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# Raw materials used for the millstones production in ancient Greece: Examples from Macedonia and Thrace

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## Abstract

Millstones were water powered, horizontal or vertical wheeled, since the 1st century BC, according to written documents. The raw materials used in ancient Greece for manufacturing millstones since the Prehistoric times, were very restricted, mainly sandstones and volcanic or pyroclastic rocks. The sources of the raw materials for the millstones in Greece varied throughout the times depending on the quality and suitability of the rocks. The Aegean islands Milos, Kimolos, Polyaiagos, Santorini, Nisyros, Skyros, Aigina, Limnos, Mytilini, and other areas such as Poros and Methoni in Peloponnesos were some of the provenance locations where the millstones were quarried and exported in other areas. In Macedonia and Thrace the main raw materials were from local sources in the beginning, during the Prehistoric times. Later, a more intense production of millstones started in various areas depending on the rock type of the raw materials. Representative examples for millstones made of sandstones are found in Chalkidiki and in Kariani of Kavala and of volcanic rocks in Petrota of Rhodopi and in Aloros of Almopia.

**Keywords:** mineralogy; NE Greece; sandstone; quarrying; volcanic rock; watermill.

## Introduction

Millstones are the heavy flat disc-shaped stones and constitute the best part of mills of any kind, animal or much later water powered, horizontal or vertical wheeled. That's why a great number of them have been found at excavated mill sites. Unfortunately, their importance in the mill mechanism is not usually appreciated by the excavators, maybe because they don't leave palpable traces in the earth and are harvested as movable archaeological finds. However, the fact is that millstones abound both as archaeological finds and in written sources.

In the ancient Greek literature there are several references about the importance of the millstones in antiquity. During Homer's times (8<sup>th</sup> century BC) the millstones were

operating manually for the flour production and were called “myli”, which means quern. The wheat seeds for the flour production were processed exclusively by women. Homer describes this process in *Odyssey*, at the Palace of King Alkinoos of the Phaeacians, where “fifty maid servants, some of whom are always grinding rich yellow grain at the hand mill” (Homer, *Odyssey*, H 103-104). This use of hand mills by women is also confirmed by the description of the palace of Odysseus in Ithaca, where “twelve miller-women whose business was to grind wheat and barley” (Homer, *Odyssey*, Y 106-107).

Later, during the 4<sup>th</sup> cent BC, Aristotle referred to the millstones, the “mylies”, which were “insoluble” and were made by “burnt earth” (Aristotle, *Meteorology*, D 12-13). Aristotle with this description probably meant the volcanic rocks. This is the first piece of information confirmed also by archaeological findings, that the raw materials for the millstones were the volcanic rocks. The volcanic origin of the millstones was also mentioned by Theophrastus (4<sup>th</sup> century BC) who described the Sicilian lava which was black in color and “its density and weight resembles a millstone” (Theophrastus, *About Stones*, 22).

In the description of Nisyros island, Strabo (1<sup>st</sup> century BC) mentioned that the island consisted of rocks used for the manufacture of millstones, implying their volcanic origin, and he called them “mylios stones” (Strabo, *Geography*, 10.16). Strabo also mentioned a millstone quarry at Cape Melaina in Minor Asia, at the coast, opposite of Chios Island, in Aegean (Strabo, *Geography*, 14.33).

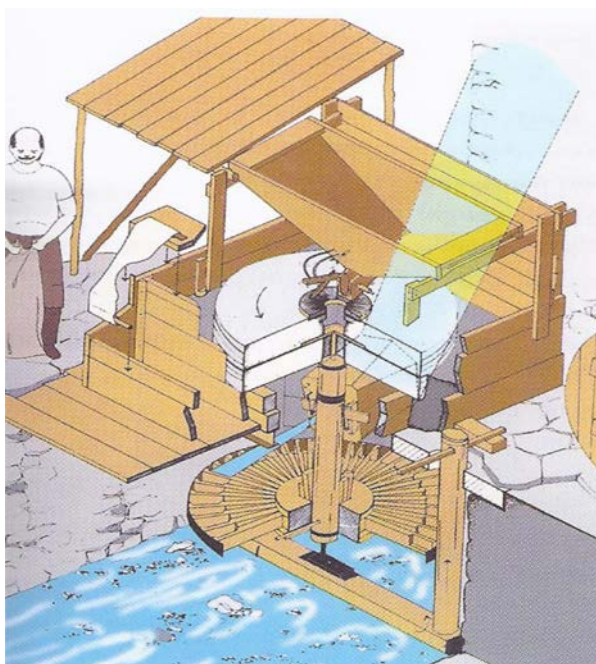
Much later, in the 6<sup>th</sup> century AD, at the time of Justinian, Procopius, a prominent Byzantine scholar, when referred to the millstones (“mylitis stones” or “milios stones”) he meant the hard volcanic rocks that were used at that time as building materials for the various constructions, such as walls and towers. Procopius characterized these stones as very rough like the millstones (Procopius, *On Buildings*).

Around the 1<sup>st</sup> century BC, the muscular power of man and animals for the rotation of the millstones was replaced by the energy of water and the first watermills were constructed in that time. This innovation allowed the grinding of bigger quantities of wheat seeds, so to cover the needs of the developing urban centers. Strabo (64 BC to 19 AD) was the first writer who mentioned the mills with water as motive power and he called them “ydraletas”. He supported that the older watermill belonged to the King Mithridates of Pontus (132-63 BC). According to some researchers (Vallianos 1997), the mathematician, physicist and engineer Heron of Alexandria (1<sup>st</sup> cent BC), Director of the Alexandrian Library, was the inventor of the watermill, although there are not any ancient references to confirm this suggestion. The watermill was adopted by the Romans and was widely spread in the Byzantine Empire and during the Middle Ages, in both main types, according to the position of the water wheel, vertical which requires a right angle gear, and horizontal, in which the rotating millstones were attached directly to the same axis (Forbes 1956, Wikander 1985, 1991, Castella et. al 1994).

Its use continued until recent times and disappeared sporadically after the 1950’s. Vertical wheeled water mills have been also described by Vitruvius, from 40/10 BC (Vitruvius, *De Architectura* X, 5.2), who makes a brief reference to the pair of millstones rotated one against the other, using the word “mola” in plural, “molarum circinationem”. At

the same time, in a poem by Antipater in Thessaloniki, of about 20 BC/10 AC, the word “mylax” was used, again in plural number, “mylakon”, describing the big and circular porous stones from Nisyros, powered by the running water through vertical and horizontal drums (Greek Anthology 9.418).

The millstones used in the watermills were larger in size compared with the manual millstones, and they consisted by two round stone slabs, a bed stone and an upper one, operating as runner, both rotating around an axis (Fig. 1). The diameter of the majority of powered stones ranged between 0.55 and 0.85 m. None of them seems to be smaller than 0.48 m or larger than 1.09 m (Wikander 1985, 2000, Castella 1994). The raw materials used for the millstones during the antiquity were very critical and it was an issue that the ancient authors were concerned about. This is because the millstones were curved on hard, porous varieties of volcanic stones, with specific characteristics and geotechnical features and their sources were relatively limited around Aegean.



**Figure 1** Reconstruction of horizontal wheelled mill (Zarkia et al. 1997).

This paper describes the rocks which were mainly used for the manufacture of millstones during the antiquity, providing information about their textures and mineralogical composition. We focus on the provenance of the rocks at various areas of Macedonia and Thrace. The aim of this work is to start collecting information and data about the quarrying sites for the raw materials of the millstones and to contribute in the discussion about the production, the trade, the transportation and the use of specific rocks in various archaeological sites in Greece and around Aegean sea.

## Raw materials for the manufacture of millstones

The raw materials used in ancient Greece for manufacturing millstones since the Prehistoric times, were very restricted, mainly sandstones and volcanic or pyroclastic rocks (Fig. 2 a,b). This exclusive selection and use of special types of rocks shows a good correlation between the raw materials and the manufacture of grinding tools. The most important characteristic of these rocks was related with the processed energetic surface of the stone which had to be rough, hard and granular, so as to ensure the appropriate results of grinding, without any damage during the use, to prevent mixing of stone slices with the flour. Consequently the prehistoric people had an excellent knowledge of the natural resources and they used the available raw materials for specific purposes.

Therefore, the experience of thousands of years, since the Neolithic times, showed that the most appropriate rocks were the sandstones and the volcanic and pyroclastics rocks (Runnels 1985, Williams-Thorpe and Thorpe 1990, 1993, Oliva et al. 1999, Melfos and Stratouli 2002, Stroulia 2003, Bekiaris 2007). Sandstone is a sedimentary rock composed of clastic grains of quartz, feldspar, calcite or mica. It is a cohesive sand with grain size <2 mm which had been compacted during diagenesis. Its texture is coarse and granular. The clastic grains can be either rounded or angular and they are respectively called conglomerates or breccias. The conglomerates were unsuitable for grinding and therefore not used in the manufacture of millstones. In contrast the sandstones with angular grains were the most proper materials because they contain quartz, a hard mineral (7 in the Mohs scale) with a hard resistance during grinding.

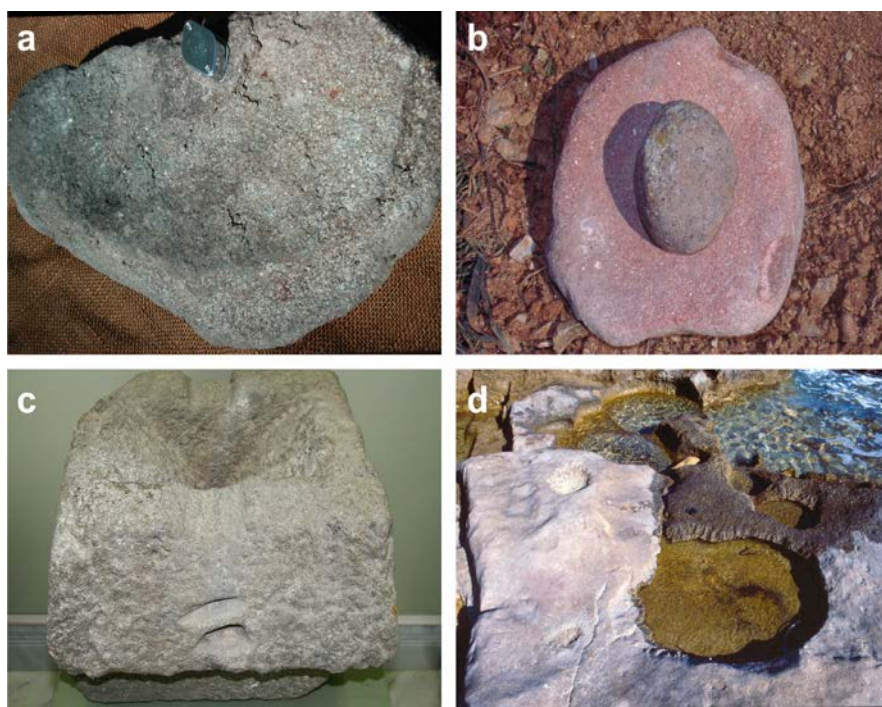
The volcanic rocks are formed from lavas which are magmas flowing at the earth's surface. The lavas are initially in fluid phase and gradually cool to form various hard rocks, which depending on their chemical composition are divided in rhyolites, andesites, trachytes, dacites and basalts. The volcanic rocks consist of the phenocrysts, such as quartz, feldspar, plagioclase and hornblende and of the groundmass, which is volcanic glass. At the millstones the glass provokes grinding, because it is tough and resistant. Often, the lavas have a scoria and porous texture due to the entrapped gas vesicles. This feature is an advantage for volcanic millstones, since they are lighter than other rocks of similar size and volume and so much easier to manage them during grinding.

The pyroclastic rocks or volcanic tuffs are formed from the solid materials (ash, dust, stones, lava) exploded during a volcanic eruption and then are deposited in sedimentary sequences. Over time these materials form compact rock units due to the diagenesis and the action of the circulating hydrothermal fluids. The large lava slabs found in the pyroclastic rocks are called volcanic bombs. In some cases, considerable volumes of these volcanic bombs can roll over a long distance around a volcano, drifted by mud-streams, which usually accompany large volcanic eruptions.

In addition to these main rock types, some other rocks were used in antiquity for the millstone manufacture, but in a lesser extent. These rocks, such as granites, limestones and metamorphic rocks share common characteristics, including large hardness and abrasion resistance.

The extraction of the millstones took place in open quarries and rarely in underground galleries. The extracted rock should be compact, unaltered, with no internal

imperfections, discontinuities or cracks. The ancient Greeks had developed simple techniques for extracting rock blocks influenced by the geological and structural features of the rock, such as fissures and cracks (Orlandos 1958, Dworakowska 1975, Koželj 1988, Korres 2000, Melfos 2008). The stones were quarried in large massive slabs and monoliths. Firstly, the quarrymen cut a bench of the length and the width required for the blocks. They disengaged the blocks from the rock mass by digging a channel 20 to 30 cm wide, around the rock slab. Then they chiseled small cavities at the bottom of the blocks, 10 to 15 cm long, and put wedges in the cavities and by hammering them they split off the rock slabs. In many cases, where vertical natural cracks and discontinuities existed, the stone cutters were used them as guides for easier extraction.



**Figure 2** a. Neolithic millstone made of sandstone, Ionian islands, western Greece; b. Neolithic millstone made of pyroclastic rock, Thrace, NE Greece; c. Ancient millstone made of trachyte, Milos island; d. Ancient millstone quarry in sandstone, Skyros island.

## Provenance of raw materials for millstones in Macedonia and Thrace

The sources of the raw materials for the millstones in Greece varied throughout the times depending on the quality and suitability of the rocks. The Aegean islands Milos, Kimolos, Polyaiagos, Santorini, Nisyros, Skyros, Aigina, Limnos, Mytilini (Fig. 2 c,d), and other areas such as Poros and Methoni in Peloponnesos were some of the provenance locations where the millstones were quarried and exported in other areas. The millstones from Milos and

Kimolos were of excellent quality, and so the most expensive, according to the Venetian cartographer and writer Marino Sanudo the Elder, in 1321 (Vaos and Nomikos 1993). Milos was the place of origin for a large number of millstones during the post-byzantine period, in all over Greece. However in some areas, such as Epirus, where the rocks were considered as appropriate, those were the raw materials for millstones in the surrounding area.

In the beginning, during the Prehistoric times in Macedonia and Thrace, the main raw material for the grinding stones was hard sandstones collected from the river alluvial sediments as pebbles around the prehistoric settlements (Bekiaris 2007). Only rarely in the volcanogenic areas the millstones were made of volcanic rocks (Runnels 1985, Williams-Thorpe and Thorpe 1993). According to Touloumis (2002) the majority of the millstones found in the prehistoric lakeside settlement of Dispilio in Kastoria (North Greece) consist of sandstones. Melfos and Startouli (2002) suggested that that the grinding stones of Dispilio made of sandstones originated from the adjacent Aliakmon river, based on the mineralogical study. The mineral composition (Fig. 3a) of both, the archaeological millstones and the river pebbles consist mainly of quartz, calcite, potassium feldspar, muscovite, biotite altered in chlorite and plagioclase altered in sericite, and the groundmass comprises calcite and iron oxides.

Flattened sandstone pebbles had been also used as grinding stones in the Neolithic settlement of Makri in Evros region of Thrace, after being chiseled and treated properly (Melfos et al. 2001, Bekiaris 2007). The raw materials were from local sources. The mineral composition of the majority of the millstones consists of quartz, microcline, calcite, muscovite, potassium feldspar, plagioclase and fossils. The groundmass comprises calcite and iron oxides.

The use of rotary millstone for the watermills started most probably during the 1<sup>st</sup> century BC. The raw materials did not change and therefore sandstones were also used for the manufacture of the millstones of rotary motion in Macedonia and Thrace. For this reason, solid blocks of suitable sedimentary rocks were quarried in different areas. According to Papagelos (1994) quarrying sites of circular sandstone millstones are found along the coasts of Chalkidiki, in Athytos, Mendi, Nikiti, Nea Roda and elsewhere. The quarrying process dates back in the 17<sup>th</sup>-18<sup>th</sup> century or even later. In addition, in Kariani of Kavala along the coastline of Northern Aegean, traces of millstones extraction are still observed in the sandstones of the area.

The millstones were made on monolithic stones, carefully selected in the quarries. The monolithic large millstones were rare and difficult to transport over long distances, due to the risk of breaking. Therefore in many cases the millstones were manufactured by gathering small pieces, rectangular or wedge shaped, and tied together with metal hoops.

As we mentioned before, the volcanic rocks constituted an excellent raw material for the construction of millstones. Volcanic rocks are not so common and are only found scattered in various locations in Thrace, such as in Ferres-Dadia, in Sapes-Kirki-Aisymi, in Petrota-Askites, in Samothrace island, in Kotani-Kalotyxo, as well in eastern Macedonia, at Dipotama-Kotyli and in Zarkadenia. The age of these rocks is about 33 to 19 My (Oligocene to Late Miocene). Later volcanic formations, more recent, with ages between 5



and 2 My (Pliocene-Pleistocene) are found in the region of Almopia of Pella and in Pontokerasia of Kilkis, in Central Macedonia. All these regions comprise potential sites for quarrying and extraction sites of millstones since antiquity, and our research has revealed many new quarrying works.

An important millstone quarrying site in Thrace is found at the village of Petrota, Rhodopi Prefecture, at the foots of the Agios Georgios hill (Fig. 3b). The area is located close to the coastline of the Thracian sea, in northern Aegean, and not far from the routes connecting West (Thessaloniki, Xanthi, Komotini) with the East (Alexandroupolis, Adrianopolis-Edirne, Constantinopolis). One of these routes were the Roman via Egnatia. Thus, Petrota was a location from which the transportation of the quarried millstones was easy, either through the terrestrial roads or from the sea.

The whole area is located on the eastern margin of the north-south trending Petrota graben, which represents a tectonic depression within the low-grade metamorphic rocks of Mesozoic age that belong to the Circum-Rhodope belt. The Petrota graben is covered mainly by calc-alkaline and shoshonitic volcanic rocks (high-K calc-alkaline andesites to dacites, shoshonitic andesites, trachytic lavas, rhyodacitic ignimbrites and rhyolites) formed during Late Eocene to Early Miocene (35-25 My). In the southern part of the area, the andesites are overlain by the Petrota tuffs, which belong to the rhyolitic sequence of the Petrota graben.

Agios Georgios hill consists of pyroclastic rocks and the millstone quarries are found scattered in the area (Kosiaris and Michael 2004). The mineralogical study showed that the rock consists of micro-breccias of rhyolitic composition with angular rock-pieces and quartz pieces about 3 cm long. The high density of this rock and the angular quartz grains, which is the main mineral of these breccias, was the major reason for the selection of this particular rock for the manufacture of millstones.

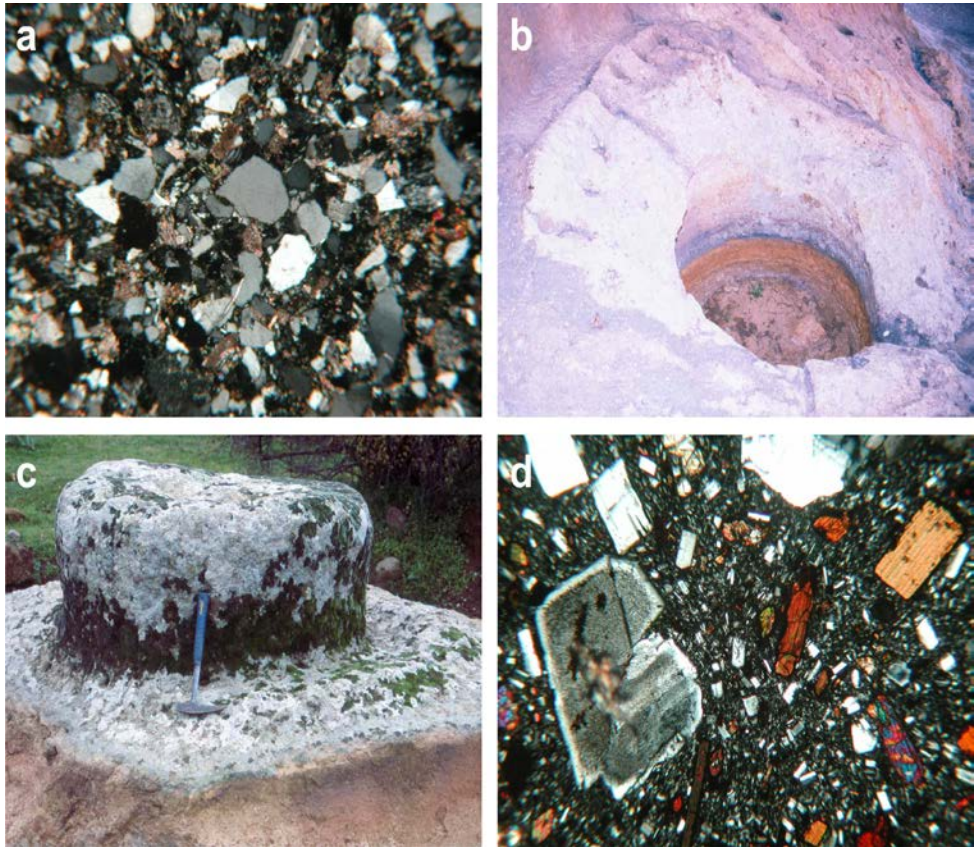
The quarries are open or underground and occupy a large area. The traces of the tools as well as the hollows on the surface where the rounded millstones were extracted still remain in situ. These hollows exceed 1 m in diameter, whereas fragments of broken millstones are found around. There is not any indication when exactly these quarries operated.

Very close to Agios Georgios hill, few hundred meters to the north, debris of ancient millstones of "Olynthos type" is found scattered in the location "Vrachos" of Petrota. Their age is unidentified, although the same type millstones have been observed during our investigations in the adjacent ancient Maronia, at the Roman and early Byzantine constructions. The rock consists of andesite of local origin and has a high porosity. The petrographic study under microscopy showed that the mineral composition consists of plagioclase, pyroxene and magnetite. Rocks of similar mineral composition are found north of Petrota. However the quarrying site has not been discovered and there is not any mention about it.

In the broader area of Macedonia in Greece, volcanic rocks are found in Almopia of Pella region at the Voras mountain and very scarcely in Pontokerasia area of Kilkis region at the Disoron mountain. According to Vouidiouklalkis (2002) the volcanic rocks of



Almopia comprise andesites-dacites, trachytes, latites, rhyolites and soshonites as intercalations, while all the area is covered by pyroclastic rocks formed by the volcanic eruptions. In these pyroclastic rocks big rounded boulders of andesitic-dacitic composition are scattered at several sites in the Almopia basin interfering the pyroclastic series. They are compact and tough rocks, reddish or grayish in color with a size from few centimeters up to 5 meters. Their mineralogical composition comprises volcanic glass and phenocrysts of plagioclase, biotite, hornblende, pyroxene and small quantities of muscovite and quartz. The reddish color of the andesite is attributed to the presence of elevated amounts of biotite.



**Figure 3** a. Microscopic clastic quartz grains in sandstone of a Neolithic grinding stone tool, Dispilio of Kastoria. Polarized light, +N. Length of picture: 4 mm; b. Millstone quarry, Agios Georgios, Petrotia of Rhodopi, Thrace, NE Greece; c. In situ quarrying of a millstone made of andesite-dacite, probably from the Byzantine times, Aloros, Almopia, N. Greece; e. Microscopic image of the andesitic-dacitic millstone in Aloros of Almopia. Polarized light, +N. Length of picture: 4 mm.

Various rotary millstones have been found in the whole area, all made by the local andesite-dacite. Their diameter ranges between 0.40 and 1.20 m and their thickness varies from 5 to 20 cm. An isolated carved boulder having the shape of an unfinished and not extracted millstone was found near the village Aloros in Almopia. The abandoned millstone has a

diameter of 1.20 m and a thickness of 0.50 m. A channel 15 cm wide was carved around the millstone and at its base several holes were engraved every 20 cm, probably for the wedges to be placed for the detachment of the millstone from the rock. This extraction technique shows a probable Byzantine age of this millstone.

## Conclusions

The millstone was one of the most important tools in the productive process of human culture for more than 10.000 years. It was adapted throughout history, in all the great technological, cultural and social changes. It was modified and transformed in form and in size, depending on the needs and the possibilities of people. It played a significant role as a piece of exchange and transaction between various populations and cultures and was transported in great distances from the quarrying sites. Due to the particular characteristics of the millstones, the raw materials were specifically selected and processed with special attention and technique.

In Macedonia and Thrace, as well as in whole Greece and Aegean, because of the very unique geological structure and the composition of the rocks, an intensive millstone quarrying took place. With a complicated technique and special tools, the quarrymen sculptured the rocks and they extracted the millstones. And then with a great attention they transported them up to long distant areas at the watermills. Hence with the permanent care of the millers, the millstones worked for long periods producing flour from the wheat, and other products.

Although the millstones went through all the technological changes, the modern technological development influenced negatively its use. In few decades it was replaced by the “machines” and was finally extrapolated by the productive process. Today, at the “dawn of 21<sup>st</sup> century”, millstone are objects in Technological or Folklore Museums. However we have to respect the history of the millstones and preserve their importance in the evolution of civilization as a part of our cultural heritage.

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