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ORIGINAL ARTICLE

Geoarchaeology of Roman Underground Quarries at Ksour Essaf (Tunisia)

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Abstract The underground quarries at Ksour Essaf hills (Tunisia) contribute to our knowledge of extraction techniques that have been in use since antiquity. The extracted stone consists of oolitic sandy limestone, dated as Lower Messinian (Ksour Essaf Formation). Geotechnical analyses have revealed that the quality of the Messinian stone is better than that of Tyrrhenian (Late Pleistocene) age from the same region (Réjiche Formation). However, the latter has been more widely used as it is more extensively exposed. The extraction technique and the use of cut blocks in Roman constructions, but not mediaeval Muslim constructions in this area, allow the approximate determination of the period of the exploitation of the underground quarries during the period of Roman occupation.

Keywords Oolitic limestone · Messinian · Underground quarries · Extraction techniques · Tunisia

Introduction

The town of Ksour Essaf lies in the southeastern Sahil region of Tunisia (part of the ancient *Byzacium* region) and is situated 6 km north northwest of the town of Sallakta (the ancient town of *Sullecthum*) and 28 km northeast of the town of El Jem (or *Thysdrus*). This region includes an eastern platform characterised by broad geological structures with NE-SW axes (Castany 1947; Burrolet 1956; Mahmoudi 1986; Brahim 2001).

Generally, in eastern Tunisia, three different geological formations have supplied building stones: marine Neogene (Miocene-Pliocene) sandy limestone, Pleistocene calcretes and Late Pleistocene (Tyrrhenian) calcareous sandstone (Fig. 1). These three lithofacies have supplied a good-quality building stone which has been appreciated by builders since ancient times (Younès and Ouaja 2008; Gaied et al. 2009; Younès and Gallala 2012).

Several ancient quarries are also present in the Pleistocene calcrete formation (Younès and Gallala 2012), in the Tyrrhenian, Réjiche Formation (Younès and Ouaja 2008; Younès and Ouaja 2009), in the Pliocene dune lines and in the Miocene deposits (Gaied et al. 2009). A large number of the quarries in the Rejiche Formation have also been previously studied (Slim et al. 2004; Younès and Ouaja 2008). The Messinian quarries in the Ksour Essaf hills are less numerous than those identified in the Tyrrhenian dune line, however, certainly due to former's smaller area of development than the latter (Fig. 1).

This work aims are as follows:

- Describe the geological features of the underground Ksour Essaf quarries
- Inventory and indicate the distribution of these quarries
- Identify the extraction techniques and tools used in antiquity
- Investigate preserved marks left on the quarry faces and to identify the size of the cut blocks
- Suggest the period of cut block exploitation

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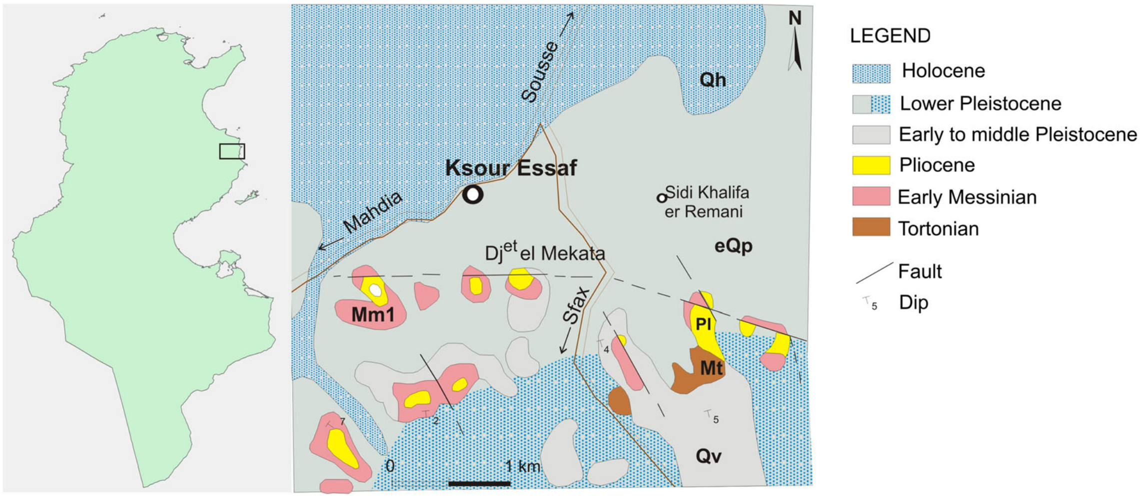


Fig. 1 Map of geological formations in the Sahil region of Tunisia

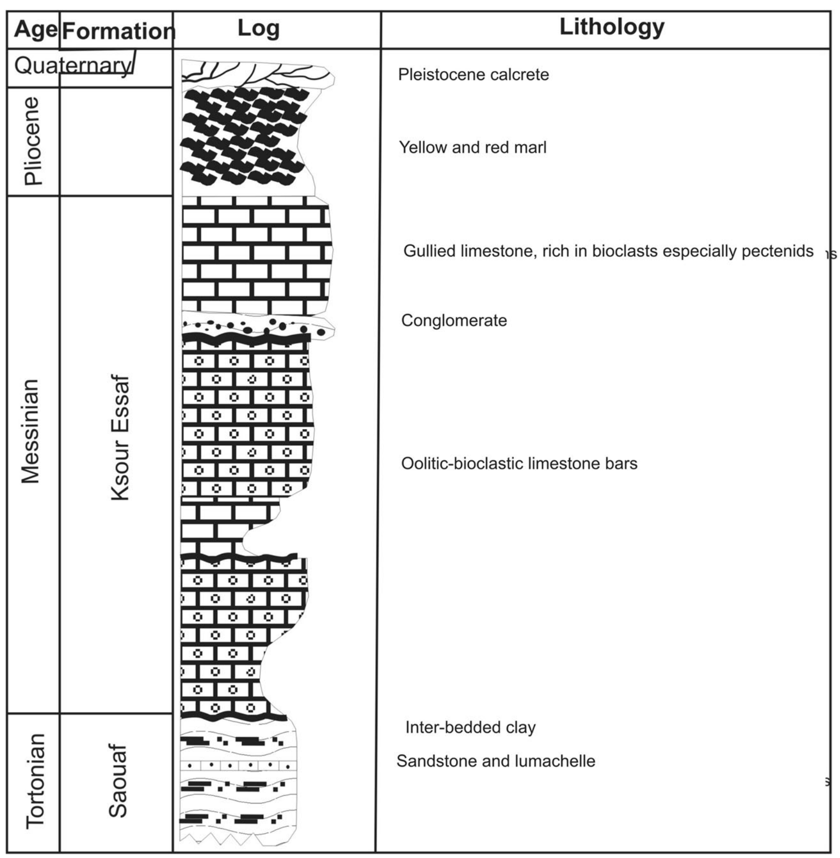
Geological Setting

Geology of Ksour Essaf Region

The eastern zones of Tunisia are characterised by a varied but not well-contrasted topography that is interrupted by local uplands such as at Bou Thadi, El Jem and Ksour Essaf. These areas make up the so-called 'Sahil Platform', which is characterised by large geological structures with NE-SW axes.

From a structural perspective, the Ksour Essaf region forms a monocline which dips gently towards the SE. It is located at the north of Mahdia graben which is the result of a fairly widespread extension of the Lower Langhian

Fig. 2 Synthetic lithostratigraphic log of the Ksour Essaf region



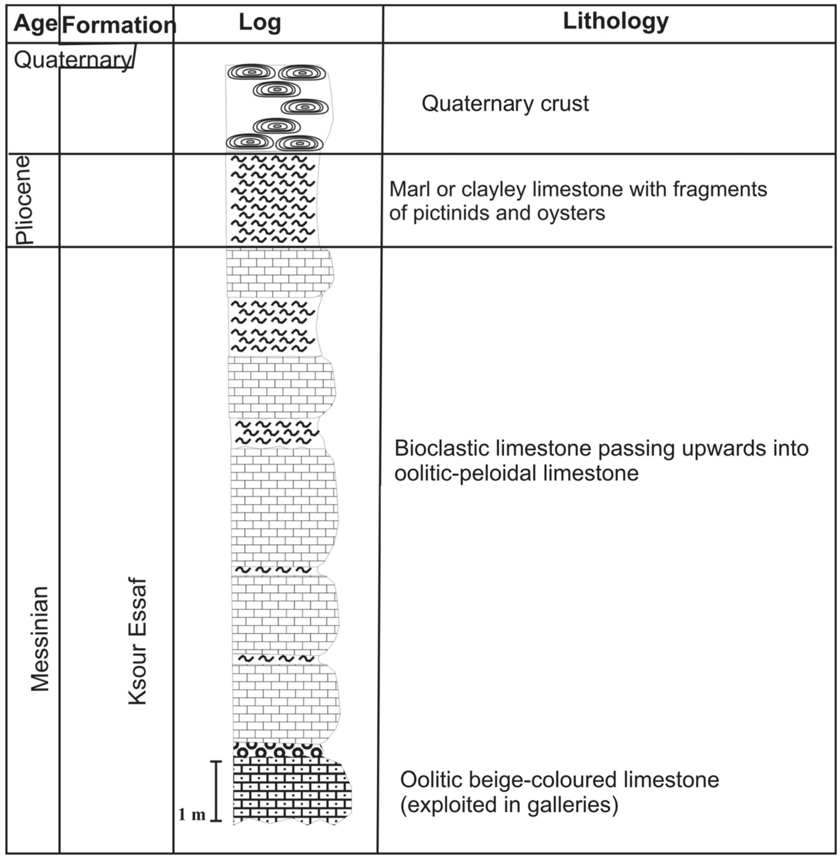


Fig. 3 Geological section of an underground quarry (area 1)

(Bédir and Zargouni 1986).

The geological map of this region shows the following stratigraphy (Fig. 2):

1. Upper member of Saouaf Formation (Tortonian) which comprises interbedded clay layers with sandstone and lumachelle levels.

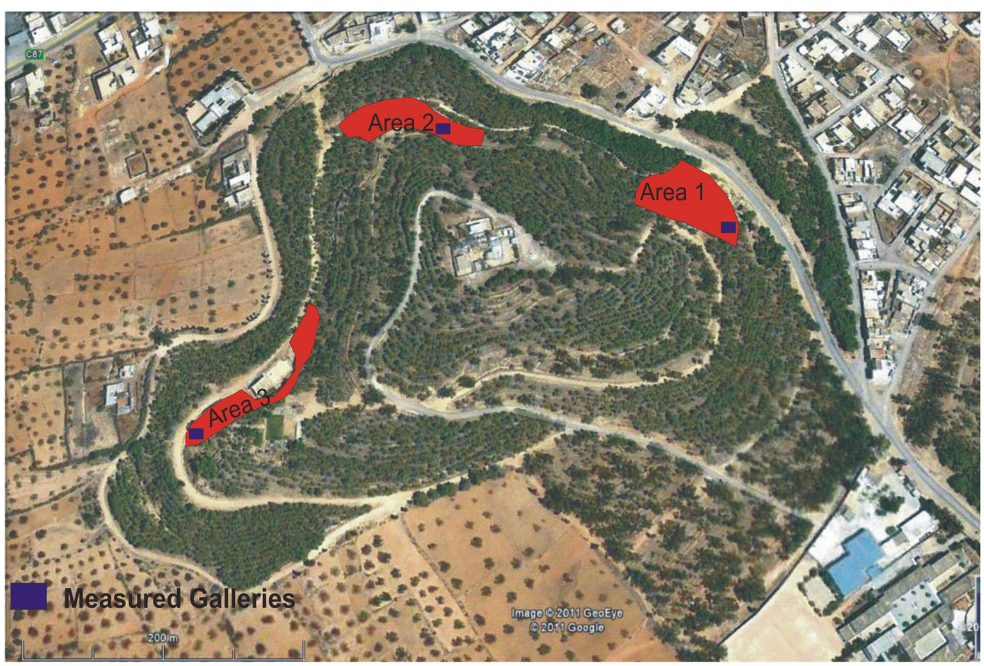


Fig. 4 Location of the Ksour Essaf underground quarries

Fig. 5 Poorly preserved quarry gallery (area 2)

2. Unconformity surface reflecting a transgressive stage as a precursor of marine sedimentation, as represented by 10 to 15 m of oolitic and bioclastic limestone. The latter is dated by several authors as Lower Messinian (Besème and Kamoun 1988; Moissette et al. 2010). This facies provides good construction stones which were widely used in the antiquity.
3. A second unconformity surface indicating a hiatus from the Upper Messinian to the Lower Pliocene identified by an erosive phase followed by a thin conglomeratic level.
4. Upper Pliocene sediments commence with hardened and burrowed bioclastic limestones very rich in pectenid bivalves.
5. Yellow and red marl levels indicating a gradual transition between marine facies and continental environments. The latter forms part of widespread Pleistocene calcrete occupying the Ksour Essaf hilltops.

Geology of Underground Quarries

The ancient underground quarries are located in the marine Lower Messinian (unit 2) within the highest hill (about 70 m in height) known as 'Hamadet al Hadida' which covers an area of about 300.000 m^2. Two lithostratigraphic sections were studied (see Figs. 3, 4 and 5). The first, in area N° 1, showed around 1 m or less of unit 2 in contact with units 3, 4 and 5. In this area, marl layers alternating with the limestone and calcrete are sometimes relatively thick, hence explaining why the extraction of a good stone from unit 2 became very difficult. For this reason, the quarry workers chose to exploit only those areas on the hill where the stone is of good quality for building.

The second studied section in area N° 3 shows that unit 2 is thicker than in area N° 1, and it can supply very well cut stone blocks.

Sampling and Analytical Procedure

In order to characterise the stone used in many public Roman monuments, two cross sections have been described and three samples were cut from quarry faces. Optical microscopy was used to identify the different constituents and textural features of these samples. Hydraulic pressure testing at the CTMCCV (Technical Centre for Construction Materials, Ceramics and Glass) was used to assess the resistance to simple compressive strength. The density and porosity of the studied stone were carried out according to French standards (NFB 10-502 to NFB 10-504).

Results

Chemical analyses indicate that the Ksour Essaf stone is very rich in CaO (52 %), slightly siliceous (% SiO_2=2.5) and contains less than 1.5 % of $MgO+Al_2O_3+Fe_2O_3$.

Geotechnical and mechanical tests, as recorded in Table 1, prove that the Ksour Essaf stone has a medium density (2.4) and relatively high porosity ranges from 5 to 9 %. Resistance to simple strength ranges from 12.5 to 15 MPa. All of these parameters indicate that the Ksour Essaf stone can be used for construction of load-bearing walls. However, the relatively high porosity can be reduced by applying a special coating.

A thin section of the studied stone reveals a biomicritic and oolitic limestones (Fig. 6) containing skeletal elements, especially bivalves and foraminifera. The latter is dominated by ooids, pellets and grain quartz with a cement of micrite and/or microsparite. According to the Dunham classification (1964), the Ksour Essaf stone is a grain stone with an intergranular microporosity.

Table 1 Geological features of the three types of stones

Types of stones	Density	Porosity	Resistance to simple strength in MPa
Réjiche Formation	2.06 to 2.24	14 to 15.3	4 to 5.2
Villafranchian crust	2.25 to 2.71	3 to 24	0.5 to 7.5
Mio-Pliocene	2.4	5 to 9	12.5 to 14

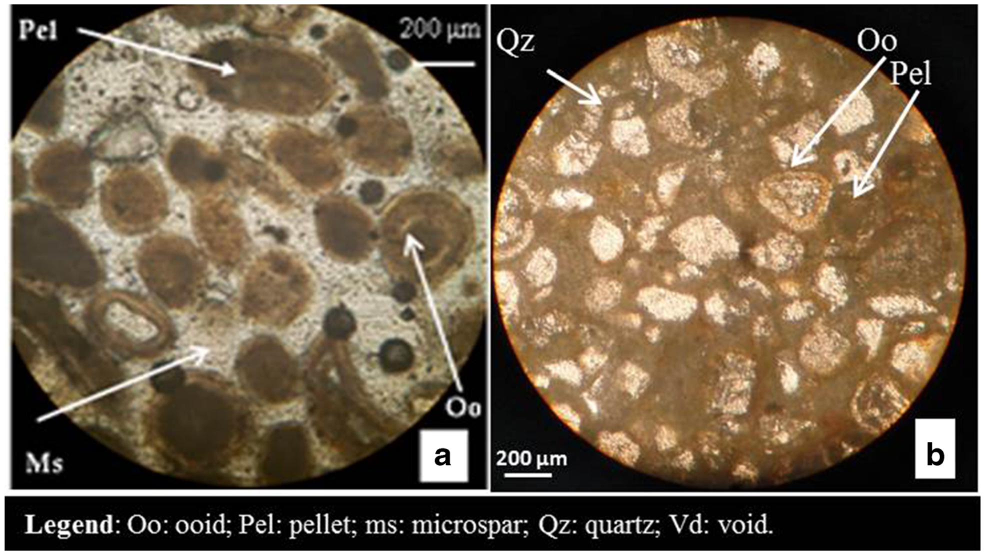


Fig. 6 Thin section of a sample from Ksour Essaf quarry: oolitic peloidal sediment in which much of depositional space between grains is unfilled by cement, i.e. the microfacies shows intergranular porosity

Location and Inventory of Quarry Galleries

The quarries identified around Ksour Essaf hill are mostly located on its east northeastern, northern and western sides (Fig. 4). On the southern side of the hill, there is no evidence of block extraction, probably because the type of stone present is of low quality. Indeed, exposures here show significant layers of marl, conglomerate and calcrete.

The identified quarries can be split into three zones, separated from one another by unexploited stone of poor quality. In the first zone, which lies on the east northeastern side of the hill, there are six galleries. In the second zone, on the northern side and in the third, on the western side, there are five galleries. Overall, sixteen galleries have been registered on the hill. However, on the eastern side of the hill, a large area, which was planted with trees in the 1960s, would have belonged to the first quarry zone. An excavation in this area would probably find evidence of further extraction.

Most of the galleries are not well preserved, and only three are almost entirely preserved, with the other thirteen galleries being partially filled (Fig. 7). Among the three well-preserved galleries, two are large sized and are situated in the first and in the second zones. The third is located in the third zone and is of smaller size. The very small number of preserved galleries prevents estimation of the overall size of galleries.

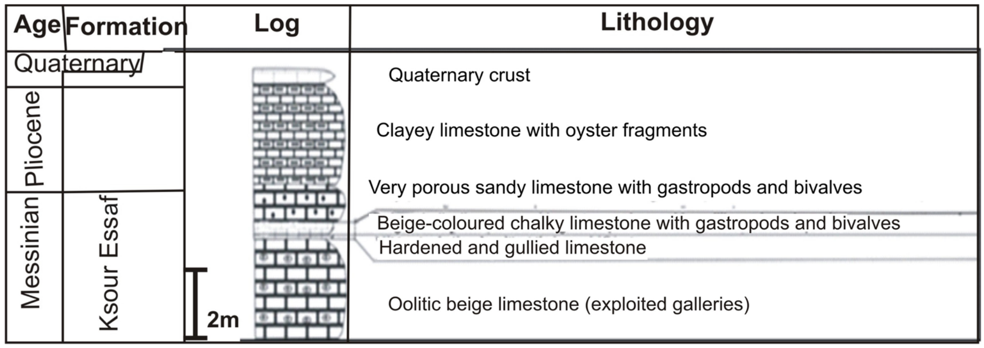
Extraction Techniques

According to the preserved archaeological data, no traces of any open air exploitation have been found. It is important, however, to consider the possibility of open-air extraction blocks before surveying the recovered surface of the area 1. Concerning the underground exploitation, quarry workers avoided the thick calcrete and marl upper layers of porous stone and looked for consolidated limestone layers to exploit (Figs. 7 and 8). Thus, in the underground quarry, the upper part of the uncut porous stone is used as a ceiling.

The block extraction technique in the galleries is the same as the technique used in the underground galleries found in the Tyrrhenian dune line about 10 km distant (Younès and Ouaja 2009) and in the northeast of Hispania (Gutiérrez 2009) or in other Roman provinces (Bessac 2003; Ward-Perkins 1971). The quarry worker started outlining the block to be cut by making slits on its upper, lower and lateral sides, since only the front had been isolated; they then widened and deepened the slit to make extraction trenches. Afterwards, the quarryman created along the lower horizontal side, a line of fracture and holes in order to insert metallic wedges which were hammered in so as to definitively cut the block. The quarry worker would also have exploited natural planes of weakness

Fig. 7 Well-preserved gallery (area 3)

Fig. 8 Section through the well-preserved gallery (area 3)



within the rock, when they are visible, in order to extract blocks. While extracting these blocks, the quarry worker deliberately left some parts of the rock as natural walls and pillars so as to strengthen the ceilings of the galleries (Fig. 7). The measured, well-preserved cutting marks in the gallery faces reveal that both the cut and precut blocks are of medium and small sizes, giving these faces a bevelled edge profile (Table 2 and Fig. 9) (Note that it is difficult to assert if large-sized blocks have been cut, since the extraction marks following the natural fissures are badly preserved in galleries 3 and 4 in the area 1).

The entrances of the galleries are situated on the east northeastern, northern and western sides of the hill. The first two entrances light up the galleries in the morning while the third offers natural light in the afternoon. This is very likely to have allowed the quarry workers to work all day long using natural light. However, as in the underground quarries in the Tyrrhenian dune lines, the lack of lighting and ventilation shafts in the large galleries would have been a problem for the quarry worker who consequently would have had to use artificial lighting and reduce the time spent in the gallery due to a lack of oxygen (Younès and Ouaja 2009).

Concerning the extraction tools, the preserved marks of holes on the quarry faces reveal that the quarry worker used chisels to make extraction trenches and wedge holes. The best preserved wedge hole is 20 cm deep, 7 cm wide and has a thickness of 30 cm (Fig. 10a). The preserved hole marks make it possible to reconstruct the type of chisel used (Fig. 10b).

The extracted blocks were used to build luxurious houses in *Thysdrus*, the amphitheatres at *Thysdrus* and at *Thapsus*. These blocks would have been carried to *Thysdrus* on the Roman road connecting *Thysdrus* to *Sullecthum* (Table de Peutinger 1983, *Segmentum VI*), and the blocks carried to *Thapsus* would most likely to have been transported by sea from the *portus* of *Sullecthum*.

Table 2 Sizes of cut and precut blocks

Area	Gallery	Length (cm)	Wide (cm)	Height (cm)
1	1	100	50	30
		75	50	25
		50	50	25
		50	40	25
		130	70	60
		100	90	50
2	5	100	90	30
		100	50	50
		70	40	30
		70	30	30
		70	30	35
		100	75	50
3	3	100	70	50
		100	70	20
		100	50	20
	5	110	80	50
		90	60	50
		70	60	50
		60	60	50
		50	50	50

Fig. 9 Bevelled edge profile of the gallery 5 (area 2)

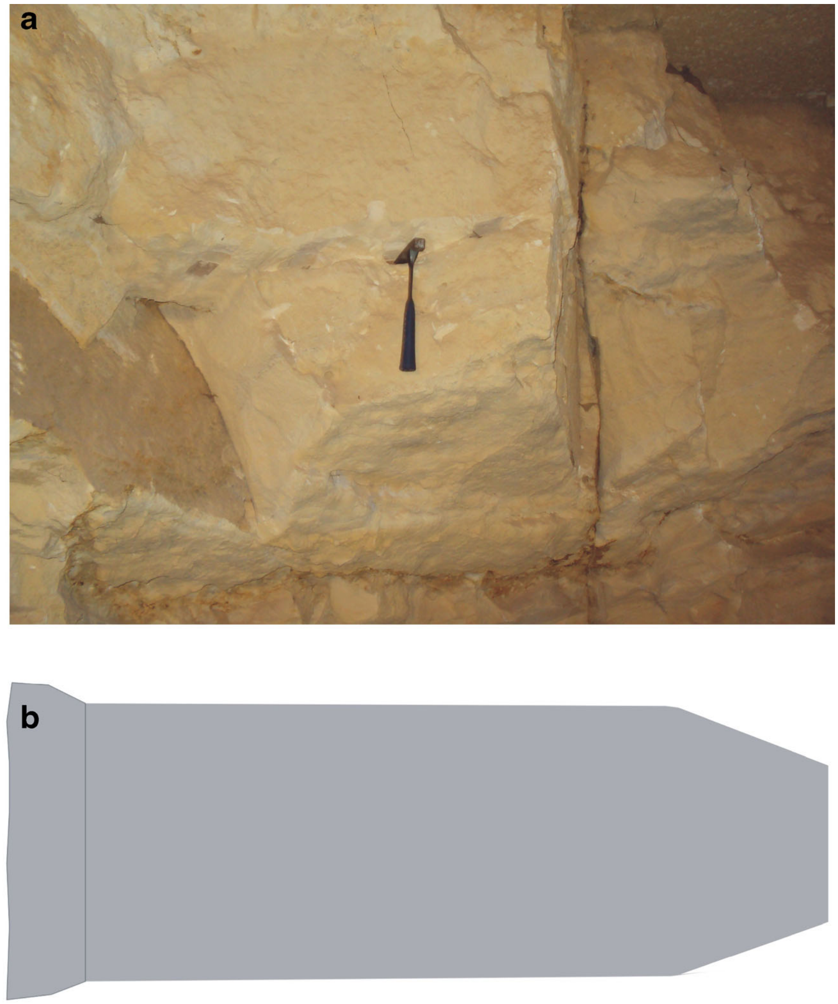


Fig. 10 **a** Chisel marks of extraction trench (area 2). **b** Attempt at a reconstruction of chisel used in the trench excavation

Attempts to Date the Quarries

Dating the exploitation of the underground quarries at Ksour Essaf is difficult because of a lack of literary and epigraphic texts. Yet, it is possible to assert that these underground quarries would have been exploited during the Roman Imperial period, due to the following evidence:

– The extraction technique is similar to the technique used in the Roman underground quarries on the Sahil Tyrrhenian dune line and in the northeast of Hispania (Gutiérrez 2009).
– The use of extracted blocks in the *Thapsus* and *Thysdrus* Roman amphitheatres (to date, blocks of Mio-Pliocene age used in mediaeval Muslim constructions have not been identified in the underground quarries).
– Blocks of typical limestone from the underground quarries are missing in mediaeval constructions in Ksour Essaf village.

Conclusion

The underground quarries in Messinian limestones situated in the Ksour Essaf hill can be added to those already registered and studied within the Tyrrhenian dune line in Tunisia. Although the Messinian limestone is less abundant than the Pleistocene calcretes and the Tyrrhenian sandstone, it was very well appreciated by the Roman builders for its good geological and geotechnical qualities. Blocks were extracted using the same techniques observed in Roman quarries in the Tyrrhenian dune line and in the northeast of Hispania. At least one tool used by the quarry workers (the chisel) has been identified thanks to the preserved tool marks left on the quarry faces of one gallery. The extracted blocks are small, medium and large sized. The extraction technique and the use of blocks in the Roman buildings make it possible to date the exploitation of the quarries as from the Roman period.

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