

TECHNICAL ISSUES OF EXPLOITATION OF MARBLE USED IN THE ANCIENT TIMES AND NOWADAYS IN QUARRIES OF ISCEHISAR IN THE MASSIF OF AFYON

Michał Ruskowski

Instytut Geochemii
Mineralogii i Petrologii, Wydział Geologii
Uniwersytet Warszawski
ul. Żwirki i Wigury 93
02-089 Warszawa
e-mail: ruszkowskimichal@wp.pl

Abstract: The purpose of this paper is to present the technical issues related to mining and quarrying of marble in Iscehisar quarris in Asia Minor.

Keywords: technology of exploitation, quarries, marble, monolith, saw rope, Iscehisar quarries.

Introduction

In antiquity understanding of the term "marble" was much more extensive and much less accurate than today. The name of "marbles" includes all decorative stones that can be polished. The Romans used the same name for all beautiful and hard rocks that could be used as a sculpting material or as a material for representative architecture.

"The first complete structures of marble appeared in the 6th century BC in the Cyclades and very quickly became a tradition on the Ionian coast, where Greek marble architecture obtained monolithic and megalithic character" [3] However, "the first marble floors appeared in the Greek Bronze Age (1600-1000 BC)" [2].

It should be noted that marble in the Roman civilization was not used as a construction material, as in Greece and Egypt. For centuries the dominant marbles on the Apennine peninsula were marbles from Luni and later during the reign of Domitian and Trajan their place, took marbles from Prokonez and Attic. After winning the Punic Wars Roman Republic became the dominant country in the Mediterranean. This situation triggered an intensive trade in luxury goods. Then the marbles acquired the status of luxury goods. In the final republican period, marbles permanently become synonymous with wealth, and wealth is power.

Marbles from the province of "Asia" in Asia Minor especially marbles called "pavonazetto" from Phrygian region were highly respected and very popular in ancient times. According to the contemporary standards they belonged to very expensive building materials. They served mainly for rimmed colourful architecture during the Roman Empire and later in Byzantine period.

Already in ancient times, these rocks were often mentioned in the literature, legal and trade documents.

Starting from Strabon in the 1st century BC to Paulus Sientius in the 5th century A.D. The first public use of these marbles in Rome was recorded in the Forum of Augustus. After Strabo this marbles were called "Roman rocks from Synada." In Asia Minor they were called Dokimia or Docimium (today, Iscehisar in Turkey).

Many varieties of marble were and still are mined in the quarries of Dokimeion. Each variety has its own literary name or trade name in ancient or Turkish origin.:

- "Pavonazetto" - "breccia marble" of the breccia structure with purple or gray-purple binder, and white clasts;
- "Gri" - "breccia marble" of blue-gray binder and white clasts;
- "Beyaz" - milky white marble, slightly marked up with yellow veins;
- "Seker" - yellow-white marble with thick clusters of yellow veins;
- "Sari demarki" - yellow-white marble.

In the Greek and Roman cities, marbles were used primarily in monumental constructions, usable small architecture, as well as in sacred and sepulchral structures. The greatest quantity of marbles were used as a flooring material, as well as sculpture. Pure white marble in the construction industry has been a feature less favourable, because in the midday sun offended eyes and needed to be cleaned.

Description issues

The issue of the mining process

The above-described quarries are example of the excavation pit mining classified as, mining of dimensional stone. The term, dimensional stone mining, means that the rock material is extracted in the form of

block-monoliths and then cut into blocks according to demand.

Today we evaluate rocks according to the following criteria: color, strength, homogeneity, durability, number of cracks and blemishes.

In the ancient times, there were no modern achievements of science and technology. People had to do the work with their own efforts often supporting it by own ingenuity. It is commonly believed that in the antiquity only simple tools and technical solutions were used. However, when we look at the achievements of ancient civilizations we begin to doubt in this usual superstition.

Starting discussion on this issue, we should consider what problems antique miners encountered during the start of operation and later during its gradual development. The first and fundamental was finding and recognizing rocks having qualities for architecture and construction purposes, in line with the prevailing architectural style. These process was long and multigenerational, limited by lack of good roads and communication. Civilizations such as the Roman and Byzantine benefit from the knowledge and findings of earlier civilizations (Fig. 1).



Fig. 1. Antique searching trench (own source).

Not once mining was resumed in the areas where it was already abandoned. Such situation occurred in a number of quarries in Asia Minor. However, no precise information has remained about the history before the Roman quarries in such quarries as those in Iscehisar in the massif of Afyon. We know many examples of sculptures and stelae from the period of classical Greek culture, made of marble from the Dokimeia quarry. However, we do not know anything about the exact location of their production. Modern instrumental methods, like isotopic methods, allow for positioning Greek excavations in the modern area of mining. Unfortunately, it is not possible to show their exact location.

Another task before starting production is to organize the miners, workers, technical and mining facilities. We must also remember about roads for import of supplies for people working in the quarries and roads of rocks export. All these problems escalate with increasing of production. According to the mining rule: "The more you bring out, the more people you need." This principle made Romans think also about financial aspect of the entire project. To reduce costs creativity and ingenuity are required. In the examined quarries lot of manual

work was replaced by work of animals and by machines. Traces of such actions are clearly visible in the quarries of Iscehisar.

Mining techniques

Today in surface mining of dimensional stone, modern tools and machinery are widely used. In ancient times, with increasing technical thought, manual work was replaced with innovative mechanical solutions.

The basic and fully manual method is a "wedge method". This method in different variants is well known to mankind throughout the world for over 5,000 years. Hammers and a set of wedges are essential tools for this method. A very accurate diagnosis of natural rocks planes of weakness, cracks and porosity is the key to work with this method. Then we use this knowledge to raise the blocks. Working procedure is very intuitive, it is simply placing the wedges in fracture lines. It is important to wedge simultaneously from quarry wall at least two surfaces and the base of the block. If there is no natural fissures one follows the gap with the help of cutting tools such as picks (Fig. 2).

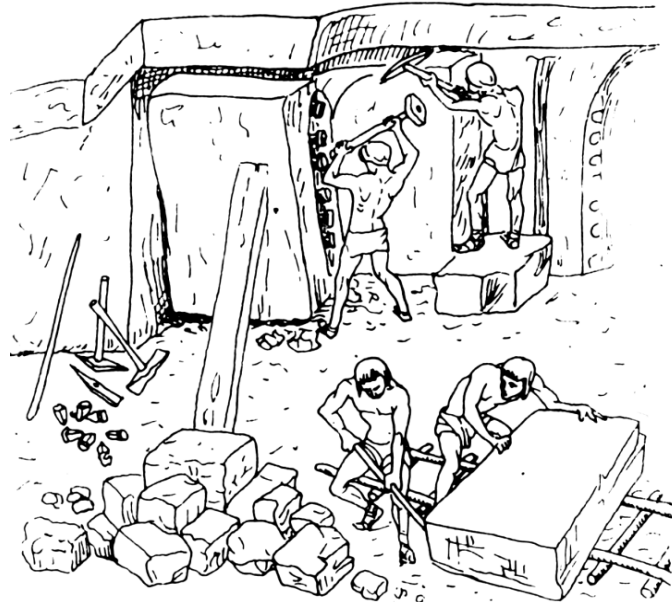


Fig. 2. Antique mining operations [4].

Currently, as a result of continued growth of mining in the area of Afyon crafts they were completely replaced with fully mechanical techniques. For example, the work so far carried out using a pickaxe, was replaced by drilling perforation holes. This method is widely used around the world since the beginning of nineteenth century. It is a proven technology, but labor-intensive. This method involves drilling a dense grid of holes along a specified line of a block. A dense grid of holes makes the rock weak. It begins to crack under its own weight by stress distribution along the dividing line.

After disconnecting the first blocks, there is a problem of the number of natural cracks. This problem was present in ancient times and is present today. In analyzing this issue, we come to the conclusion that it is necessary to

plan the order of breakout. Without first defining plan we lose facilitating work gaps very quickly. Construction of artificial discontinuities in the rock is time consuming and expensive. Planned economy used in the area of Iscehisar today eliminates this problem by using solutions such as a saw rope and chain saws (Fig.3). These machines makes formatting blocks easy, and their detachment does not pose a big problems. The Afyon region is known as one of the most important marble production and processing centres in Turkey. "The Afyon province, which possesses 3.5% of exploitable marble reserves (3,872,000,000 tonne) in Turkey, yields 9% of the total marble block production. The 409 marble processing plants in Afyon produce 19% of the total slab in Turkey" [1].



Fig. 3. Saw rope cutting process (own source).

In the period when the Roman quarries in Iscehisar reached its maximum size, they faced the problem described above. This area has a rich network of weathering and tectonic cracks associated with

geological structure of the massif to a depth of 8 m. Below this zones there is another one reaching a depth of 25-30 m below the surface which includes the fractures related to hydrothermal veins (Fig. 4).



Fig. 4. Wall of abandoned quarry. In the upper part there are visible traces of ancient mining. In the lower part there are visible traces of contemporary works (own source).

Conclusions

Observation of the geology within rock mass required considerable knowledge about earth sciences. Such knowledge at that time was only available for top class specialists. It also demonstrates that best specialists worked in the quarries. Traces of mining are preserved on many quarry walls (Fig. 5).

They allow to describe the techniques used during the Roman period and probably also in the Byzantine. There are no methods of dating of traces. Nores left behind by miners in pits or carved in the blocks, which could not be transported out of quarry can be helpful (Fig. 6).

So-called caving arcs are the clearest traces left behind by the miners. They are remains of the operation in mining zones. The arcuate shape served two functions. Like indentation in the felling of trees such chiselling resulted in a controlled direction tear of monolith rock. To break the monolith, slanting chiselling is made and it forms a trench below the block. Depending on the required size of the block or monolith deep chiselling of natural shallow tunnels is carried out. This allowed for

directional separation of block and made it easier for further processing. This method was very common in this area (Fig. 7).

After separation miners gave shape to the desired portion of the rock allowing for transport. Unfortunately, clear traces of this type of construction have not survived in the area of Iscehisar. This method was widely used in Roman times. Today, this process is carried out by small systems of wire saws. They allow to trim the blocks to tonnage allowing for transport by loaders and dumpers. In antiquity a similar way to transport the excavated rock was framing columns or cylinders (Fig. 6). After forming they were equipped with transport wheels or suspended specially adapted heavy wagons. Then they were exported from quarries onto a special ramp. Both solutions are very large and require large amounts of workers and draft animals. According to various sources, describing numerous quarries of this size in Italy and in the Iberian Peninsula, there could have been up to several thousand people working in such great mining areas.



Fig. 5. Ancient pit wall with visible traces of pickaxes (own source).



Fig. 6. Heap of ancient blocks and columns in the modern quarry (own source).



Fig. 7. The remains of carving arc (own source).

The way of export of these beautiful marbles began in quarries in Dokimia from where they were transported to a local administrative center in Synada (today Suhut). Synada lies about 40 km from quarries in Dokimia. In this city there were the main warehouses of architectural and artistic products, it also served as the head office. From here the products were sent as ready-made

elements in further multi-stage long way. The next stage of transportation was Apamea (now Dinar), then navigable part of the river Meander and from there they were transported to the coast. In port cities at the mouth of the river, such as Miletus, Priene and Myusa stone blocks were reloaded on ships and were exported to the farthest corners of the Empire.

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