãs al-'Ayn quarry; and Al-istiqlal Street quarry. Wãdi al-'Ish quarry (Fig. 2) is the most important among the quarry system in Jordan. It is located about 10 kms to the east of Amman, close to the location of modern quarries over the adjacent hills where limestone is crushed into gravel using modern machinery; its materials are characterized by pinkish white limestone texture with shell inclusions and few voids (Abed 1982; Kanellopoulos 1994).

Looking right from the Amman – Zarqa modern highway, after about 6 kms driving distance from Amman toward the Zarqa city, a hill with a slope toward the west can be seen where the historical Wãdi al-'Ish quarry is located on its summit. To the west of the quarry area, a small settlement is located on the summit of a high hill. The survey of the

(A) General View

(B) Quarried segments

(C) rectangular blocks

Fig. 2: Wãdi al-'Ish quarry:

site highlights the existence of tumbled stones that were constructed using a roughly trimmed limestone blocks; additionally, some pieces of Roman pottery sherds were scattered over the surface.

The most visible monument in the quarry location is a column drum that can be seen from the distance of 200m (Fig. 3). At the northern part of the quarry, two huge drums are shifted to the edge of the quarry (Fig. 4). Another drum is still attached, partly channeled. Also, a long rectangular block was detached and left in situ. At the quarry edge, at the northern part as well, an ashlar of a partly hewn small drum is noticeable. Impression of few transported blocks can be noticed. Pick marks and chiseling are still clear on the step-cut face.

The southern part of Wãdi al-'Ish quarry (Fig. 5) is still holding three whole column shafts that are partially buried in the ground and attached

Fig. 3: A column drum located at Wãdi al-'Ish quarry

Fig. 4: A column of two huge drums at Wãdi al-'Ish quarry

Fig. 5: Three whole column shafts located at the southern part of Wãdi al-'Ish quarry

Fig. 6: (A-B). Old quarrying at Rãs al-'Ayn site

horizontally. Little channeling of a few blocks of different forms can be recognized.

It is very clear that the limestone outcrop surface is continuous with shallow scars indicating a common quarrying practice at that time where you need to quarry deeper, usually by few centimeters, to avoid such scars. The quarry>s material structure, as mentioned earlier, is best described as a semi-pure pinkish hard limestone with very few shell inclusions. No flint or conglomerate rocks are noticeable in the area or in the neighborhood.

The second site under investigation is Rãs al-'Ayn quarry, located near the intersection of the roads coming from Naour and Al-Wihdat towns. The quarry site is situated over a high limestone rocky hill, with a northwest extremely deep cut as a result of old quarrying, forming a sharp vertical deep facade, in some parts step-like cut (Fig. 6A and 6B).

The rock formation consists of slightly hard off-white limestone. Impressions of quarrying tools are defaced. Quarrying was mainly vertical; due to the thickness of the limestone layers which usually dictate the thickness of the blocks located in a mountainous topography. The quarry site is within a distance of 300m to the north of Umm Swaywina (a large settlement of long history) and easily accessible along the main valley from the old city of Philadelphia. Modern quarrying in the site, started about 50 years ago to produce gravel through crushing limestone rocks, removed all traces of old quarrying except that of the south hill which

Fig. 7: Vertical quarrying at Al-Istiqlal Street quarry showing the general geology of the area.

was protected by a modern forestry established in the area 30 years ago.

The last quarry site under study is Al-Istiqlal Street quarry (Fig. 7) located at the

intersection of Al-Urdun and Al-Istiqlal streets. This quarry was easily accessible from the modern location of Al-Urdun Street through a Roman paved road, possibly the Via Nova Traiana; in fact, a fragment of that road, with a milestone, is still visible in the site.

Pottery sherds collected on the surface indicated the Roman period as an episode of its long history that started from the first millennium BC. At this site, rock abruptly rises up forming a high plateau overlooking a deep north-south valley. The western extremity of that rocky area was vertically quarried in the Classical periods (probably Roman). The western quarried end looks like a deep step-wise facade. Evidence of quarrying is preserved by step cutting and by the impressions of extracted blocks. Tool marks are defaced. The thickness of the rock layers was sufficient to produce any type of blocks and ashlars. The material component in the quarry is off-white hard limestone (Fig. 8).

Indicators of in Situ Historical Quarrying

At each of the three quarry sites, a number of indicators and evidences testify to the characteristics of the quarrying system. At Wãdi al-'Ish quarry, some huge whole columns and column drums were cut and roughly carved and left in situ still attached to the bedrock. Three huge drums were already extracted from the bedrock and slightly shifted out of the quarry in order to transport them, but cessation of the work hindered that operation (Fig. 5). Few long rectangular blocks were outlined with deep grooves at different parts of the site. Vertical faces of the outcrop were step-like cut. Tool

Fig. 8: Limestone rock as a source material for quarrying

marks are clearly visible in different spots such as those of picks and chisels. A domed impression of an already exploited, but not transported, drum can be recognized in the bedrock. At the other two quarry sites, due to the steepness of the mountainous topography (Saleh 1980), an exploitation method was adapted on the vertical faces of the outcrop. Most of the faces were left step-like cut after the cessation of quarrying. Impressions of huge rectangular exploited blocks are still clearly visible. The exaggerated thickness of layers helped the quarrymen to outline any demanded size of blocks.

Historical Quarrying Methods and Tools

A careful investigation of the quarrying tools left at different quarries in the study area indicates that picks, hammers, wedges and chisels were mainly used to outline blocks with grooves and channels to split them free. This method is conservatively adopted in ancient Mediterranean quarries for ages (Fig. 3). Quarrying methods and tools changed very little in antiquity. Classical methods were still in use at the end of the nineteenth century. The Romans developed the use of metal wedges or plugs, feathers and metal broad chisels or blades and abrasives (Durkin and Lister 1983; Ward- Perkins 1971).

Fig. 9: Rectangular block at Wãdi al-'Ish quarry shows unfinished and unsmoothed face

In Wãdi al-'Ish quarry, rough surfaces or sides of drums and rectangular blocks show that they were exploited and transported in the form of ashlar blocks or roughly-hewn pieces. One column drum ends with terminal flange to allow a measure of adjustment to the finished length and diameter. Worked capitals, bases and friezes were found. Few extracted rectangular blocks at Wãdi al-'Ish quarry show unfinished and unsmoothed faces (Fig. 9). The absence of debris at all quarries supports the hypothesis that the final dressing may have been carried out somewhere around the construction destinations. No scrap is disbursed on or around the quarries. Even the broken pieces or those blocks which did not fit the measurements were transported and used as filling material for foundations and broad walls such as the material used in the construction of the great Temple of Amman. For the foundations of the great Temple of Amman, mortar mixed with earth and ashes was used to bond the foundation blocks and ashlars which were mainly of uneven surfaces and unequal measurements (Kanellopoulos 1994). The masonry blocks of that temple, built in the second century AD, are said to have been brought from the Wãdi al-'Ish quarry and other quarries around the city of Amman (Paradise 1994).

Also, a close examination of the quarrying technologies at other sites toward the south of Amman indicates that running drill was used vertically in the case of extracting huge boulders which fitted the size of blocks used in construction (Fig. 10). Once drilling was executed, hammered metal wedges were accommodated in holes to split the drilled blocks. Bases of some vertically channeled blocks show lunatic horizontal holes for the accommodation of water soaked wood and/ or hammered metal wedges in an attempt to exploit them. Chisel and pointed pick marks are still visible vertically and diagonally on a few channeled blocks. Channeling or grooving operations, as shown on some spots, were executed by chiseling the outline of the channel,

Fig. 10: A running drill mark

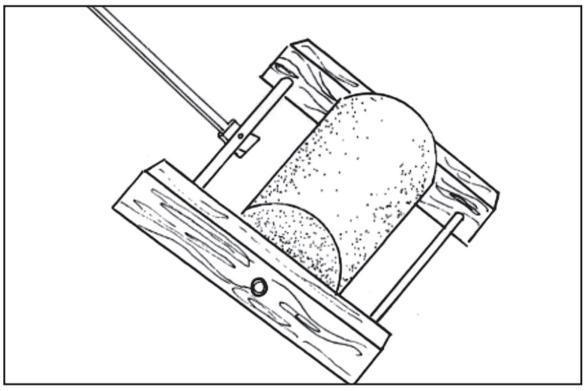

Fig. 11: Chersiphron's method for transporting quarried blocks

then picking besides chiseling started in a next step.

Who did the Quarrying?

The organization, transportation and extent of trade in the stone reached its peak by people of specialty within the Roman Empire. In the case of Roman quarries in Jordan, there is no decisive indication as to the type or class of the quarrymen. In a papyrus from Kanaris, dated to AD 107, there is a clue. It mentions the work of legionaries as stone cutting all day in south Jordan after the annexation of the new Arabian province by Trajan, who was responsible of the construction of the Via Nova Traiana (Bowersock 1983. Killick 1987) regarding the extensive limestone quarries discovered in 1980 near Udhruh in southern Jordan. Its possible to relate these quarries to the legionaries mentioned in the papyrus of Kanaris. In addition to that those legionaries and the limestone quarries could be related to the construction of the military and trade roads of Trajan rather than to a civilian project. As for the Amman quarries, it should be mentioned that a large settlement is still located 200 m to the southwest of Wãdi al-'Ish quarry. There is no reason to argue against the possibility of considering the work of that settlement as stone cutting and trading. Roman pottery is scattered on the surface. Projects of building in Philadelphia were various, in number and utility, and were generally of a civic rather than military character (Hadidi 1974; Northedge 1992). The area of east Amman is plotted with different limestone quarry sites, since most of the outcrops of that area and the area to the south are of the same white and pinkish limestone used in constructing Classical Philadelphia.

Transportation of Quarried Blocks

To complete the picture of the historical quarrying system in the study area, a brief note on the method of transporting the quarried blocks is in order. Small blocks could be easily transported on wheeled carriages, but in the case of huge blocks it was not an easy matter considering the local uneven topography. In Wãdi al-'Ish quarry, huge columns and drums had already been exploited with round forms. It is believed that a square socket was carved in the center of each side of the drum so as to fix pivots on both sides. The pivots are fixed in a wooden square frame that could be pulled (Fig. 11). The rounded block served as a wheel, a mechanism called Chersiphron's, named after the Greek architect who supervised the construction of the Artemis Temple at Ephesus in the fourth century BC (Kanellopoulos 1994; Toorn 1995; Nasiri 1977). Large rectangular

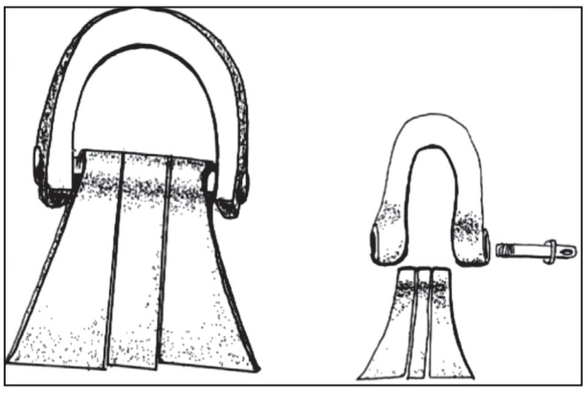

Fig. 12: Illustration drawing of lewis lifting device

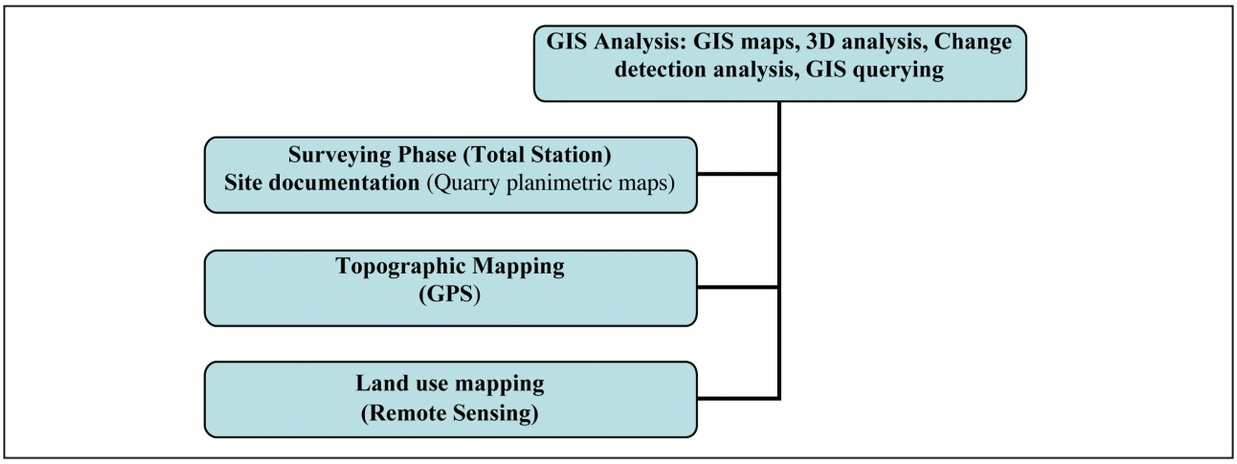

Fig. 13: A flow chart for the proposed system

blocks could have been pulled along rollers to the site and then slid into position by men operating pulleys through windlasses (cranes) (Adam 1966).

A lifting device, called lewis shown in Fig. 12, consisting of three metal pieces was used to lift blocks. A replica was manufactured and used to lift blocks during the anastylosis projects of the great Temple of Amman. Lewis sockets were hewn on certain sides of the blocks such as the upper surfaces of column drums. In heavy blocks, more than one lewis was used. The number and depth of sockets depends on the hardness of the lifted stone (Kanallopoulos 1994).

Destination and Dating

In the absence of documentary evidence, the dating of quarrying operations poses particular problems, as very similar practices continued for centuries and even millennia (Durkin and Lister 1983). Quarrying and stone working are among the most conservative of trades maintaining the traditional techniques in defiance of the passage of time, in many parts of the world. Classical quarrying methods were still in use at the end of the nineteenth century A.D. Hence, exact dating indicators are few (Durkin and Lister 1983). The method of grooving and channeling around blocks, particularly rectangular, which is evident to some extent at Wãdi al-'Ish quarry, was practiced in old quarries of all ages throughout the Mediterranean area. This system persisted even though the Romans, by the early first century AD, had developed the use of metal wedges and feathers. Besides, they were aware of the use of saw and metal blades to cut stone and the use of abrasive sand to help in fixing joints (Durkin and Lister 1983; Kanellopoulos 1994).

Insertion of metal wedges, plugs and feathers all around the periphery of blocks noticed at Wadi al-'Ish quarry, was practiced in the Roman Empire quarries. Metal wedges were even used for stone-dressing. (Durkin and Lister 1983). Pliny, in his Naturalis Historia (XXXVI, IV, 14) mentioned the use of wedges to split blocks by the Romans. Herson of Alexandria referred, in the middle of the first century AD, to the striking of wedges in the operation of detaching blocks (Durkin and Lister 1983). The use of wooden wedges, expanded by soaking in water, should be considered as well. Wadi al-'Ish quarry and other Amman quarries have some traces

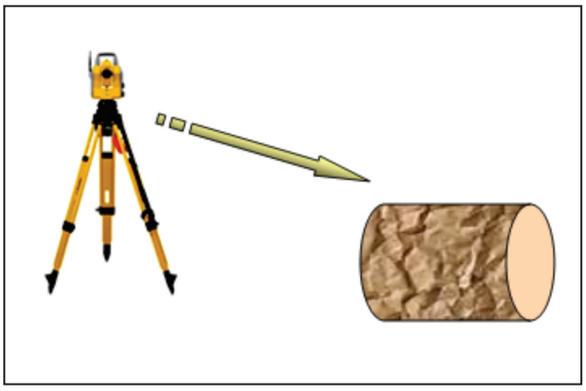

Fig. 14: Surveying by Total Station

and indicators of the use of wooden wedges. Wãdi al-'Ish and other quarries, in and around Amman, undoubtedly supported the numerous projects carried out in Philadelphia at the second century for different elements of architecture. The city with its multi and huge projects such as The Great Temple and the Roman complex on the Citadel Hill, in that period, looked as a burst of activity.

Diameters of average drums at Wadi al-'Ish quarry range from 130 to 142 cm. The same measurements were noticed for the columns of the Great Temple. The texture material of the temple matches the texture of Wadi al-'Ish and other quarries in and around Amman. Roman pottery fragments collected on the surface of Wadi al-'Ish quarry could be dated to the second century AD. The Amman quarries started in the Early Roman period or before that, but continued in use during all phases of the Roman era.

A Proposed GIS-Based Quarries Documentation System

This paper highlights an important heritage segment of Jordan, that is, the historical quarries, located in and near Amman. Those quarries were the source of material for construction in the past. They are now facing excessive threats: lack of maintenance, rehabilitation, and the danger of destruction arising from the fast urbanization rates near these sites. Owing to this awareness, we propose a GIS-based framework (Fig. 13) to document the existing quarries with their entire structural elements as a pre-step for preparing a master plan to rehabilitate such sites. GIS is defined as a georeferenced spatial database that links the information with its specific location, and it is a system capable of spatial data management, mapping and modeling. This proposal will be part of a currently running project in the study area, integrating modern spatial technology such as Geographic Information Systems (GIS) and Global Positioning System (GPS) to record the site features. The current project agenda in progress will be integrated into the proposed documentation system in different levels and phases as follows:

Surveying phase: This phase of the project

Fig. 15: GPS for topography modeling.

includes field work with the Total Station surveying equipment (Fig. 14) to take and calculate all the required measurements (distances, areas, volumes) of the quarry components. These measurements are useful for preparing detailed quarry-based planimetric maps. All other observations of interest relating to the quarry site are among the recorded information.

Topographic Mapping: The second phase of the project involves collecting GPS points (Fig. 15) at different locations within the quarry site. This will help in generating 3D elevation models (DEMs) and extraction of topographic maps of historical quarrying sites to understand their relations to different quarrying aspects such as transporting the quarried blocks.

Land use mapping: through classifying the satellite imageries, after being rectified to the correct geographic coordinates, and to generate land use change maps. This will help in studying the role of the change in land uses (e.g., to urban uses) as well as in the study of deterioration and destruction of such quarries.

Digital Mapping: The final stage in the project is to create a multi-layered GIS system for designing and building of databases for all the collected quarry-related spatial information. The complete GIS-based system will include different layers such as the geo-referenced GPS way points, surveying measurements, historical data, urban centers and much more. This will help the coming phases of the project through performing advanced spatial analysis necessary for the study of different geographic relationships within the quarry sites. Finally, one of the anticipated benefits of the proposed system is the advancement and encouragement of tourism in these historical sites in Jordan.

Conclusion

The great distribution and variety of stone monument installations throughout the highlands of Jordan provide us with strong evidence that stone was the most usable and locally available material for the construction of buildings over the ages, particularly in the Roman era, in Jordan. The massive Coquinoidal Limestone Component "Amman-Muwaqqar" and "Middle Jordan" formations provided building material that made most of the Roman structure look white except those of North Jordan, where igneous black basalt is the most available component of the outcrop.

The limestone horizon ranges in thickness from 70 to 80m, essentianally composed of sedimental dense grain cemented oyster shell. Colour ranges from chalky white to off and pinkish white. The quarries in question supplied limestone of the same given component. Different elements of masonry were quarried up to the standards and transported as ashlar blocks or roughly hewn and dressed rounded unfluted columns and drums, to be finally finished and smoothed at the construction destinations.

Different means of transportation were adapted. Rectangular blocks and long columns were carried on wheeled carriages, or on rollers. Huge drums were rolled using Chersiphron's method, pivoted on each side and fixed in wooden frames to be pulled as rollers.

Quarries were chosen and opened as needed. Villages or settlements of quarrymen were established adjacent to some quarries. The people who worked in quarrying were sometimes of the legionaries in case of official and urgent cases. In other cases civic quarrymen practiced stone trading. Since big stone elements are heavy and liable to break or crack, quarries were planned to be

as near to construction destinations as possible.

In the absence of documentary records or evidence, it was not easy to give a firm and decisive, or even to narrow, dating for quarries depending on quarrying methods which only conservatively changed over the ages. The existence or scattering of any typologically dated evidence, such as pottery fragments on the surface, could help to give semi absolute dating. The comparison of the embedded or exploited elements at the quarries with the masonry of different neighbouring monuments contributes to the narrowing of the absolute dating.

Although in their extensions and branching Roman roads reached different communities and fortifications, no paved roads could be traced into stone quarries. Dirt routes were probably used efficiently. To conclude this study, it is worth mentioning that, at least from the point of view of archaeology, architecture should be taken and considered as an operation of two components: the building operation, on the one hand. and the quarries as a place of supply, on the other. That is to say, quarries should not be lowly classified as a cultural resource. They should be recognized and protected as a heritage material in the same way standing monuments are recognized and protected. The paper concludes with paving the way for the next project phase through a proposed GIS-based documentation system aiming to record and geo-reference all quarries architecture on special purpose maps. This essentially includes preparing digital GIS maps that show accurately the location-based information of such quarries, using GPS technology, besides showing detailed maps for each quarry with all the related fine details such as construction design and transportation systems. Upon completion the system will reflect a comprehensive database for quarries and perform advanced spatial analysis for managing historical sites in Jordan.

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ملخص: يتناول البحث المحاجر التاريخية المنتشرة في منطقة وسط الأردن، وبخاصة في مدينة عمان (فيلادلفيا قديماً)، حيث كانت مستغلة خلال العصور الرومانية في إنشاء المدن والمباني العامة والخاصة. وقد أمكن تفحص عدد من المحاجر والوقوف على طرق التحجير المستخدمة في اقتلاع الحجارة وتصنيعها، ومن ثم نقلها إلى أماكن الإنشاء. وتشمل هذه القطع الحجرية على أعمدة، وأفاريز، وكتل مشذبة استخدمت خلال القرنين الأول والثاني في المباني الأثرية في عمان، وبخاصة من محاجر وادي العش، والاستقلال. كما يشمل البحث على استخدام تقنية التوثيق بوساطة نظام المعلومات الجغرافية GIS من حيث استخدام الخرائط الإلكترونية ووظائف البرنامج بطريقة مبسطة. إضافة إلى تحديد المواقع باستخدام نظام الإحداثيات العالمي GPS، وتطبيقه على المحاجر المكتشفة.

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