Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 208 (2017) 136–144

Procedia Engineering

www.elsevier.com/locate/procedia

2nd International Joint Conference on Innovative Solutions in Construction Engineering and Management: 16th Lithuanian-German-Polish colloquium and 6th meeting of EURO working group Operational Research in Sustainable Development and Civil Engineering 24 May- 2nd International Workshop on flexibility in sustainable construction, ORSDCE 2017, 24-26 April 2017, Poznan-Puszczykowo, Poland

"Facies Analysis Applied To Quarrying"

A review of the possible use of sedimentology to increase knowledge and use of ornamental sandstones

Francesco Giuseppe Rossi[a, *], Sergio Madonna[a], Salvatore Milli[b]

[a]*Università della Tuscia D.A.F.N.E., via San Camillo del lellis, Viterbo 01100, Italy*
[b]*SAPIENZA Università di Roma, Dipartimento di Scienze della Terra, Piazzale aldo Moro 5, 00185 Roma, Italy*

Abstract

Quarrying is an important economic activity but has several impacts on environment. Some of these impacts can be mitigated or compensated during the activity but the main goal to obtain better results would be digging less material and augmenting the marketable percentage over the amount extracted. Facies analysis could be a useful tool to ameliorate an overall knowledge on sedimentary stone materials, helping improving marketability and reducing the volumes of waste material. This is particularly true on sandstones, usually used as ornamental stones because of their peculiarity in colour, geometry and fossils.
Here we present an example of facies studies on the Manciano Sandstone of the Gamberaio quarry in Tuscany (Italy), in order to valorize its commercial varieties.

Peer-review under responsibility ofthe scientific committee of ORSDCE 2017.

*Keywords:*Quarrying; Manciano; Sandstone; building material; commercial variants;

* Corresponding author. Tel.: +39-0761-357259;
E-mail address: fg.rossi@unitus.it

1877-7058 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of ORSDCE 2017.
10.1016/j.proeng.2017.11.031

1. Introduction

In this paper we present a case-study regarding the application of sedimentological analysis to quarrying activity of a Miocene stratigraphic unit known in the Italian geological literature as Manciano Sandstone. This unit forms several discontinuous outcrops in different zones of north western Latium and southern Tuscany, although the more important outcrops, about one hundred meters thick, occur in southern Tuscany in an area of about 8 square kilometers at 5 km south-eastward from the town of Manciano (Fig. 1). Here this unit is well exposed in three quarries, from north to south, Poggio la Vecchia, Scarceta, and Gamberaio, extracting sandstones mainly for ornamental use (Fig. 1). Despite the name of the lithotype is "Manciano sandstone", there are more than one material produced in these quarries. For example in “Gamberaio” quarry, there are two commercial variants: Grigio Perla Toscano® and Pietra Dorata® (Fig. 2). The main differences between these variants are to be referred to Liesegang rings, a phenomenon strictly related to water circulation, and to the rock colour: Grigio Perla Toscano ® is light grey, whereas Pietra Dorata ® is yellowish. Commercials names themselves reflect this aspect, in fact in the English language their names can be translated as Tuscan Grey Perl and Golden Stone respectively.

In these quarries rock is cut with a diamond-line, and the 3D exposures of the quarry fronts provide good conditions for stratigraphic and sedimentological analyses, a prerequisite in order to define volumes and characteristics of the extracted materials and optimize production. So the main objectives of this paper are: i) describe the sedimentological features of the Manciano Sandstone; ii) define the main depositional environments where these sediments were deposited; iii) assign the main facies and facies association types to the commercial variants, characterizing each depositional environment.

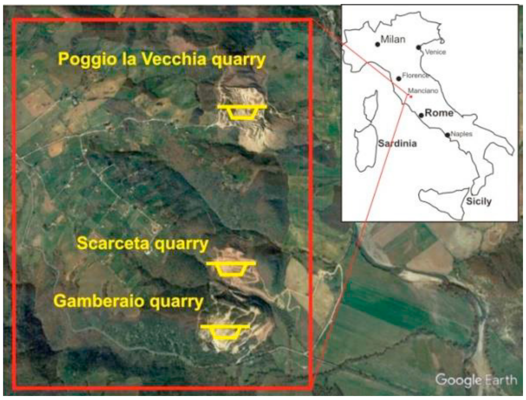


Fig. 1. Location of the study area

a) b)

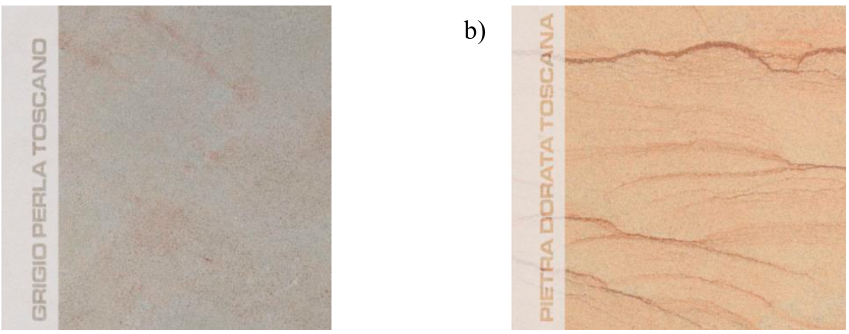


Fig. 2. Commercial variants of the Manciano Sandstone in the Gamberaio quarry: (a) Grigio Perla Toscano ® ; (b) Pietra Dorata ® with distinctive Liesegang rings

2. Materials and methods

2.1. Drone data

Drones or UAVs (Unmanned aerial vehicles) are widely used in mining industry to monitor extracted volumes each year. UAVs collect several overlapping pictures during each survey. These images can be used to return a threedimensional landform model. We acquired data from a recent drone flight over the quarry. We obtained precise details on the site morphology by using an HD ortophotoimage with a resolution as high as 5cm/pixel (Fig. 3). These data were subsequently used for the field work to choose the best fitting sampling sites .

Fig. 3. Orthophotoimage of the "Gamberaio" quarry

2.2. Field data, stratigraphic logs and GIS

In order to obtain detailed stratigraphic data we analyzed every vertical wall in the Gamberaio quarry. Every step of the site was investigated using a self-built device with a HD camera on top and a bluetooth remote control to take pictures (Fig. 4). Images were captured each 40 to 50cm for a maximum of 7 meters high in some steps.

Fig. 4. Self built device with a Camera on top, during the field work.

Pictures, logs and other data were collected and organized with a GIS software (QGIS) for steps and positions. High resolutions images (Fig. 5a) were adjusted (fisheye effect, perspective transformations, etc) and merged with graphic softwares. We obtained 31 columns for each sampling site including detailed photographic data (Fig. 5b).

We finally placed these columns on the orthophotoimage in order to produce an interactive PDF file from GIS data (Fig. 5c).

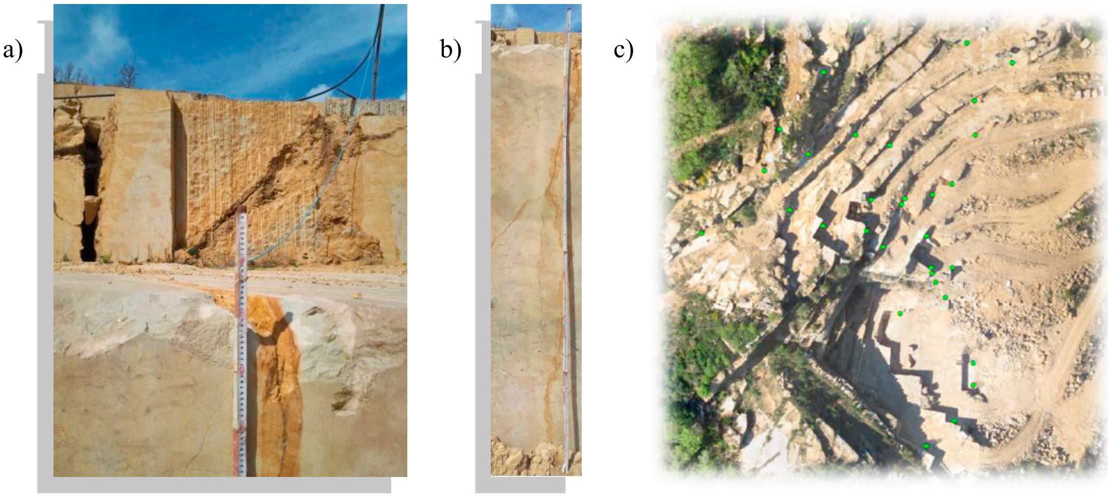


Fig. 5. (a) Single pictures with high resolutions; (b) Merged photographic Columns; (c) Interactive Orthophotoimage

Every step of the quarry was measured and described utilizing the procedure related to facies analysis. We obtained several detailed stratigraphic logs or sections (Fig. 6a) containing data on thickness, lithology and texture of the sediments, type of bedding, physical and biogenic sedimentary structures, paleocurrent directions, fossils and colours. All this allowed us to recognize several facies (i.e beds or bedsets having similiar features in terms of sediment texture, physical and biogenic structures) whose association was used to define the depositional context of the Manciano Sandstone. The different logs were also correlated in order to obtain a correlation panel that allowed to show the geometry of the depositional bodies. Recognized facies are summarized in Tab.1.

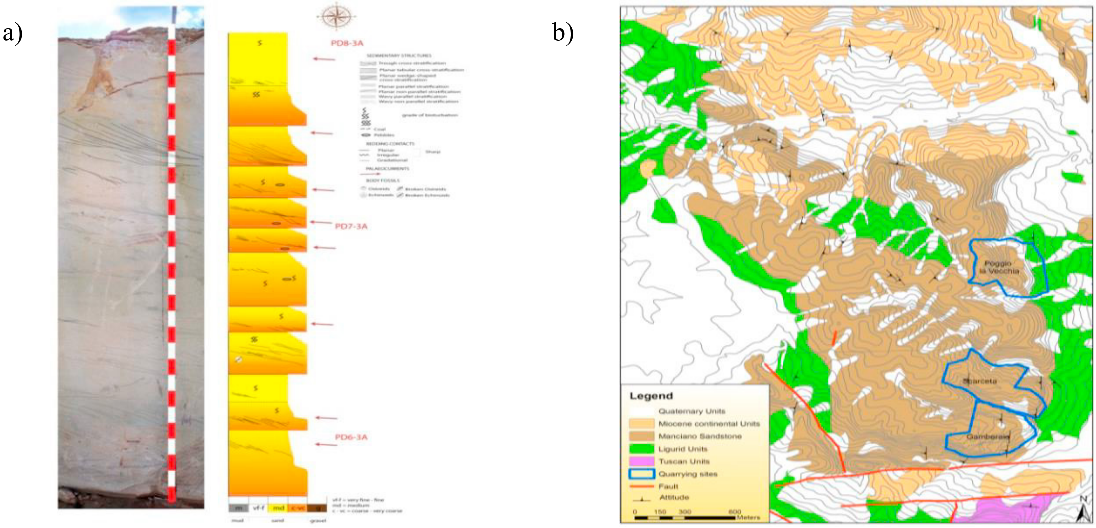


Fig. 6. (a) Example of stratigraphic log; (b) Simplified geological map of the study area showing the location of the quarries.

3. Discussion

3.1. Sedimentological and stratigraphic results

In the investigated sector, the Manciano Sandstone lie down unconformably over a tectonized rock units, known in the Italian geological literature as Ligurids and Epiligure units (Fig. 6b). Both these units developed from the Jurassic to the Eocene and from the Oligocene to the Miocene respectively. [1] [2 [3] [4]

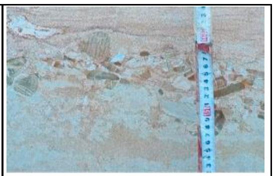
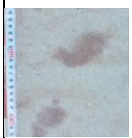
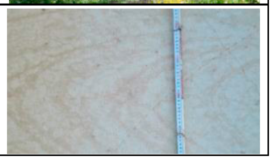
The Manciano Sandstone consists of medium to very coarse, washed, fairly well sorted, lithic to lithic-arkosic sandstone, with calcite cement, and minor intercalations of sandy conglomerates, The sandstone is rich in quartz (30% to 40%), micritic carbonate fragments (up to 30%), feldspar (up to 10%) (both plagioclase and minor microcline), chert and quartzite fragments (3%-5%) and minor amounts of spilitic lavas (possibly of pillow origin) and micas. Zircon, garnet, chromite, magnetite and titanite form the heavy mineral assemblage. Concentrations of heavy minerals (ilmenite, magnetite and minor zircon) occur in thin laminae at a few levels [1] [2]. On the whole, lithology and texture are apparently rather homogeneous in the Gamberaio quarry. However, variations occur from the base to the top of the quarry front that show thick units characterized by thin sandy conglomerates at the base passing upward to thick coarse and medium sands. These units are internally subdivided into smaller units about 30-40 cm thick, which include several physical and biogenic sedimentary structures. The fossils consist primarily of oysters, echinoids (Scutella), sparse microfossils such as foraminifera and occasional bryozoa, and algal fragments.

In the Gamberaio quarry, some main sedimentary facies (Tab.1) have been identified, described and reported in the measured logs (Fig. 6a). Similiar facies have been recognized by Fontana (1980) [1] and Martini et al. (1995) [2], in the quarries of Scarceta and Poggio la Vecchia respectively (Fig.1). These sedimentary facies are present almost in all commercial varieties of Manciano Sandstone, but with different degrees of expression in function of numerous parameters: diagenesis, Liesegang structures, bioturbation, ecc.

The most common structures occurring in the lower and in the middle parts of the Gamberaio quarry (Fig. 7, sectors A and B) include medium-scale cross-stratification formed by the migration of 2D and 3D dunes (tabular and trough-cross-bedding) and small-scale cross-lamination formed by the migration of wave and current ripples; in the upper portion of the succession (upper sector of the quarry front) hummocky (HCS) and swaley (SCS) cross-stratification occur, in some cases strongly folded by post-depositional deformation (Fig. 7, sector D). Other sedimentary features that can be observed along the quarry front are the structures formed by the action of animals within the sediment and at the interface between water/sediment. They include an irregular disruption of the deposits (bioturbation) and the presence of several fossil traces produced by the organisms life style. Locally post-depositional deformation and dewatering structure occur (Fig. 7, sector C). Liesegang rings, which are a constant throughout the succession, follow the main fracture systems interesting the rock bodies, although they are more frequent in the middle western part of the quarry (Fig. 7, sector B).

All of the sedimentary features described above and the types of facies that have been recognized suggest a shallow water marine environment deposition of these sediments, attributable to the sub-environments of upper and lower shoreface. In addition, the evolutionary trend that shows the vertical succession in the Gamberaio quarry is typically transgressive, since it shows, from the bottom to the top of the quarry front, a passage from upper to lower shoreface. Such a trend suggest, over time, a migration of the coastline from the sea to land, a process that, independently of the geological context, is closely linked to a relative rise in the sea level associated with a contiguous decrease of sediment supply to the coastal system.

Tab. 1 - Example of main sedimentary facies (Gamberaio quarry)

Coarse, sandy conglomerates - well washed, poorly to medium well sorted. They are composed of middle-sized pebbles with a few large pebbles to cobbles some with a certain degree of flattening. The clasts are angular to sub rounded and composed of limestone, marlstone, chert, and other lithologies from local substratum; fragments of oysters are present, rare echinoid (Scutella) Matrix is of a very coarse sand and granules.	
Trough cross-bedded sandstone - this facies is composed of fairly well sorted medium to coarse and, in some case very coarse sand forming beds with an average thickness of 20-30 cm. It constitutes the product of migration of small and medium–scale 3D dunes that often are stacked to form more complex bodies 1-2 m thick.	
Planar cross-bedded sandstone - this facies consists of 20-30 cm thick cross-beds, formed by the migration of 2D bedforms, that often are stacked to give rise to more complex bodies 1-1.5 m thick.	
Planar parallel-bedded sandstone - this facies consists of planar parallel lamination medium to fine sandstone where the laminations are marked by good to fairly good separation of dark heavy minerals.	
Bioturbated sandstone - this facies are characterized by dark grayish medium-fine sandstone that are almost completely homogenized, although remnant of cross-bedding and, more rarely, plane stratifications can still be recognized. Where the trace fossils are well-recognized, they give to the rock a particular character that can be used, together with the other physical sedimentary facies for a further and detailed characterization of commercial varieties.	 
Hummocky-cross bedding sandstone - This facies develop in medium to fine sandstone and is characterized by curving lamination with both convex-up (hummocks) and concave-up (swales) portions. Genesis of this structure is strictly related to the action of the wave or to combined flows (wave plus current) that moved during storm events.	
Overturned beds - This facies constitute the product of the sin- and the post-depositional deformation interesting the deposits showing the trough. and the hummocky cross-stratification. Their formation can be related to local gravitative instabilities triggered by high sedimentation rate or by tectonic movements	

3.2. Quarrying techniques and Commercial mapping

In the studied site, production is realized without the use of explosives to avoid rock fragmentation. Quarry has been divided in different areas each one containing similar materials (Fig. 7). Preliminary operations consist in drilling slots. Then vertical and horizontal cuts are made by chainsaws and diamond wires. When wall-cutting operations are over, the block is turned horizontally and cut in rectangular shapes (trimmed). This quarrying technique imply some spatial limitation. In fact, after the detachment of the block, caterpillar, chainsaws and diamond wires needs at least 6 to 10 meters of distance from the wall to work. This means that before extracting stones in the lower part of the quarry, the upper steps has to be quarried.

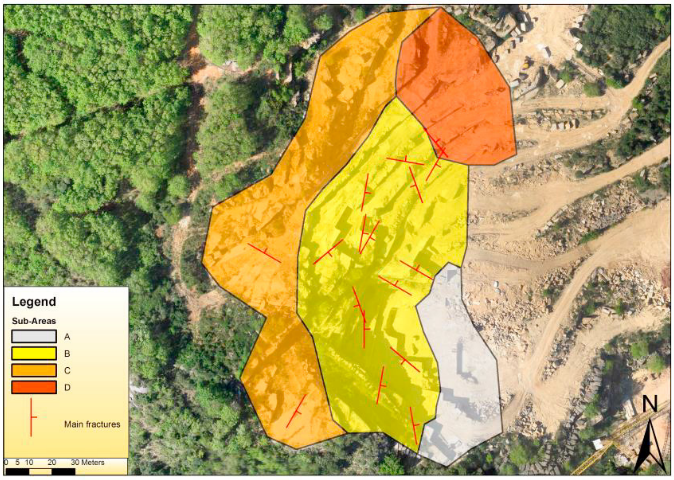


Fig. 7. Commercials subdivision of the "Gamberaio" quarry

In our case, Grigio Perla Toscano and Pietra Dorata are extracted in the lower and in the middle part of the quarry and corresponds with the deposits formed in the proximal to distal upper shoreface respectively; (see figure 7, sub-area A and B). Production in these latter sectors is allowed only after excavation of the upper portion of the quarry corresponding to the sectors C (highly bioturbated upper shoreface) and D (lower shoreface). The rocks of sectors C and D show many characters that do not find much appreciation among potential customers and consequently they are discarded. Since not a large amount of waste can be reused for the final morphological recovery of the site, a large amount of non-sellable material is produced, with an aggravating economic cost and environmental impact.

Market trends are now much oriented to stone materials with homogeneous technical properties such as colour and texture. This homogeneity is achieved in sectors A and B of "Gamberaio" quarry, where Pietra Dorata and Grigio Perla are quarried respectively.

The aim of this study is to identify, within sectors C and D, facies associations that could be considered sufficiently similar, in their "uniqueness" for commercial purposes. If extensions and volumes are sufficient to obtain an homogeneous marketable material, this could lead to plan an excavation in these sectors, increasing production volumes and reducing wastes. An example of how the facies analysis can allow to define within the blocks extracted from the C sector numerous new commercial varieties is shown in the figure 8. Usually rough blocks are 1.7 x 2.5 x 1m but dimensions may vary in case of fractures or for logistic needs. Rough blocks are then cut into slabs with different thicknesses but essentially 2 to 5 centimeters. Slabs are finally cut into commercial dimensions, i.e. 30x20cm or 30x50cm but in general the final product is highly customizable and there is not a specific size for the market.

Fig. 8. An example of the varieties (each of which corresponds to a sedimentary facies), that can be produced by a rational use of the blocks (highlighted in yellow) which can be extracted in the sector C of the quarry

4. Conclusions

Unlike other stones, studying the genetic environment that lead to the formation of sandstones, definining the position and volumes of the main sedimentary facies (through the measure of detailed stratigraphic logs), collecting and organizing data with a GIS program, can give an even more effective tool to help quarrying activities reducing operational costs and emphasizing stone materials. This would translate into a higher pricing, less quarrying activity and more money to apply mitigations and compensations techniques.

Cuts orientation is crucial to highlight sedimentary structures in commercial varieties. Texture and petrographic composition are critical to define the technical characteristics of the stones. Colour (and its variations over time) and the treatments to which each material must be subjected to ensure its durability and stability after it has been extracted and put in place. Moreover, monitoring the quality of each consignment at the extraction site level, could help improving the efficiency of the extraction.

As much data we obtain on particular features and distinctive shapes, the better chance the stone has to be marketable. 3D-modeling of the quarry can help this process too. In fact, applying data collected on a 3D-model can be used as an important commercial tool to show customers, before extraction, which kind of material is feasible for them. As an alternative, selection could be carried out after quarrying, among stocks categories of homogeneous materials with a production fixed cap for each category. However, cutting operations are very expensive thus the last alternative has to be discouraged. This process could be proficiently applied to other quarrying activities and different stones. For these reasons, facies analysis applied to quarrying could lead to a product optimization, less wasting and less environmental impact.

Acknowledgments

This work was supported by Pietra Dorata S.r.l. and Pietre Santafiora S.r.l. who provided commercial and technical data.

References

[1] D. Fontana, Caratteri petrografici e sedimentologici delle Arenarie di Manciano nella Toscana meridionale, Miner. Petrogr. Acta, 1980, pp. 77–94.

[2] I.P. Martini, A. Cascella, A. Rau, The Manciano Sandstone: a shoreface deposit of Miocene basins of the Northern Apennines, Italy, Sediment. Geol. 99 (1995) 37–59.
[3] M. Pellegrini, Osservazioni geologiche sull'Arenaria di Manciano, Mem. Soc. Geol. (1967) 329–342.
[4]M. Barbieri, U. Chiocchini, S. Madonna, Nuovi dati sull'eta dell'Arenaria di Manciano (Miocene) sulla base dei valori di rapporto isotopico 87 Sr/86 Sr (Italia centrale), Boll. Della Soc. Geol. Ital. 122 (2003) 351–354.