The Green Schist Marble Stone of Jebel El Hairech (North West of Tunisia): a Multi-Analytical Approach and its Uses in Antiquity

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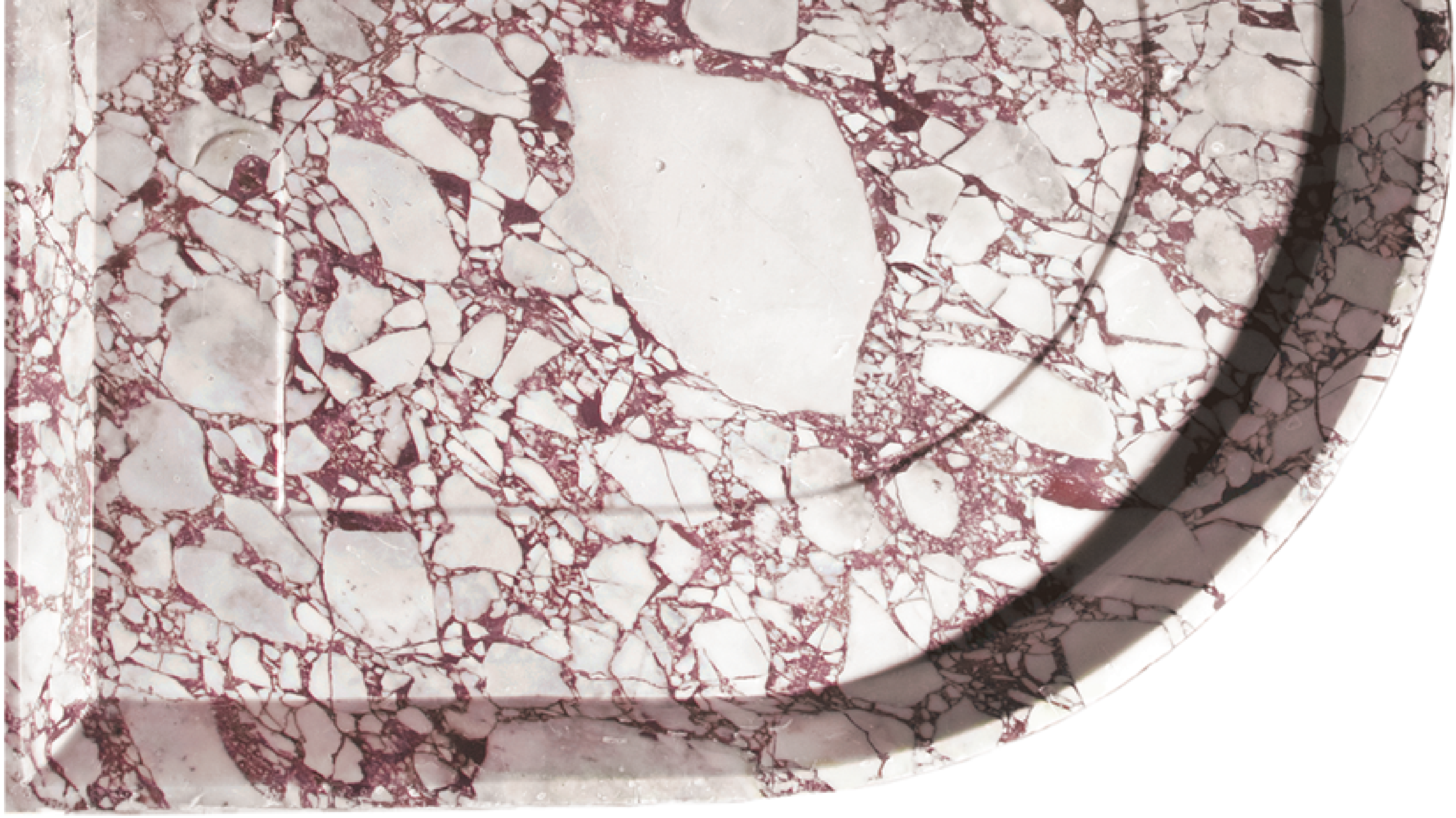

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CONTENT

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THE GREEN SCHIST MARBLE STONE OF JEBEL EL HAIRECH (NORTH WEST OF TUNISIA): A MULTI-ANALYTICAL APPROACH AND ITS USES IN ANTIQUITY

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Abstract

Green schist marble stone was used in Antiquity both as a building stone for private and public constructions, and as an ornamental stone for sculpting funeral monuments and for engraving epigraphic texts. Three quarries that once provided green schist blocks have been located to the Eastern part of Jebel el Hairech situated in the governorate of Jendouba (North-West of Tunisia). The preserved cutting marks left on the quarry fronts led to the identification of the quarrying techniques and the determination of the sizes of some cut blocks. The results of petro-mineralogical and chemical analyses, together with physico-mechanical tests, revealed the green schist marble stones to be of high quality with physical and mechanical properties that are fully adapted for construction as well as for the sculpture of architectural and funeral structures.

Keywords
Jebel el Hairech, Tunisia, green schist

Introduction

Marble stones[1] have been considered since ancient times as "select stones" both for the production of their art and for the construction of various public and private buildings, because of their physical and aesthetic properties. In the African Roman cities, various and numerous constructions were made and decorated with marble stones, but no inventory study has been made to list their different varieties, excepting an attempt to identify the ancient marble stones located to the North of the Tunisian Dorsale[2]. This study led to the identification of 8 varieties of marble stone used for both building and decorating public and private constructions, and for engraving texts of different types in the Roman cities of northern *Africa Proconsularis*. Among the identified marble stones, green schist stone was located in Jebel el Hairech in the governorate of Jendouba situated in the northwest region of Tunisia (Fig. 1). Jebel el Hairech covers a much wider area of the el Hairech massif than Jebel Chemtou which provided the Antique Yellow marble (*Marmor Numidicum*). Green schist marble stone was widely used in Antiquity in the ancient cities of *Simitthus* (Chemtou) and *Thunusuda* (Borj Hellal?), both located near Jebel el Hairech. Yet very few studies have been made of green schist marble, stone, in contrast to Yellow Numidian marble (*Marmor Numidicum*) which caught the attention of several researchers in geology, archaeology and history.[3]

The present paper aims at increasing the previous geological and archaeological knowledge in the light of new data collected during field prospecting in Jebel el Hairech and in the archaeological sites of Chemtou, Borj Hellal, Bulla Regia and Dougga, together with further analytical analyses performed on the green schist marble stone.

1 The term "marble stone" used both by geologists and geoarchaeologists was preferred to the word "marble" used by ancient authors, because the majority of these marbles are hard limestones with various colours able to take a very high polish, and used both for building and ornamenting constructions.

2 YOUNES 2014, 161-192.

3 These important geological researches (3 doctoral theses and 1 mémoire) were made on the el Hairech massif (see ROUVIER 1985; ALOUANI 1988; *ibid*, 1991; SOUSSI 2002). Only two preliminary studies concerned green schist marble stone (YOUNES 2014(a), 231-248; WEDERNI 2014). For safety reasons, the student who wrote the mémoire that I supervised was unable to conduct surveys in Jebel el Hairech. I provided her the necessary documents (photos, schemes, samples of the rock, etc.) which she used in the redaction of her mémoire. The results of the analyses she performed on the green schist stone have been deepened and reused in this present paper.

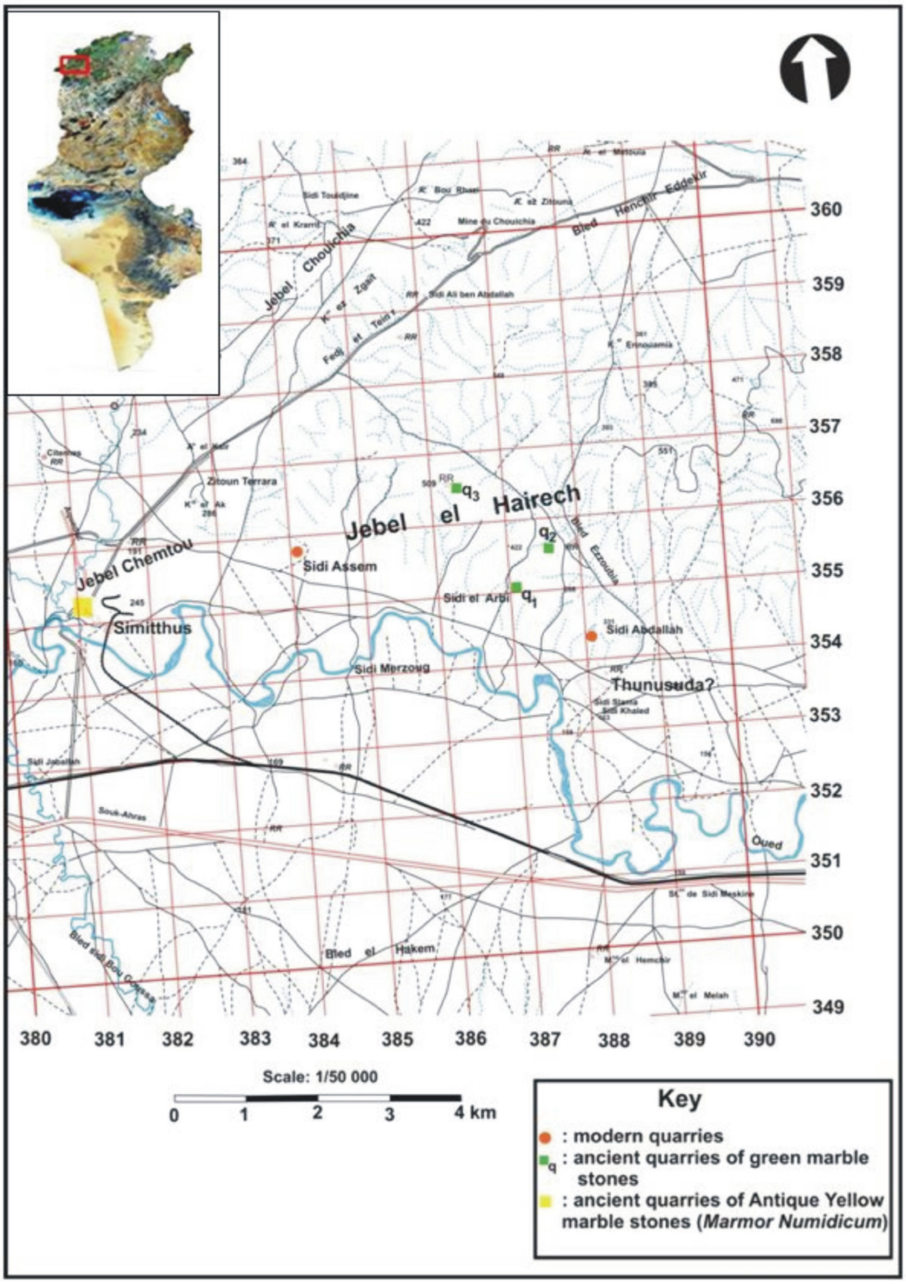

Fig. 1.
Location of Jebel el Hairech massif and the green schist marble stone quarries (map: A. Younès)

I) Geological setting

The massif of Jebel el Hairech, culminating at 690 m, is situated 8 km north-west of the town of Jendouba (Fig. 1). The two anticlinal structures constituting the massif are made of Permo-Triassic oolitic sandstone cores. These structures oriented ENE-WSW are separated by an intensely brecciated Syncline[4].

From a stratigraphic point of view, Jebel el Hairech is known for having the same name as its geological formation (el Hairech Formation); it is characterized by a strong sandstone oolitic sequence with ripple marks and is rich in plant fossils (especially Equisetites). The top of the sequence is defined by grey to black dolomites and dolomitic sandstones about 50 m thick.

Jurassic outcrops occur to the south and to the east of the massif, and consist of grey-beige, blackish and pink-whitish dolomites mainly invaded by iron oxide mineralization caused by fractures. The dolomites are strongly recrystallized and are characterized by albite porphyroblasts showing simple and polysynthetic twinning[5] (Fig. 2).

4 ROUVIER 1985, *op. cit.*; ALOUANI 1988, *op. cit.;* GHARBI, HENRY 1992, 187-194.

5 SOUSSI 2002, *op. cit.*

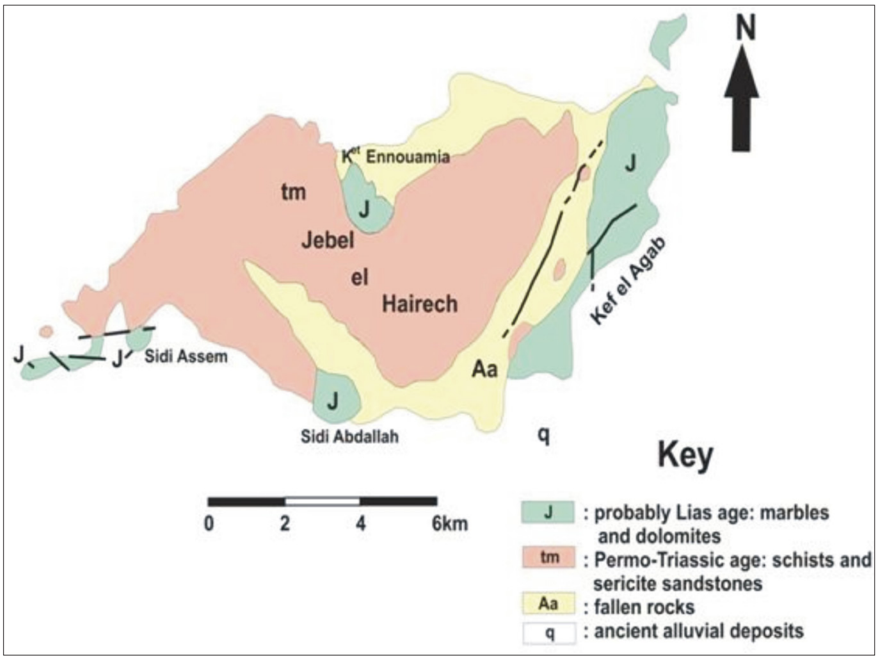

Fig. 2.
Geological map of the studied area (from the geological map of Ghardimaou, 1/50000) (map: A. Younès)

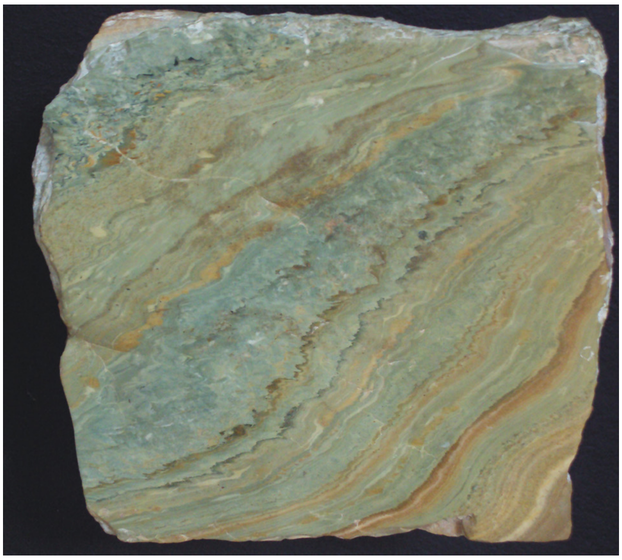

Fig. 3. Picture showing green schist marble stone (photo: A. Younès)

II) Characterization of the green schist marble stone

1) Material and methods

Sampling

Several fragments of the green schist rock were analyzed macroscopically to identify the colour and the texture. Then, small homogeneous samples of about 7cm x 7cm x 7cm were obtained from these green schist fragments. Part of these samples was powdered for analysis with powder X-ray diffraction (XRD), and the remaining part of each sample was used to produce thin sections to be viewed using a microscope. Chemical analyses, together with physico-mechanical tests, were also performed.

Minero-petrographic analyses

Petrographic analyses

Samples have been studied mineralogically in thin sections under the polarizing microscope Leica DM 500 MP and their mineralogical composition evaluated by means of a swift point counter. Thin sections observations permit the determination of the fabric of the green schist marble stone and the identification of the accessory and secondary minerals.

XRD analyses

XRD measurements were also performed on powdered samples in order to obtain semi-quantitative information about the mineral phases present in the samples.

Chemical analyses

The samples were also been subjected to chemical analyses and their chemical compositions were performed under Atomic Absorption Spectroscopy (AAS).

Physico-mechanical tests

A series of physico-mechanical tests were performed on approximately 7cm x 7cm x 7cm homogeneous samples to determine the density, porosity, water absorption and simple strength of the studied rock.

2) Results

Macroscopic results

The texture of the green schist marble stone is fine grained with a light to dark green background containing light or dark brown streaks and rare white spots (Fig. 3).

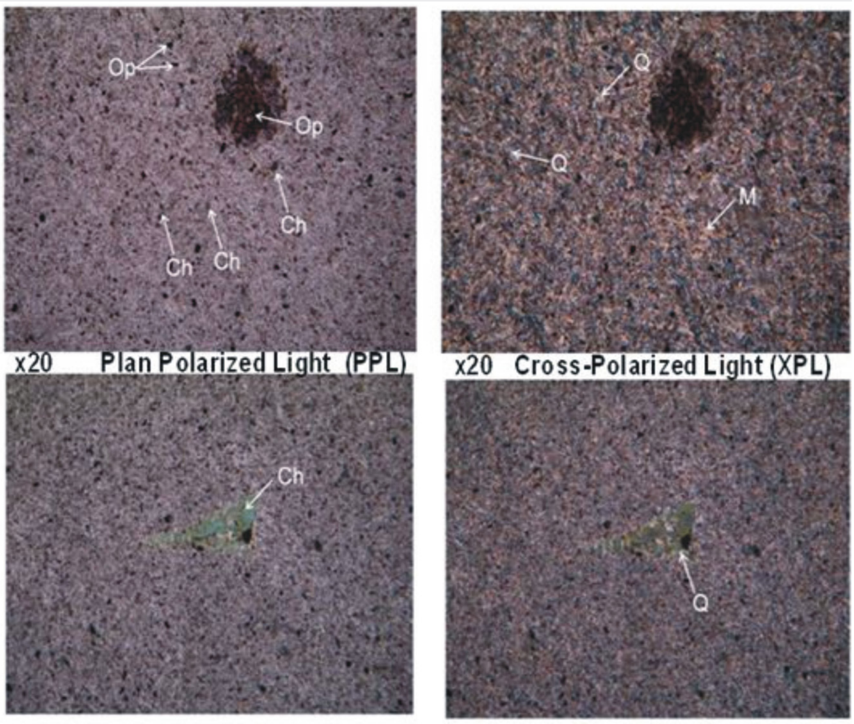

Fig. 4.
Thin-section micrographs of green schist stone (photos: M. Gaied, W. Gallala)

Minerals	Quartz	Muscovite	Chlorite	Chloritoïde	Albite
%	60%	23%	10%	4%	2%

Table 1.
Mineralogical composition of the green schist stone

Oxides	CaO	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O	Cl	MgO	TiO_2	Total
Average in %	0,20	59,15	22,02	6,10	3,75	0,12	2,9	3,38	0,03	98,26

Table 2.
Chemical composition of the green schist marble stone

Absorption rate	Density	Porosity	Compressive strength
0.427%	2.71 g/cm^3	2.64%	95.4 MPa

Table 3.
Physico-mechanical results of the green schist marble stone

Minero-petrographic results

The minero-petrographic analyses of thin sections performed on the green schist samples reveal a lepidoblastic, slightly schistose texture constituted of chlorites and chloritoïdes dominating the coloured background. The small light coloured quartz and plagioclase crystals, together with dark muscovites are irregularly disseminated (Fig. 4 and Table 1).

XRD analyses, in agreement with petrographic analyses reveal that the samples contain large amounts of quartz with picks ranging from 4.23Å to 1.81Å (diffractograms, Fig. 5)[6], abundance of phyllosicates (muscovite, chlorite and chloritoïdes), and a small amount of albite (Table 1).

Chemical results

The chemical results confirm the minero-petrographic and XRD results. Indeed, the ACF diagram (Fig. 6) shows that green schist marble stone has a pelite composition, characterized by a high content in Al_2O_3 essentially due to the presence of aluminosilicates (muscovite, chloritoïdes and chlorites) (Table 2)[7].

Physico-mechanical results

The results of the physico-mechanical tests are shown on Table 3. A low density rate is observed (2.71g/cm^3) and this result is very close to the density of each of the main constituents of the rock (quartz: 2.65 g/cm^3;

6 WEDERNI 2014, *op. cit.*, 29.

7 WEDERNI 2014, *op. cit.*, 31.

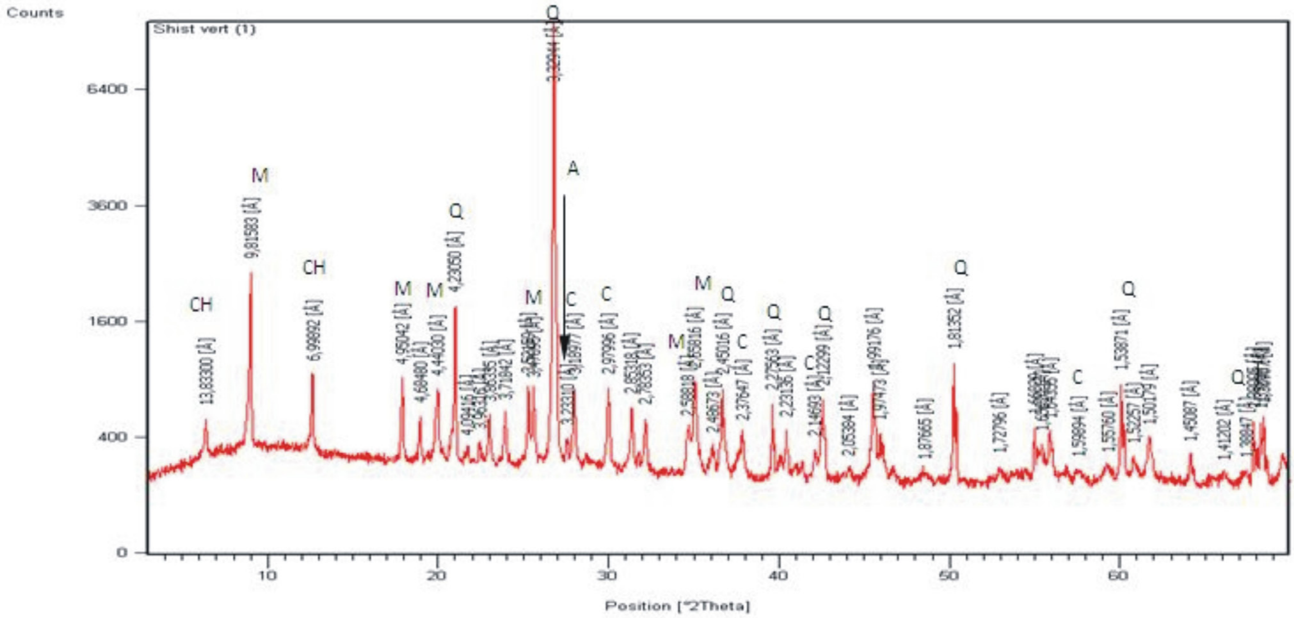

Fig. 5. X-ray diffraction pattern of the green schist (scheme: D. Wederni)

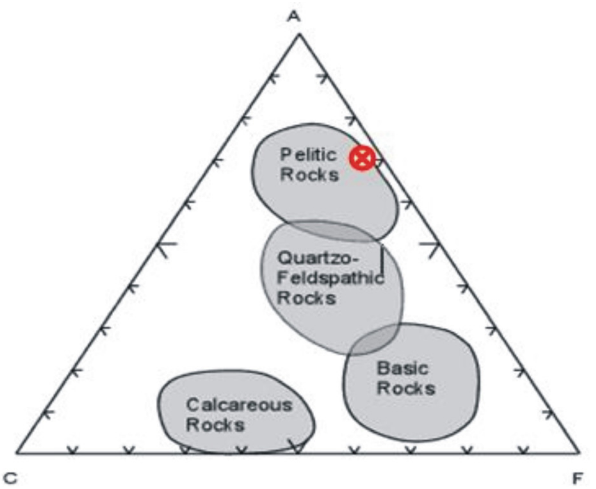

Fig. 6. ACF diagram (scheme: W. Gallala)

micas: 2.7 to 3.3 g/cm^3; chlorite: 2.6 to 3.3 g/cm^3; feldspaths: 2.55 to 2.76 g/cm^3). Porosity is also low (2.64%) due to the size and shapes of the grains, together with the little space that is free. This low porosity results in low permeability (0.427%) (Fig. 7)[8].

From a mechanical point of view, the green schist stone shows a high compressive strength higher than 95MPa (Table 3 and Fig. 7). This indicates that this stone is a hard marble rock according to AFNOR norms situating marble stones between 92 and 100 MPa. This high resistance is due to its high compaction and hardness.

8 *Idem*, 38.

III) Exploitation of the ancient quarries

1) Location of the quarries

Three ancient quarries situated in close proximity to each other were found during two archaeological surveys[9] in the south eastern area of Jebel el Hairech. The first one, identified during the 2009 survey[10] is located downhill from Jebel el Hairech, north-north-east of sidi el Arbi Marabout. The other two quarries were found during the 2014 and 2015 surveys. They are situated respectively 600 m north-east and 1700 m north-north-west of the first quarry[11] (Figs. 1, 8a, 8b and 8c).

The three quarries are situated in close proximity from the archaeological site of Borj Hellal[12] (the first quarry is approximately 1.5 km north-north-west of Borj Hellal), and not very far from *Simitthus* site (the third quarry is about 5 km from *Simitthus* site) (Fig. 1).

Nowadays, a little path linked to the asphalted Tunis-Ghardimaou road leads down to the quarries (Fig. 1).

9 Our activity has been limited to a small area of Jebel el Hairech due the lack of security in the sector.

10 YOUNES 2014(a), *op. cit.*

11 The third quarry was found near the place indicated by the letters "RR" in the topographic map at scale 1/50000 and in the Archaeological Atlas, sheet N° 31, Ghardimaou. According to the team who carried out the topographic surveys the letters "RR" indicate the presence of Roman archaeological remains.

12 See *infra*, footnote n° 14.

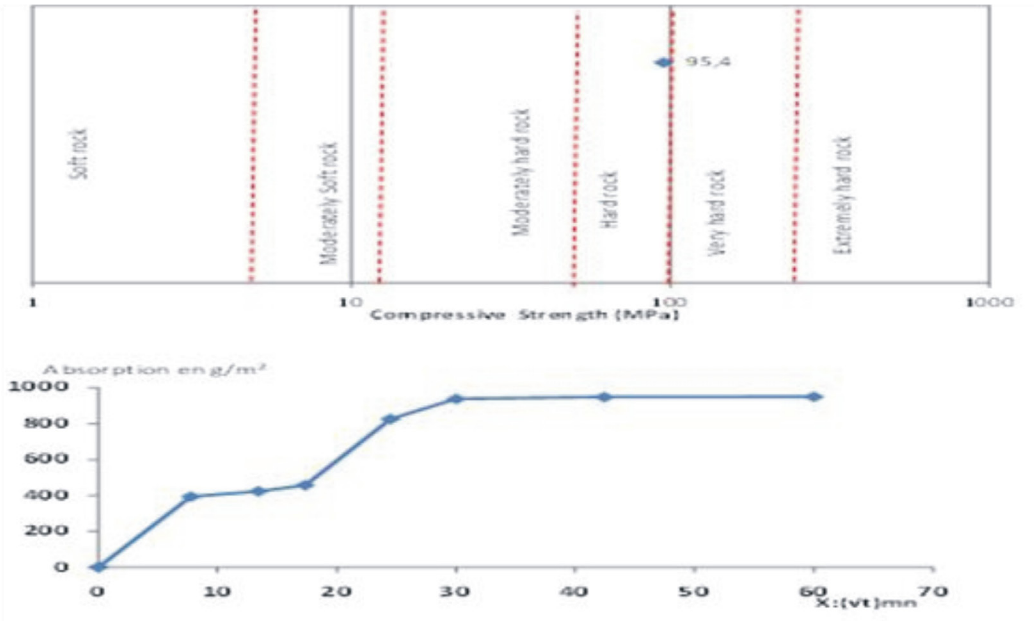

Fig. 7. Absorption rate coefficient and compressive strength diagrams (scheme: D. Wederni)

Fig. 8a. View of quarry 1 (photo: A. Younès)

Fig. 8c. View of quarry 3 (photo: A. Younès)

Fig. 8b. View of quarry 2 (photo: A. Younès)

2) Ancient quarrying techniques

Nowadays, the extraction areas of the quarries that were exploited in the open-air are not well preserved, being partially filled up with alluvium brought by runoffs and soil (Figs. 8a and 8b). Nevertheless, the cutting marks still visible on the quarry fronts provide us with very useful information concerning the extraction techniques and the sizes of the cut blocks. Hence, two methods of extraction could be observed.

The first strategy consisted in exploiting the natural fissures of the rock. Indeed, when the green schist rock did not provide a compact and solid block, but only bedded large-sized blocks separated horizontally and vertically by fissures (*diaklasis* and stratigraphic levels) (Fig. 9), the quarry workers outlined the schist block to be cut by widening these natural planes of weakness

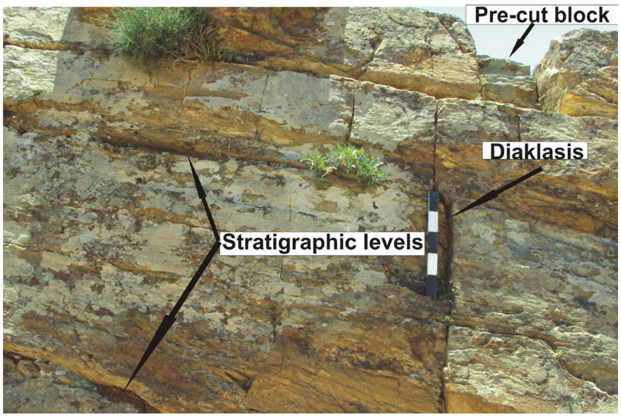

Fig. 9. *Diaklasis* and stratigraphic levels on the front of quarry 1 (photo: A. Younès)

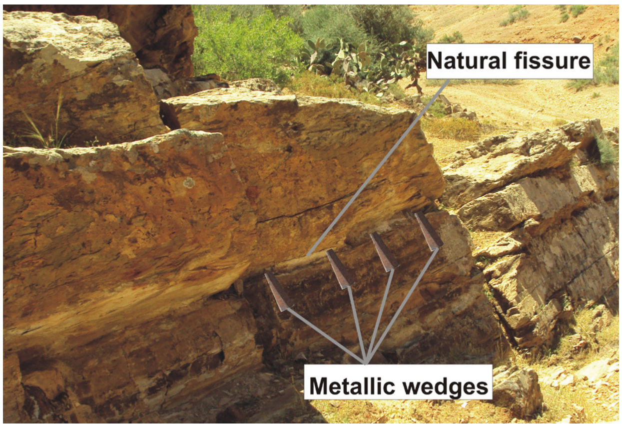

Fig. 10. Extraction technique following the natural fissures in quarry 1 (photo: A. Younès)

LENGTH (m)	WIDTH (m)	HEIGHT (m)
1.25	0.50	0.45
1.22	0.50	0.45
1.20	0.50	0.45
1.15	0.55	0.50
1.08	0.55	0.50
1.02	0.47	0.45
0.98	0.75	0.55
0.97	0.77	0.55
0.96	0.50	0.45
0.90	0.50	0.45
0.83	0.47	0.45
0.75	0.47	0.45
0.60	0.45	0.45
0.52	0.45	0.45
0.50	0.45	0.45
0.42	0.35	0.30

Table 4. Sizes of extracted blocks according to the marks left on the quarry fronts

Fig. 11a. Green schist and antique yellow rubble stones used to build the *cavea* substructions in the Roman theatre (photo: A. Younès)

Fig. 11b. Green schist and antique yellow rubble stones used to build construction walls (photo: A. Younès)

using the *escoude* or the awl in order to get extraction slits (trenches) whom depth depended on the height of the *diaklasis*. Then, they inserted metallic wedges only in the horizontal natural fractures, for it was useless to create a line of fracture in the lower upright side of the rock. Finally, they hammered the wedges in order to break the rock apart (Fig. 10). This quarrying technique, consisting in following the natural fissures of the rock, did not allow the extraction of equal sized-blocks. That's why the large-sized blocks extracted in the quarry site were then cut into small and medium-sized blocks to be then carried to the building sites.

The second strategy concerned rock that did not show any fissures. The quarry workers first outlined the blocks to be extracted on three sides (two vertical and the lower horizontal, because the upper horizontal side of the block has already been detached). Then, with a pick or an *escoude*, they made extraction trenches whose width ranged from 8 to 15 cm allowing the awl or the *escoude* to move in easily. The depth of these extraction trenches depended on the height of the block to be cut.

Fig. 12. Green schist squared blocks used to build a Byzantine tower (photo: A. Younès)

Fig. 13. Remaining parts of column shafts (photo: A. Younès)

Finally, the quarry workers made a line of fracture and wedge holes on the lower horizontal side of the rock in order to insert metallic wedges on which they hammered to detach the schist block from the bedrock. The extracted blocks were small and medium-sized, and required just a little adjustment to be used in the constructions[13] (Table 4)**.**

IV) The uses of the green schist marble stones

The different archaeological field excursions organized with colleagues, archaeologists and students in the ancient archaeological sites situated in the region of Jendouba (*Simitthus*, *Thunusuda*[14], *Bulla Regia and Thugga*) allowed us to identify, even if only partially, the different uses of the green schist marble stones. Indeed, this marble stone was used both as a building stone (building of walls), and an ornamental stone (sculpting columns and funerary monuments, engraving texts).

1) Building stone

In both archaeological sites of Borj Hellal and Chemtou, a number of public constructions and unidentified structures were partially built with green schist squared stones and rubble stones. In Chemtou, the substructures of the theatre *cavea* were constructed with green schist and antique yellow rubble stones, and in both sites the walls of the non identified structures were made of green schist rubble stones (Figs. 11a and 11b). In the site of Borj Hellal, the fortifications and a Byzantine tower were built with medium and large-sized green schist squared blocks (Fig. 12). The sizes of these squared blocks are reported on Table 5[15] and most of these sizes are different from the ancient Roman and Punic units of measurements (cubit and foot)[16].

2)Ornamental stone

a) Sculptured columns

At the site of Borj Hellal several columns were found; some are still in place while others are scattered on the archaeological ground. The bases and the shafts of the columns still in place are partially filled with soil, whereas

13 These two types of extraction techniques were observed in other ancient Tunisian quarries. See YOUNES, OUAJA 2008, 55-82; GAIED *et al.* 2010, 531-549.

14 The ancient town of *Thunusuda* was mentioned through ancient literary and epigraphic sources, but its location in the site of Borj Hellal, situated about 7.5 km East-South-East of *Simitthus* (Chemtou) remains uncertain. This ancient town may correspond to the archaeological site of sidi Meskine located 11 km South-East of ancient *Simitthus* (see CIL, VIII, 22194; SAUMAGNE 1950, 130, note 20 ; Pline l'Ancien, V, 29, . 293 ; LANCEL 1991, 1493 ; VICTOR DE VITA, 292-293, note 93 ; DESANGES *et al.* 2010, 262-263).

15 Some of the squared blocks reported on this table have been mentioned in a previous article (See YOUNES 2014a).

16 The Punic cubit used at Carthage during the Roman period: 50 cm; the Punic cubit used at Lepcis Magna during the Roman period: 51.5 cm; the Roman cubit: 44.4 cm; the Punic foot: 34.3-34.5 cm; the Roman foot used in Africa: 29.4 cm (see HALLIER 1993, paragraphs 2112 and 2116).

Block N°	LENGTH (cm)	WIDTH (cm)	HEIGHT (cm)
1	188	50	38
2	170	65	43
3	130	50	50
4	125	53	50
5	125	50	43
6	122	45	42
7	120	53	41
8	113	53	53
9	110	50	53
10	95	53	45
11	93	75	55
12	91	75	50
13	90	75	53
14	90	50	65
15	80	70	50
16	80	50	30
17	75	60	50
18	70	55	55
19	70	50	50
20	70	50	32

Table 5.
Sizes of the measured squared blocks from the site of Borj Hellal

Fig. 14. Votive stele (photo: A. Younès)

their capitals have disappeared (Fig. 13). The circumferences of the smooth shafts range between 57 cm and 45 cm, and their remaining heights vary from 285 cm to 97 cm. These columns might have been employed for the decoration of an important civic building. A number of the column shafts were measured and their sizes are reported in Table 6 [17].

b) Ornamented and inscribed funerary monuments

Schist marble stone was also used in the decoration of funerary monuments such as the bas- reliefs, steles and funerary cupules.

Thus, in the site of Borj-Hellal a marble bas-relief, representing 8 Moorish divinities aligned in profile with thick hair, was discovered.

The majority of the well preserved funeral steles were discovered in the site of *Simitthus* and are held in the exhibition hall of the Chemtou Museum. A few of them are anepigraphic, only ornamented with decorations, whereas the majority contain epigraphic texts and are sometimes accompanied by decorations[18]. The ane-

17 Some of these column shafts have been mentioned in a previous article (YOUNES 2014a, 241-243).

18 A detailed study on the overall steles exhibited in the Chemtou Museum will give us an invaluable source of information concerning the epigraphic materials, the decorations used and the life of the deceased person.

	Ø x preserved height (cm)
Column shafts still in place partially filled with soil.	50 x 116
	45 x 117
	45 x 97
	40 x 200
	35 x 130
Column shafts scattered on the archaeological ground.	50 x 144
	50 x 136
	45 x 113
	45 x 97
Column shafts re-employed in the Byzantine fortification.	57 x 285
Column shafts re-employed in the marabout of sidi Slama.	Non measured

Table 6.
Sizes of the measured column shafts

Fig. 15. Epitaph of the *Stabilii* family (photo: A. Younès)

pigraphic steles ornamented with decorations date back to the Roman period, such as the votive steles dedicated to Baal Saturne (2nd century - 3rd century) (Fig. 14). Among the inscribed steles sculpted during the Roman period (from the 1st century AD to the 3rd century AD), there is the Gargilius stele (2nd half of the 1st century), the stele of the slave Musunia (end of the 2nd century – 1st half of the 3rd century), and the stele dedicated to the Stabilii family (1st half of the 3rd century) (Fig. 15).

The stone-cutters did not only engrave texts on steles (epitaphs), but also on marble slabs such as the inscription dedicated in honour of Trajan and on columns such as the milestone discovered in the site of *Simitthus* dating back to the end of the 1st century – 2nd century (Fig. 16).

The epigraphs inscribed on the green schist marble steles, inscriptions and milestone were painted in red colour so as to make the engraved letters more visible and more readable[19].

Finally, green schist marble blocks were also used for the sculpting of funerary cupules such as the Gargilii family cupule dating back to the end of the 1st century – first half of the 2nd century (Fig. 17).

19 Further analyses will be made to determine the nature and the components of this red product.

Fig. 16.
Honorific inscription of Trajan (photo: A. Younès)

Fig. 17. Funerary cupules (photo: A. Younès)

V) Attempts to date the quarries and their administration

The green schist archaeological remains discovered at the ancient sites of Chemtou, Borj Hellal, Bulla Regia and Dougga, together with the cutting marks left on the quarry fronts provide only few datable elements concerning the quarrying exploitation and the use of this material.

Indeed, to date the columns still in place, an archaeological excavation is necessary in order to identify the nature and the building date of the monument for which they served as decorations. Moreover, the squared blocks, and the column shaft reused in the Byzantine fortifications in the site of Borj Hellal do not provide any evidence concerning the exact period of their use in the previous constructions. Yet, both the epigraphic (epitaphs) and the anepigraphic steles, together with the inscriptions, give evidence that this green schist marble stone was used during the Roman period (1st century – 3rd century), allowing us to assert that at least one quarry was exploited during the Roman Empire.

Concerning the administration of these quarries no data are available to clarify this question, but their proximity to the Antique Yellow marble quarries in Chemtou (*Marmor Numidicum*) which were an imperial property may lead us to make a link between these quarries. Indeed, according to ancient texts, the exploitation of Numidian marble was under the control of the imperial administration from the rule of the Julio-Claudians to the rule of the Severan Dynasty (14 AD – 235 AD)[20]. Thus, the hypothesis that the green schist marble stone quarries were exploited under the Imperial administration, like the Antique Yellow marble quarries, is probable.

Conclusions

The green schist marble stone from Jebel el Hairech was very well appreciated by builders, sculptors and stone-cutters who used it as building and ornamental stone in the ancient cities of *Thunusuda* (Borj Hellal or sidi Meskine) and *Simitthus* (Chemtou) during the Roman period.

The minero-petrographic analyses, together with chemical analyses and physico-mechanical tests performed on the green schist stone led to the identification of its colour, texture, chemical and mineralogical

20 KRAUS 1993, 55-59; KHANNOUSSI 1993, 65-68; same author 1993(a), 69; RAKOB 1995, 65; KHANNOUSSI 1998, 997-1016; YOUNES 2014, *op. cit.*

composition, as well as its physical properties. The results reveal that this rock is a good construction material as well as a good ornamental stone.

Three quarries were found in the surveyed area of Jebel el Hairech and the preserved cutting marks left on the quarry fronts enabled the identification of the quarrying technique (percussion technique by exploiting the natural planes of weakness of the rock when visible), and the determination of the sizes of the extracted blocks, which vary according to the natural features of the rock face. Indeed, when the rock presented natural fracturing (*diaklasis*), the majority of the extracted blocks were large sized, whereas when the rock face did not show any fissures, the extracted blocks were medium-sized. The large-sized blocks were then cut into small and medium-sized blocks very likely at the quarry site. However, because the three quarries were filled with soil, it was impossible to evaluate the volume of the extracted blocks without making archaeological excavations.

Rubble stones, together with small and medium-sized green schist marble blocks were used in Roman and Byzantine structures. Most sizes of the measured blocks are different from the ancient units of measurements used during the Roman period (Roman Cubit/foot).

Because of the lack of epigraphic texts it is difficult to date the exploitation of the quarries, and to know how they were administered. Nevertheless, other important data such as the periods of use of the green schist marble stone can allow us to assert that these quarries were exploited during the Roman period (1st century AD - 3rd century AD).

Concerning their administration, the hypothesis that these quarries could have been under imperial administration, just like the nearby *Marmor Numidicum* quarries, is plausible.

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