

Hypogea2023

Proceedings of IV International Congress of Speleology in Artificial Cavities
Italy, Genoa, September 29th / October 1st



EDITORS

Stefano Saj, Carla Galeazzi

Michele Betti, Francesco Faccini, Paolo Madonia





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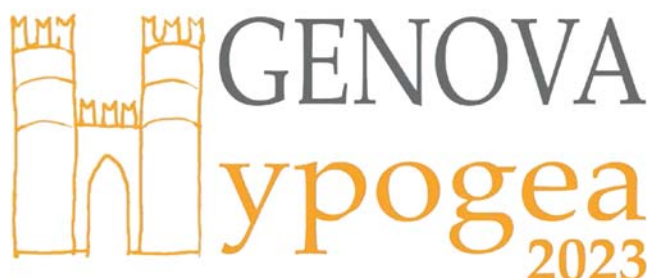


PROCEEDINGS OF IV INTERNATIONAL CONGRESS OF SPELEOLOGY IN ARTIFICIAL CAVITIES

HYPOGEA2023

SEPTEMBER 29th / OCTOBER 1st
GENOA, ITALY

PALAZZO DUCALE, SALA MINOR CONSIGLIO
Piazza Matteotti 9, Genova



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Edited by
CENTRO STUDI SOTTERRANEI

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FOREWARD

Mario Parise^{1,2}



The Doge's Palace view from Piazza Giacomo Matteotti (photo G. Cavalieri)

It is with huge pleasure that I am writing these lines, in order to present the congress *Hypogea2023*, and to introduce this piece of work, the 2023 proceedings that represent the new-born member of the Hypogea family, adding to those produced at the previous meetings in Rome (Italy), Cappadocia (Turkey) and Dobrich (Bulgaria). As President of the Commission on Artificial Cavities of the International Union of Speleology (UIS), I am very proud of this work, that continues the road started 8 years ago when we realized the need of organizing an international congress dedicated to

artificial cavities. The idea, unanimously approved by the Commission, resulted in a success well above our initial expectations, and as such has been in the following years.

After the first edition of Hypogea, held in 2015 in Rome, we are back in Italy, this time being hosted in Genoa, a beautiful town in the north-western Italian coasts of Liguria, characterized by a long history and a wide use of the underground: as many other towns in Italy, the underground of Genoa presents a great variety of sites of interest, but have been many times,

¹ Earth and Environmental Sciences Department, University Aldo Moro, Bari, Italy

² International Union of Speleology, President of the Commission on Artificial Cavities

during the last decades, also places that in some ways played a role on the occasion of the main flood events affecting the town. As elsewhere, the human actions in the underground environment have resulted in locally exacerbating the negative effects of natural hazards, and their impacts on society.

In the attempt to put together cavers and scientists from very different disciplines, the issue of artificial cavities is particularly suitable for merging different expertise: within artificial cavities many professionals and scholars actually work and make research activities, from geologists, to archaeologists, historians, architects, engineers, hydrologists, biologists, just to mention some disciplines. Artificial cavities are the perfect place for multi-disciplinary works, and this is widely documented in these proceedings, where many contributions put together scholars coming from quite diverse experience and background.

50 articles included in the proceedings (out of the 52 presented at the congress), counting 150 authors from 8 countries worldwide, and dealing with case studies from artificial cavities in 10 countries, is a great result! Of course, countries as Italy (the hosting nation) and Turkey are the most represented, and in particular the Italian contributions cover not less than 15 regions in the country, thus testifying the variety of underground sites, and of their typologies as well, in Italy. Beside the geographical distribution, the works are also extremely varied in terms of topics, ranging from archaeology and history, to geology, hydrogeology and geotechnics, to survey techniques, geotourism, and mitigation of natural hazards. At the same

time, practically all the categories of artificial cavities in the UIS classification (Parise et al., 2013) are dealt with, with great emphasis on worship sites, hydraulic works, civilian settlements, military works, but also with regard to quarries and mines and dovecots as well. Worth to be mentioned are also the several works about inventory of caves or deriving from projects that had artificial cavities as the main object of their study. This testifies, once again, the growing interest for the underground world created by man, and the importance to know as much as we can of what is present beneath our inhabited areas. In the case of artificial cavities, knowledge goes necessarily through the collection of data, possibly organized by means of inventories or catalogues, a very difficult work that, once started, can really make the difference for the complete knowledge of any territory.

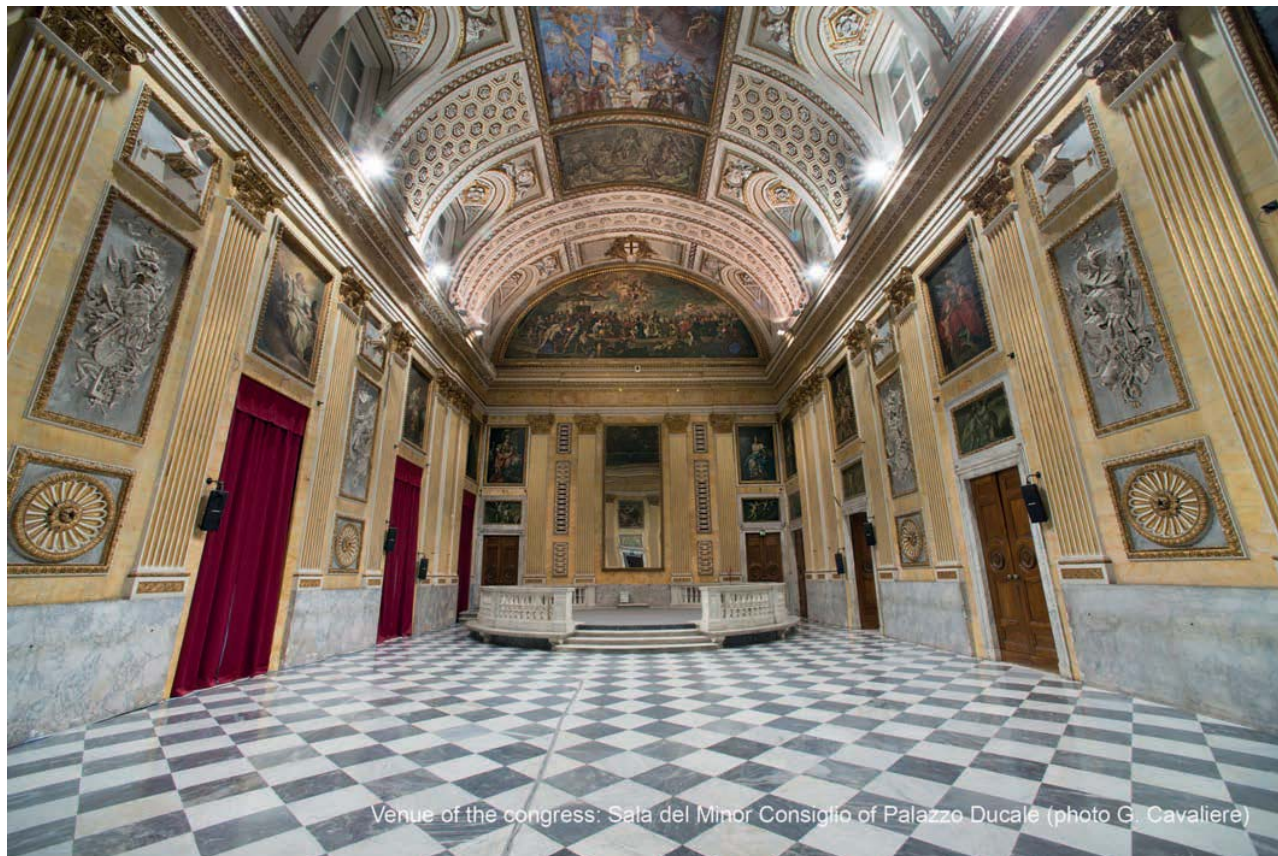
When preparing these lines of preface to the *Hypogea2023* proceedings, I went back to the preface authored by Carla Galeazzi and myself in Rome, in 2015: there, we presented our auspice that this congress “*might have in the future a cyclic nature, in order to allow a constant discussion on the issues regarding artificial cavities*” (Galeazzi and Parise, 2015, p. 7). Today, I am extremely happy to confirm that Hypogea, at its fourth edition, has become a fundamental occasion of meeting for all scholars dealing with artificial cavities, notwithstanding the great difficulties posed in the last years by the pandemic. Thus, I am sure that the congress will keep going, and look forward to visiting other countries in the next future, on the occasion of the Hypogea to come.

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CONGRESS PRESENTATION

Stefano Saj^{1,2,3}, Carla Galeazzi^{1,4,5}



Venue of the congress: Sala del Minor Consiglio of Palazzo Ducale (photo G. Cavaliere)

This publication gathers the contributions presented during the IV International Congress of Speleology in Artificial Cavities, *Hypogea2023*, organized in Genoa by Centro Studi Sotterranei (Underground Studies Center) with the support of the SSI - Società Speleologica Italiana (Italian Speleological Society), in partnership with the UIS - Union Internationale de Spéléologie (International Union of Speleology) and in collaboration with the Hypogean Federation, the SSI Artificial Cavities Commission, the Ligurian Speleological Delegation and the Opera Ipogea - *Journal of Speleology in Artificial Cavities*.

The Genoa Congress is the first one organized in presence after the restrictions and great difficulties faced by all communities due to the Covid-19 pandemic, following the previous ones held in Italy - Rome (*Hy-*

pogea2015), Turkey - Cappadocia (*Hypogea2017*) and Bulgaria - Dobrich (*Hypogea2019*).

In the prestigious historical venue of the Palazzo Ducale in Genoa, the 52 congress contributions (oral and poster) confirm the synergistic commitment that has characterized research over these last few difficult years in which the pandemic has never stopped.

The Congress, distinguished by the same scientific rigor as the previous editions, constitutes a strategic moment for the exchange of experiences in various high-level scientific, technical, and design fields thanks to the participation of Italian and international experts. Different methodologies, issues and achieved results are shared.

The research lines are organized divided into 11 ses-

¹ General chair of the Congress

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³ Opera Ipogea - *Journal of Speleology in Artificial Cavities*

⁴ Società Speleologia Italiana, Bologna, Italy

⁵ Hypogea Federation for research and enhancement artificial cavities, Rome, Italy



Main courtyard of Palazzo Ducale (photo G. Cavaliere)

sions, each addressing a significant topic related to the central focus of the conference.

It emerged from the speeches that cooperation between academic and non-academic entities and that the cooperation between these entities and the institutions has strengthened in recent years. Even in the more strictly scientific field, decisive steps forward have been taken. The complex picture emerging from the congress provides theoretical and practical insights, bibliographical and documentary references related to the multitude of areas of intervention, which are useful for the best continuation of our studies and researches.

Talking about the state-of-the-art means drawing lines between what has been done, what is currently being done, and what will be done taking advantage of new knowledge, renewed skills, and technological progress. Multidisciplinarity is essential in the path of study, research, and efficient management of results, and it is worth highlighting how the commitment of each entity and the recognition of expertises can make a difference.

Based on the work carried out in the years which preceded to the congress and based on the organization of *Hypogea2023*, the need for constant experimentation in speleology has emerged, requiring a flexible attitude.

The transformation process that has characterized our work at the Centro Studi Sotterranei has led us to redefine our project year after year, and continuous connections have emerged among the different levels of research of those involved.

The congress represents an essential point of reference for the knowledge, protection, and enhancement

of underground heritage of historical and archaeological interest at international level.

In fact, it provides a reading of a wide-ranging researches and monitoring of completed and ongoing initiatives, offering an updated, innovative, yet realistic picture of a field which is constantly evolving and therefore increasingly complex.

In this journey, it is fundamental the commitment of administrative leaders at various levels and, also, the need to share the importance of the topic with the society. Local government represents a key role to coordinate and influence what can be implemented in the territory, and its cooperation with higher institutions represents the possibility of developing more effective policies.

The growing interest in topics covered by the scientific literature sector, of which the journal *Opera Ipogea* is a significant example, has not yet significantly reflected in local policy, where the issue is still largely experimental.

Fortunately, there are representative cases in the management and urban planning of the underground, with adequate regulatory support from the urban resilience perspective, as it is the case of Helsinki has demonstrated for many years (Helsinki Underground Master Plan).

The *Hypogea2023* Congress also aims to provide a contribution and stimulus in this direction, focusing on the active role of those within Public Administrations who are tasked with making decisions or systematic evaluations at the local level.

The result of this IV Congress represents valuable support for the fruitful future work of a relatively recent discipline such as Speleology in Artificial Cavities.

Quarrying Methods in the Cave of Zedekiah in Jerusalem at the Ancient time (Israel)

Aвраham (Avi) Sasson¹

Abstract

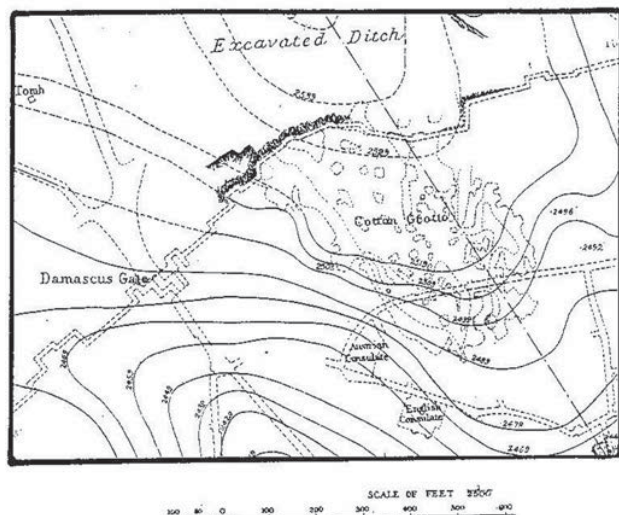
The historical and archaeological testimonies teach that the Cave of Zedekiah was used as a quarry from the First Temple period to the end of the Second Temple period, and possibly even a bit later. The archaeological remains and the unique nature of the rock in the cave indicate that this was a governmental quarrying site, as was already suggested in the past. The remains of the yards and the work areas bear evidence of the methodical and economic organization of the work within the cave. The cave contains signs of singular quarrying methods that, to the present, have not been located and characterized in other quarrying sites in Palestine, such as the "column" method and the "windows" method. These and other testimonies lead us to determine that the cave was mainly active in the Second Temple period, using technologies that were imported from throughout the Roman world. The quarrying remains in the cave of Zedekiah constitute a sort of catalog of ancient quarrying methods, as we learn of them from the grooves, trenches, yards, and many other testimonies in the rock.

Keywords: Zedekiah cave, quarrying sites, quarrying methods in ancient Jerusalem.

The Cave of Zedekiah, that is one of the largest quarry-caves in Palestine, is located at the foot of the northern Ottoman wall of the Old City in Jerusalem, between Damascus Gate and Herod's Gate, below the houses of the old city (Map 1). This site was already known in early periods, and popular legends and traditions were woven about this cave in relation to the construction enterprises of Kings Solomon and Herod, and especially to the construction of the Temple. This was also the source of the wide range of names given to the cave, such as "King Solomon's

Quarries," the "Caves of the Kings," "Ma'arat el-Hajr" (the "Cave of Stones"), "Ma'arat el-Kitan" (the "Cotton Cave," since it served as a store for cotton). The cave whetted the curiosity of various researchers and travelers, although few actually were physically present at it. Most of the researchers who explored the cave and its surroundings were attracted by the aura of mystery that enveloped it, and did not pay attention to the technological aspects reflected within the walls and most remote corners of the cave, that attest to the similar and traditional quarrying methods employed in Palestine. The different quarrying marks in the cave represent various methods that are known from ancient times (the Bronze Age) to the late Ottoman period. From this respect, the Cave of Zedekiah, with the traces of quarrying within it, constitutes a physical "catalog" of the quarrying technologies and methods in use in Palestine (Safrai and Sasson, 2001). The background of the folklore that developed around the cave is connected to the story of the flight of King Zedekiah (II Kings 25:4). This was followed by the development in the Talmudic literature and the commentaries of traditions concerning a large cave that was situated below Jerusalem, and from which one could arrive at Jericho¹.

Legends and beliefs connected with the Cave of Zedekiah continued to develop until the end of the



Map 1 – Interior of the Cave of Zedekiah, on the background of the topography of the city (source: Warren, 1884).

¹ *Tanhumah*, Num. 1:9; Rashi on II Kings 25:4; idem on Jer. 39:4; idem on Ezek. 12:13, followed by commentators such as R. David Kimhi and *Metzudat David*, ad loc. T Eruvin 3:13, ed. S. Lieberman (New York, 1962), p. 101; BT Eruvin 61b.



Fig. 1 – The northern wall overlooking the facade of the entrance to the Cave of Zedekiah (source: Barclay, 1858).

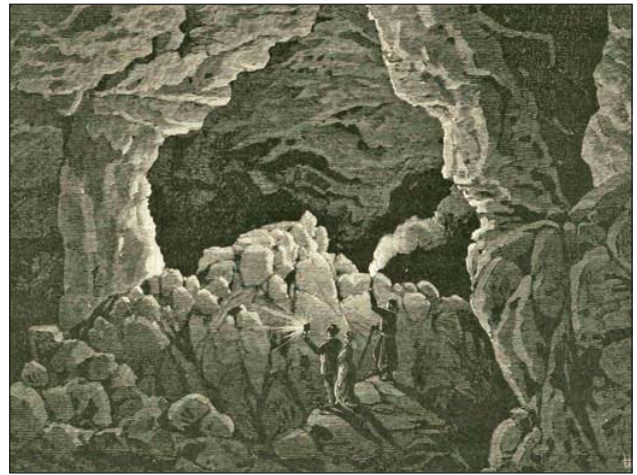


Fig. 2 – General view of the cave in Wilson's drawing (Wilson, 1866).

19-20 centuries (Ben-Ami, 1947; Vilnay 1973, 1974; Berkovits, 2000; Michelson *et al.*, 1996).

This article will present the archaeological testimonies to the quarrying methods used in the cave, in order to draw scholarly attention to the technological and organizational aspects of the quarry learned from them. We will not discuss economic aspects, despite the importance of the topic, since we shall examine this in a separate article. The modern archaeological study of the cave is in progress, and it is our hope that this article will provide archaeologists and other researchers with points for thought and attention in future research.

The geological section contains different types of limestone, mainly of the *ba'anah* formation of Turoanian limestone, in the Judea group (Avnimelech 1957, 1968; Rot and Flexer, 1977).

The thickest and dominant stratum is of the *meleke* type, a dense and crystallized soft limestone, despite the hardness of this rock. It is relatively easier to quarry and work than other types of hard limestone, since it is originally relatively soft, and hardens only upon exposure to air (Schik, 1887; Canaan, 1933).

A small part in the cave is *mizzi yahudi* rock, that also was used for construction of the city's houses in different periods.

The History of the Discovery and Research of the Cave

The memory of the cave progressively waned during the course of the medieval period, both in Jewish and other traditions (Prawer, 1991; Bahat, 1996; Gil, 1996; Ben-Dov, 1986; Vilnay, 1993; Yaari, 1976).

The first to explore the cave in the nineteenth century was the American researcher Dr. James Thomas Barclay (1807-1874), in 1852 (Barclay 1858; Schur 1988, 1992; Ben-Arieh, 1984; Luncz, 1970; Yaari, 1976; Clermont-Ganneau, 1899).

Charles Wilson, who came to Jerusalem in 1864, described the remains of the quarrying technology (fig. 2) (Wilson 1866, 1880; Conder and Kitchner, 1882).

Charles Warren was the first to actually examine the engineering and topographical (Warren, 1884).

The Frenchman Charles Clermont-Ganneau explored the cave in 1873-1874 (Clermont-Ganneau, 1899; Barclay, 1858).

In 1904 stones were quarried in the cave for the construction of the clock tower in Jaffa Gate that was erected in honor of the sultan Abdul Hamid II (Ben-Arieh, 1984).

Methods of Quarrying in the Cave

The maximal length of the cave that is exposed at present is some 230 m., with its maximal width reaching more than 100 m., and with an average height of approx. 15 m. The total area that is known today is approx. 25,000 sq. m. At its entrance, it is very close to ground level, and its continuation descends to the south, with no additional exit (Ben-Dov, 1986).

A recently initiated study indicates that there are additional chambers of which the explorers of the cave in previous centuries were unaware (Seliger 2007, 2012). It is difficult to determine just how the cave was quarried. The quarriers proceeded from the higher part of the cave (the current entrance) southward (fig. 3) (Avnimelech 1966a, 1966b; Warren, 1884).

The lower part of the cave exhibits traces of stone blocks that were removed from the ceiling of the cave. In other words, in these extensive portions of the cave, it was also quarried from below to above, in addition to the usual extracting of rock from the center to the edges. At the same time, the cave was also deepened. Many stone blocks were removed from the walls of the cave, that at present is four m. high or more, while these walls were patently much lower in the past. The quarriers were careful to leave in the center of the

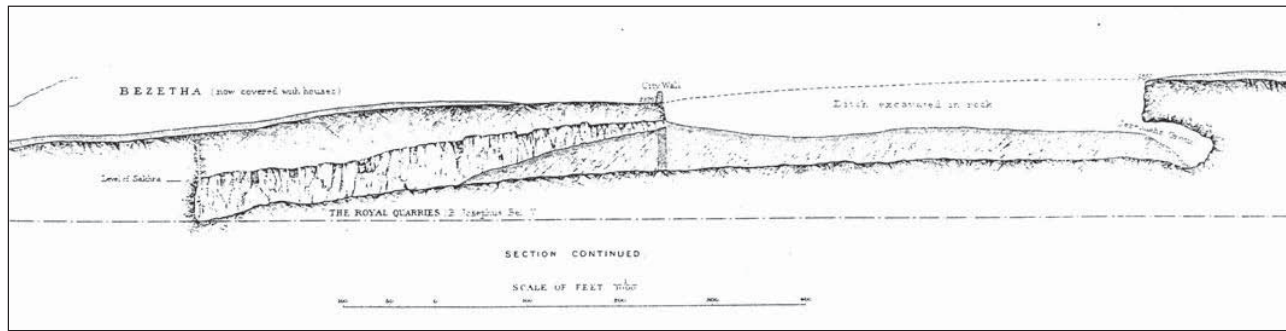


Fig. 3 – Section of the past and present strata of the Cave of Zedekiah and its surroundings (source: Warren, 1884).

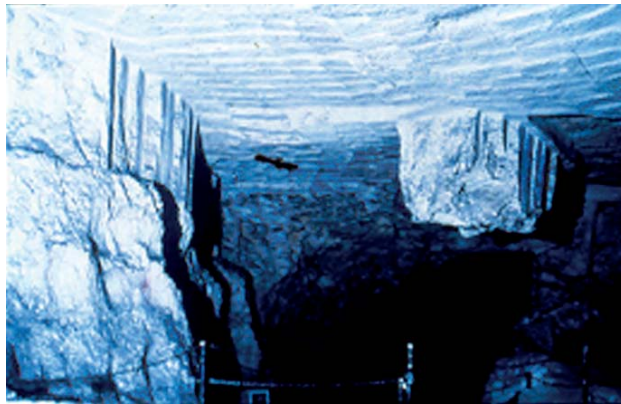
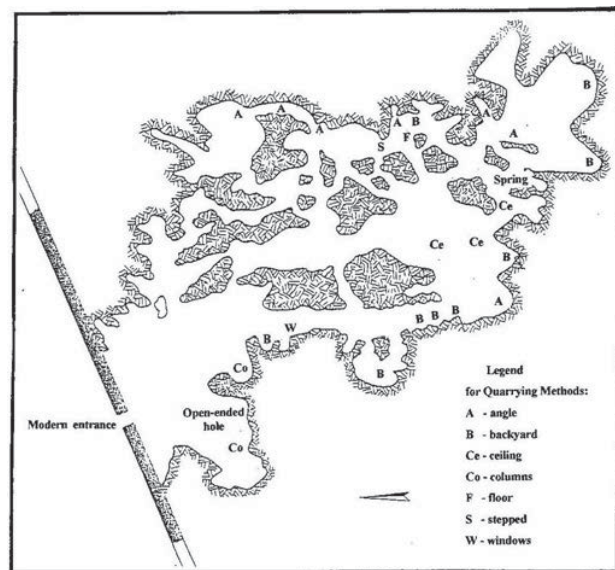


Fig. 4 – Remains of the quarried supporting column in the cave ceiling. To the right of the column: remains of upper quarrying in the ceiling (courtesy of the Israel Antiquities Authority - picture 728321).



Map 2. General plan of the Cave of Zedekiah and the location of the quarrying methods used in it.

Map 2 – General plan of the Cave of Zedekiah and the location of the quarrying methods used in it.

cave large columnlike stone blocks that were meant to support the ceiling and prevent the collapse of the cave (fig. 4).

A number of quarrying methods that were common in ancient technology were employed in the cave (Map 2), along with a number of special methods that were preferred by the quarriers of the Cave of Zedekiah.

“Backyard” Quarrying

This method, that was common throughout Palestine, created “working yards,” a sort of closed or open “backyard,” generally with three rock faces. The “backyard” walls were formed during the process of quarrying, with the rock removed from these faces, as the quarriers dug steps in the. The “backyard” in early quarries was generally square in shape, with the walls at right angles or close to this. The nature of the quarrying in the Cave of Zedekiah, however, was influenced in great measure by the natural infrastructure, karstic erosion, and the rock strata, so that the backyards that were created are not symmetrical and methodical as was the practice in regular quarries (Map 2). The backyards attest in certain measure to the manner in which the work in the cave was organized, for the courtyards were suitable for work by one or two workers in each yard, and even more in some yards.

“Stepped” Quarrying

The most efficient method of quarrying, in terms of the work invested by the individual quarrier, is the “stepped” method. In order to facilitate the process of quarrying and the extraction of the stone from the bedrock, the quarriers made steps, whose size matched that of the stones. This enabled them to reach almost all the corners and faces of the stone being removed. This quarrying method was the most widespread of all the quarrying techniques known, both in Palestine, and throughout the world. This method was employed both in “backyard” and in cave quarries. The steps were made both to provide access to all the corners of

the stone, and to create a working path for the quarriers who were working on a higher level. Additionally, this method enabled several quarriers to work in the same backyard or work area, with each one working on a different level. This method as well was both the result of planning by the quarriers, and a function of the quarrying process itself.

Interestingly, in the Cave of Zedekiah itself, this method was not clearly dominant among the other quarrying methods. In our opinion, this ensues from the advantage offered by the nature of the stratification within the cave, that enabled efficient and maximal quarrying, without leaving the remains generated by the steps. It may be assumed that additional stepped quarries will be located in the lower strata of the cave, that are currently covered by waste, and that are under the *meleke* rock.

Quarrying at an Angle

The most common method in the Cave of Zedekiah is the “angled” method. It is somewhat similar to the “backyard” method but is characterized separately because of its predominance in the cave. In this method, the walls of the small yards were quarried at an angle of approximately 45° from the cave wall, thus creating small and angled yards (fig. 5).

This method provided the quarrier with easy access to all corners of the stone. The cave contains the quarrying angles, sort of quarried columns, measuring 30-50 X 40-50 cm, with the height of the “column” averaging 160-180 cm. This means that the quarriers intended to extract relatively large stone blocks. In some places this sort of column was clearly cut into two or even three stones, and the quarriers intended to divide it into even smaller stones. The angled method was the dominant procedure in the inner section of the cave. We did not find any parallels to this method or reports of it in other Palestine sites; it may have been characteristic of a certain period, but, at present, we do not possess sufficient evidence to draw such a conclusion.

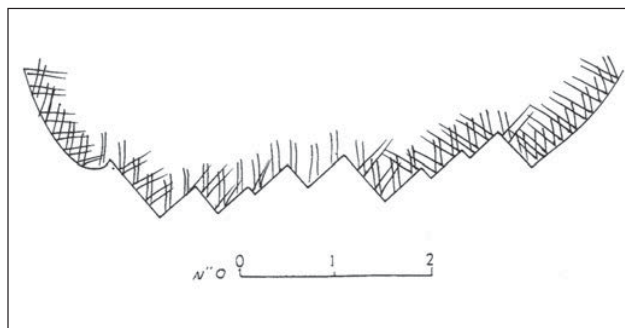


Fig. 5 – Section of a quarrying wall employing the “quarrying at an angle” method.

Quarrying in the Floor

In this method, the stones were dug up from the surface of the bedrock, both in the stage of the opening of the quarry or of the yard, and, frequently, during the leveling of the ground, as preparation for the building of houses. A quarry of this type is of extremely low output, since the number of workers in it is limited, and it is characteristic of areas in which the rock strata are horizontally fractured, thus making possible the speedy quarrying and detachment of the stones. If these quarries did not develop into yards, they would leave hardly any trace.

Traces of this type of quarrying are visible in the floor of the Cave of Zedekiah, mainly in its higher and exposed part.

“Ceiling Quarrying” - Upper Quarrying

The use of this method, that is parallel to floor quarrying, also was spurred by the stratification of the bedrock, since the stratification facilitated the severing and removal of the stone from the ceiling. In upper quarrying, the quarrier follows the natural horizontal fissures in the bedrock ceiling. In the places where the fissure is several centimeters in size, a large iron crowbar is wedged in it, between the rock stratum and the ceiling, and the stone is detached by pulling the bar down. In the places where the fissure is too small, a hammer and chisel are used, to quarry while proceeding upwards (the reverse of the usual direction), in preparation for the final detachment of the stone. This method is not common in open quarries, and was typical mainly of caves, in which the quarrying is done from the low entrance upwards. The infrequent use of this method ensues from the physical difficulty and awkwardness of working in this direction. Traces of this quarrying method are visible in a number of spots in the ceiling of the cave.

“Column” Quarrying

This, too, is a method rare in Palestine, in which the stones are quarried vertically, along the walls of the cave (figs. 6, 7). This method entailed the digging of channels the entire height of the wall, thereby forming between them a sort of series of columns, that usually reached a height of 180 cm., and with an average width of 55 cm. These channels were generally about 10 cm. wide (as was common in ancient quarries - corresponding to the fist of the quarrier), but wider channels, with a maximal width of 25 cm., also were found. We did not find evidence of secondary quarrying to split the stone blocks into smaller pieces, thus leading us to believe that monumental stones were quarried here, for use in a structure constructed of stones the length of the “column” height.



Fig. 6 – Remains of the column method of quarrying (photograph: Avraham Sasson; photograph 20/304).

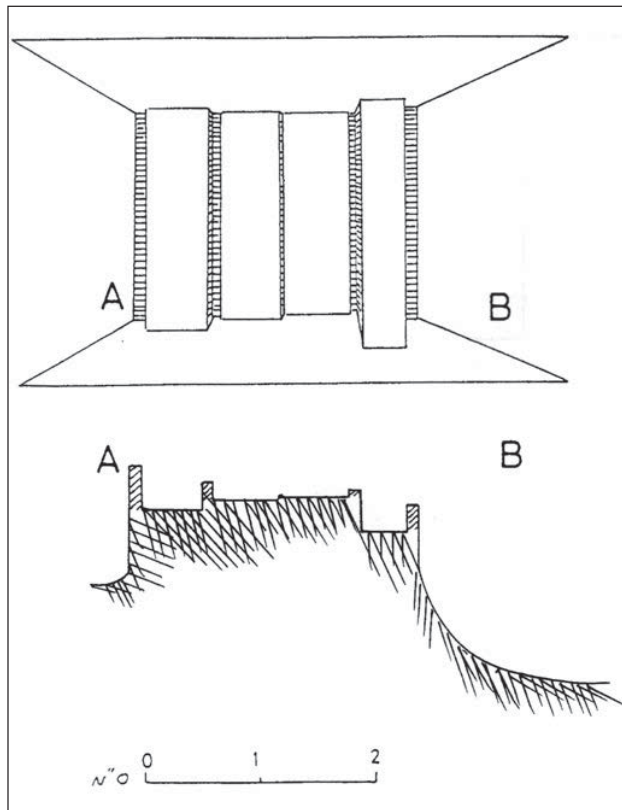


Fig. 7 – Facade and section of a quarry face using the “column” method.

Until now, scholarly research contains no reports of the use of this method in Palestine, possibly because the researchers did not pay attention to this detail, or because it did not in fact exist. This method made partial use of the natural lengthwise fissures in the cave, that facilitated the work of the quarriers, as we have also seen regarding the other methods employed in the cave.

It should be noted that this method does not relate to the cut columns remaining in the cave, that were left by the quarriers to support the roof and prevent its collapse. These columns are part of the adjoining quarrying, with each column intended to support the cave in each of the areas using different quarrying method.

The “Windows” Method

This method as well is unknown in the scholarly literature, and it, too, most probably made use of natural fissures in the bedrock. In this method, stones, generally square in shape, were extracted from the wall of the cave in a process that created a niche in the wall (fig. 8), thus forming a sort of alcove or blocked window in the quarry wall (fig. 9). These typically measured some 100 X 70 cm. The final thickness of the stones has not been determined, but it did not exceed 20 cm., because this method was not suited for the extraction of large stones.



Fig. 8 – Facade and section of a quarry face using the “windows” method.

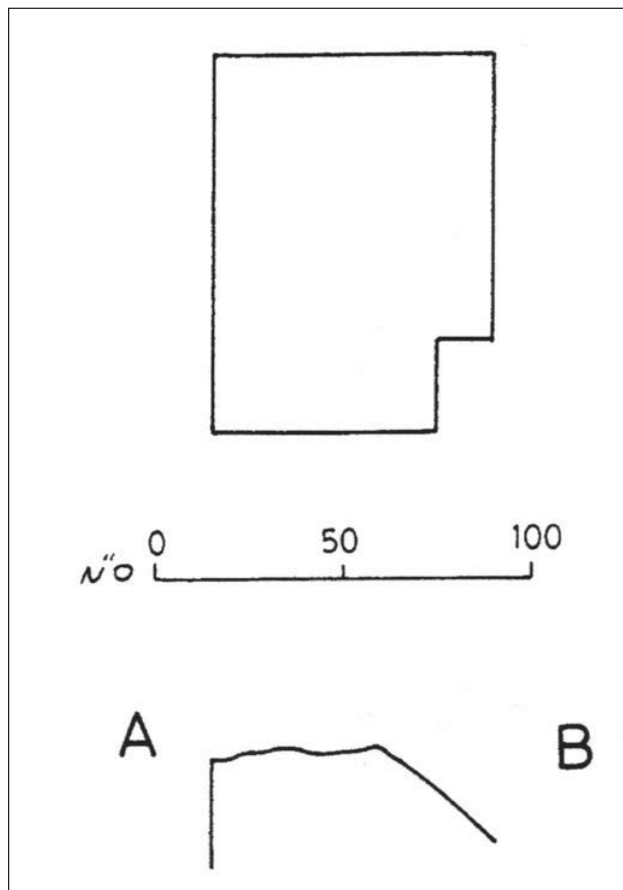


Fig. 9 – Remains of “window” quarrying in the cave wall (photograph: Avraham Sasson).

Were Stones Removed with Wet Wooden Beams?

Several scholars who examined quarrying technology mentioned an additional method for removing stones from the bedrock, in which wooden wedges were inserted in the rock. These wedges were moistened,

leading them to swell, thus bursting the rock. This method was probably used in European quarries, and possibly also in the East in the nineteenth century (Avitsur, 1976; Durkin and Lister, 1983).

Many other scholars, however, oppose this interpretation (thus, e.g. Roeder, 1965).

In her description of this method, Dworakowska showed that large cylindrical holes were cut in the rock, into which the wooden beams were inserted. The circular shape was necessary in order to split the rock in a more or less straight fashion. The moistening process, under European conditions (Austria-Germany), took at least twelve hours. Dworakowska is of the opinion that this method was not used in antiquity (Dworakowska, 1987).

There is no evidence in all the quarries of round holes, but only of the small trapezoidal holes characteristic of iron wedges. The method of wet wood splints should have left traces of the wedge tracks in the bedrock that remained after the removal of the quarried stone, or, alternately, the use of these wedges will leave behind split and torn rock, but there is no evidence of this. The literary sources frequently mention the iron wedges, traces of which were discovered in excavations, while the sources are silent regarding their wooden counterparts.

Material from Palestine confirms Dworakowska's conclusions. Quarries in Israel contain no evidence of the use of wood beams. The stone remaining after the removal of the rocks in the dozens of quarries that were examined is almost straight and is suitable for the quarrying of additional stones. Furthermore, the bore holes for wedges that were found (see above) indicate a series of closely-spaced wedges. These holes sufficed to split the rock, with no need for the wetting method. Consequently, this method was not used in Palestine. One possible reason for the disregard of this method may have been its lack of precision and its relative slowness. It was suited, at best, for the detachment from the bedrock of large stone blocks, from which the stones used in construction would then be cut. As we have seen, however, and as the stepped quarries attest, the quarriers were accustomed to cut the small stones directly from the bedrock, thereby canceling any advantage to be gained by the detaching and removal of a large stone block directly from the earth. This is especially so since the climatic conditions of Palestine militate against the use of the tremendous quantities of water required by this method, although some scholars suggested the use of such a technique in this land (Ben-Dov, 1986; Magen and Dadon, 1999; Amiran, 1951; Ritmeyer, 1989).

Our proposal regarding the method of quarrying, however, seems to be more accepted in current scholarly thought (Shiloh and Hurwitz, 1975).

It was also suggested that the wide quarrying channels in the Cave of Zedekiah resulted from the use of moistened wooden wedges, a theory advanced, for example, by Wilson (Wilson, 1880) and in the reconstruction by those initiating the “History of Stone Museum in the Cave of Zedekiah” (Ariel, 1986).

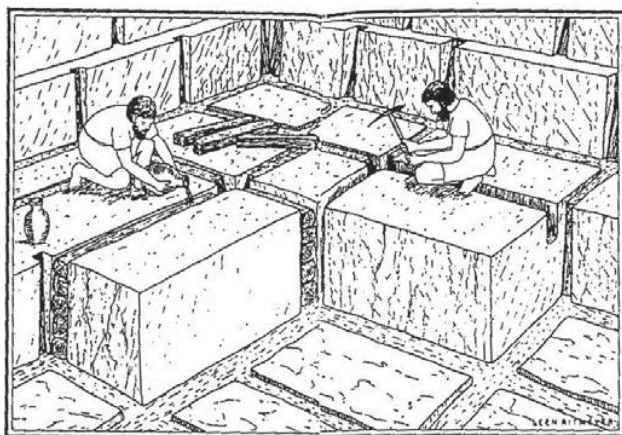


Fig. 10 – Reconstruction of work in the quarry and the detachment of stone with wooden wedges (source: Ritmeyer, 1989).

Work Tools Used by the Quarriers

Quarrying tools

The testimonies to the quarrying tools have survived in the form of the grooves and the bore holes in the cave walls. The tools used in the quarrying operations in the cave generally resembled those known to us from the historical sources and the archaeological testimonies. We will not discuss this issue at length, but we will describe a number of tools that left distinct traces in the walls of the cave (fig. 10).

Marks were left by two chisels, one narrow (2-3 cm. in width), and the other 5-6 cm. wide. Most of the quarrying channels were made with these chisels. At the same time, use was made of a quarrying axe, that leaves circular quarrying marks characteristic of one who quarries while standing, swinging an axe at arm's length. A few traces of drill bits were discovered.

The Moving of the Stone within the Cave

A number of open-ended holes and rock-cut stone rings were discerned to the right of the cave entrance, that were used for hitching animals, or to anchor ropes in the cave roof. This may have been the central point from where the stones were transported, and a base for a system of ropes used to lift the stones, an apparatus that is known from other locations throughout the world. Here the quarriers might have also loaded and unloaded other burdens possibly connected with the cave's functioning in the Ottoman period as a storehouse. It is noteworthy that rings of this type have not yet been found in the lower part of the cave.

There are no testimonies regarding the method for moving the stones within the cave. From our knowledge of other sites, we may assume that there were paths on which the stones were dragged, using the moving techniques common in that period.

Quarrying within a Cave - Advantages and Disadvantages

Advantages

We know of many cave quarries in Palestine, the largest of which is the Cave of Zedekiah. Quarrying within a cave possessed a number of advantages, along with economic considerations for this type of quarrying:

1. the utilization of geological strata: as we have seen, the horizontal geological stratification is extremely clear and pronounced. The horizontal fissuring between the strata makes stone removal easier for the quarriers. At times large stone slabs would be quarried, from which smaller stones would then be cut and dressed on the floor of the cave. In this method, the dressing phase requires less work and time, since the natural stratification provides the initial dressing. Making use of the geological strata enables a better classification of the types of stones in accordance with building type. Thus, it was possible to set aside the *meleke* stones for Jerusalem's public structures.
2. Similar to their utilization of the horizontal strata, the quarriers also made use of the lengthwise fissures that were formed by karstic activity. These fissures led to the development of a quarrying method that is unique among all the techniques known to us, that of "columns", that is, vertical quarrying.
3. Quarrying into the cave does not harm agricultural areas or those earmarked for construction, since it penetrates under the rock strata on which a settlement is built.
4. The relatively high humidity within the cave softens the bedrock to a certain degree, thus facilitating the quarrying and the detachment of the stone.
5. From the perspective of the quarriers, the climatic conditions and the shade provided by the cave created more congenial basic working conditions, including the ability to work on rainy days, that was not possible in open quarries.

Disadvantages

1. The transport of the stone was one of the factors influencing the choice of quarry locations, and as a general rule their opening was based primarily on this consideration. Accordingly, many quarries are built close to roads. Large quarries were usually dug above the construction site, with the stones rolled down in various manners. The Cave of Zedekiah was inferior from these two aspects, because the stone was quarried in a relatively low location, that required it to be lifted from the bottom of the cave to ground level, and then transported to the construction site.
2. In light both of the above and of additional technical drawbacks, the stones extracted from the cave were not among the large stones known to us from Jerusalem, such as the stones of the Western Wall, but were building stones of medium size.
3. The work in the cave was convenient from the cli-

matic aspect, but required the intensive use of artificial lighting, a need that did not exist in open quarries. A number of niches for oil-lamps were

found in the cave, but the economic significance and extent of the use of oil has not yet been examined.

Acknowledgments

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This work had its beginnings in a joint study that I conducted with Prof. Zeev Safrai, *Quarrying and Quarriers in the Land of Israel* (Hebrew; Elkana, 2001). Parallel to our work, the Israel Antiquities Authority has begun an archaeological study of the cave, under the direction of J. Zeligman. His excavations are as yet unpublished; my thanks to him for his cooperation and for the initial information and photographs that he made available to me.

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