15 DEFENSIVE ARCHITECTURE OF THE MEDITERRANEAN

Marco Giorgio BEVILACQUA, Denise ULIVIERI (Eds.)

DEFENSIVE ARCHITECTURE OF THE MEDITERRANEAN

Vol. XV

PROCEEDINGS of the International Conference on Fortifications of the Mediterranean Coast
FORTMED 2023

DEFENSIVE ARCHITECTURE OF THE MEDITERRANEAN
Vol. XV

Editors
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Università di Pisa

PISA UNIVERSITY PRESS
edUPV
Universitat Politècnica de València

International conference on fortifications of the Mediterranean coast FORTMED 2023, 6. <2023 ; Pisa>
Defensive architecture of the Mediterranean, vol. XIII-XV : proceedings of the International conference on fortifications of the Mediterranean coast FORTMED 2023 : Pisa, 23, 24 and 25 March 2023 / editors Marco Giorgio Bevilacqua, Denise Ulivieri. - 3 volumi. - Pisa : Pisa university press, 2023.

Contiene:
[Vol. 1]: Defensive architecture of the Mediterranean, vol. XIII / editors Marco Giorgio Bevilacqua, Denise Ulivieri
[Vol. 2]: Defensive architecture of the Mediterranean, vol. XIV / editors Marco Giorgio Bevilacqua, Denise Ulivieri
[Vol. 3]: Defensive architecture of the Mediterranean, vol. XV / editors Marco Giorgio Bevilacqua, Denise Ulivieri

725.18091638 (23.)
I. Bevilacqua, Marco Giorgio II. Ulivieri, Denise 1. Architettura militare - Fortificazioni - Mar Mediterraneo - Coste - Congressi

CIP a cura del Sistema bibliotecario dell'Università di Pisa

Membro Coordinamento
University Press Italiane

Series *Defensive Architecture of the Mediterranean*
General editor: Pablo Rodriguez-Navarro

The papers published in this volume have been peer-reviewed by the Scientific Committee of FORTMED2023_Pisa

Published with the contribution of the University of Pisa

Pisa University Press
Polo editoriale - Centro per l'innovazione e la diffusione della cultura
Università di Pisa
Piazza Torricelli 4 · 56126 Pisa
P. IVA 00286820501 · Codice Fiscale 80003670504
Tel. +39 050 2212056 · Fax +39 050 2212945
E-mail press@unipi.it · PEC cidic@pec.unipi.it
www.pisauniversitypress.it
ISBN 978-88-3339-794-8 (three-volume collection)
ISBN 978-88-3339-797-9 (vol. 15 and electronic version)

ISBN: 978-84-1396-125-5 (three-volume collection)
ISBN: 978-84-1396-129-3 (electronic version)
ISBN: 978-84-1396-128-6 (vol. 15)

PROCEEDINGS of the International Conference on Fortifications of the Mediterranean Coast FORTMED 2023
Pisa, 23, 24 and 25 March 2023

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DOI:10.12871/9788833397948118

Preface

The heritage of military architecture brings together many fields; it's been called an "inexhaustible source of research and perspectives" for architects, engineers, archaeologists, historians, and operators in the field of cultural heritage. The subject of knowledge and valorization of fortification works presupposes a multidisciplinary approach aimed at recognizing the different values found in the constructions. Only recently has there been an awareness of the importance of this heritage, which is in constant danger; such attention has helped in defining a series of international strategies "for the protection, conservation, interpretation and preservation of fortifications and military heritage" (ICOMOS Guidelines on fortifications and military heritage, 2021).

FORTMED 2023 moves within this rich cultural context in the belief that the dissemination of data is the essential tool for sharing knowledge.

The international conference Fortifications of the Mediterranean Coast, FORTMED 2023, opens its sixth edition in Pisa. The conference, organized by the Dipartimento di Ingegneria dell'Energia, dei Sistemi, del Territorio e delle Costruzioni (DESTeC) of the University of Pisa, in collaboration and with the contribution of the Municipality of San Giuliano Terme, will be held on March 23, 24, and 25, 2023, at the Centro Congressi Le Benedettine.

The original idea of FORTMED, borne of the initiative of a Polytechnic University of Valencia research group coordinated by Pablo Rodríguez-Navarro, was "bringing together researchers working on this topic at a conference whose main objective would be knowledge exchange for the better understanding, assessment, management and exploitation of the culture and heritage developed on the Mediterranean coast in the modern era, bearing in mind the need for the dissemination of the results" (FORTMED 2015, vol. 1).

Thus, the FORTMED 2015 conference, organized at the Instituto Universitario de Restauración del Patrimonio of the Universitat Politècnica de València (October 15, 16, and 17, 2015), was created with the hope that it would be carried on by other research groups and institutions, which would take over the baton to make FORTMED an established reality. And so, it was.

The second edition of the conference, organized at the Dipartimento di Architettura of Università degli Studi di Firenze (November 10, 11, and 12, 2016) and chaired by Giorgio Verdiani, expanded the theme to "the whole family of fortifications of the Mare Nostrum, (from Spain, to France, Italy, Malta, Tunisia, Algeria, Morocco, Cyprus, Greece, Albania, Croatia, etc…) mainly dating from the 15th to the 18th centuries, but not excluding other countries or other fortifications or coastal settlement capable to raise specific interest from the point of view of the suggestions, the methodologies, the complex and inspiring history" (FORTMED 2016, vol. 3).

FORTMED 2017, the third edition, curated (chaired) by Víctor Echarri Iribarren, held on October 26, 27, and 28, 2017, at the Escuela Técnica Superior de Arquitectura of the Universitat d'Alacant, focused "on western Mediterranean fortifications (Spain, France, Italy, Malta, Croatia, Albania, Greece, Turkey, Cyprus, Tunisia, Algeria and Morocco) dating from the 15th to the 18th centuries, including the rest of Mediterranean countries and the fortifications of this era that were built overseas (Cuba, Puerto Rico, Philippines, Panama, etc.)" (FORTMED 2017, vol. 5) and introduced the theme of "Port and Fortification."

The fourth edition of the conference, organized at the Dipartimento di Architettura e Design of the Università Politecnica di Torino, in the Valentino Castle venue (October 18, 19, and 20, 2018), chaired by Anna Marotta and Roberta Spallone, broadened the field of interest in terms of "space, including both

Northern Europe (i.e., Sweden) and Far Eastern (i.e., China) countries; and in [terms of] time, involving studies both on Middle Age defensive architecture and contemporary military buildings and settlements (from the 19th to 21st century)" (FORTMED 2018, vol. 7).

The fifth conference, FORTMED 2020, went through the vicissitudes caused by the COVID-19 pandemic. Initially scheduled for March 26, 27, and 28, 2020, in Granada, it was then moved to an online conference held on November 4, 5, and 6, 2020, organized by the Escuela de Estudios Árabes of Granada under the coordination of Julio Navarro Palazón and Luis José García-Pulido. Fortunately, the web platform allowed for the inclusion of "live talks by invited lecturers, recorded videos, and presentations with the possibility for attendees to comment on and discuss each presentation" (FORTMED 2020, vol. 10). On this occasion, given the relevance of Islamic architecture in the Mediterranean and the previous studies carried out by the Escuela de Estudios Árabes of Granada, this theme was included in the conference.

For this sixth edition, the idea is to foster the solidification of a collaborative, integrated, and up-to-date vision that leads research on this theme to the highest levels, ferrying it into the 21st century. This means also recognizing the value of contemporary architectural heritage (e.g., bunkers built during World War II) and addressing new issues related to its preservation and restoration.

The focal centers of FORTMED 2023 investigations are fortifications in the Mediterranean (Spain, France, Italy, Malta, Tunisia, Cyprus, Greece, Albania, Algeria, Morocco) without excluding other Mediterranean countries and other fortifications built overseas (Cuba, Puerto Rico, Philippines, Panama...).

The conference has an interdisciplinary nature, to which architects, engineers, archaeologists, historians, geographers, cartographers, heritage workers and administrators, tourism professionals, and experts in heritage restoration-conservation and dissemination have contributed.

The results of the research presented at FORTMED conferences over the years are collected in the volumes of the Defensive Architecture of the Mediterranean Series, which with Pisa amounts to 15.

FORTMED 2023 received numerous contributions, which demonstrates the growing interest of scholars in the topic of promoting knowledge, preservation, and enhancement of the heritage of fortified architecture. All the submitted papers were double-blind and peer-reviewed by the members of the Scientific Committee, and among them, about 160 were selected, with authors from Algeria, Austria, Colombia, Croatia, France, Greece, Italy, Morocco, Poland, Portugal, and Spain.

The contributions are collected in these three volumes (vols. 13, 14, and 15), organized according to their content into thematic sections, representing different topics and ways of approaching the study of defensive heritage: Historical research, Theoretical concepts, Research on Built Heritage, Characterization of geomaterials, Digital Heritage, Culture, and Management, and finally Miscellany.

We hope FORTMED 2023 will strengthen knowledge exchange and sharing for better understanding, evaluation, management, and enhancement of the culture and heritage of fortified architecture.

The entire organizing committee gives special thanks to Pablo Rodríguez-Navarro, president of FORTMED©, and to all the members of the Advisory Committee for their valuable advice and constant presence during all phases of the organization of the conference. Heartfelt thanks go to all the members of the Scientific Committee for their expertise and the time they were willing to devote to thoroughly reviewing the submitted proposals.

We also thank the University of Pisa and the administrative secretary of the DESTeC for their active support in the organization of the conference. Special thanks go to the Organizing Committee members for their valuable cooperation. We also thank the municipality of San Giuliano Terme for cooperation in the organization and support.

Heartfelt thanks go to the scientific associations and institutions that were willing to grant their patronage: UID Unione Italiana Disegno, Istituto Italiano dei Castelli – Sezione Toscana, ICOMOS Italia (Consiglio Internazionale dei Monumenti e dei Siti. Comitato Nazionale Italiano), AISTARCH (Associazione Italiana di Storia dell'Architettura), CSSAr (Centro di Studi per la Storia dell'Architettura), Ordine degli Architetti, Pianificatori, Paesaggisti e Conservatori della Provincia di Pisa, municipality of Pisa, municipality of Vicopisano, and Museo Multimediale Rocche e Fortificazioni Valle del Serchio.

Finally, we would like to express our gratitude to all the authors for the quality of their contributions, their attitude regarding the adequacy of the reviews, and their patience throughout the editing process and registration.

The hope is that those who will pick up the baton of the next FORTMED edition will realize increasingly effective synergies and networking opportunities.

Marco Giorgio Bevilacqua, Denise Ulivieri

FORTMED2023 Chairs

Contributions

Characterization of geomaterials

Defensive Architecture of the Mediterranean / Vol. XV / Bevilacqua, Ulivieri (Eds.)

DOI:10.12871/9788833397948122

The building materials of the Rocca della Verruca fortress (Tuscany-Italy)

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Abstract

The Rocca della Verruca fortress rises on the summit of the homonymous mountain, on the eastern side of the Pisan Mountain. It is located in a strategic position which allowed to control the whole mouth of the Arno River. The fortress remained under the Pisan influence until the 15th century, when the Florentine rule begun. After the Florentine takeover, the fortress was inspected by illustrious architects, such as Giuliano da Sangallo and Leonardo da Vinci, who planned to improve its defensive structure. It was the moment when the medieval fortress began to be modernized with the insertion of circular towers and pentagonal bastions, in the same way as the other castles conquered during the wars: the modernization of the defences was attributed to Luca del Caprina and Giuliano da Sangallo. The paper will examine the geomaterials used in the building with a particular focus on mortars and bricks studied according to mineralogical and petrographic methodologies and will verify both the variations occurred during the construction phases and the relationships with the local supply sources.

Keywords: Pisan fortress, Tuscany, geomaterials, building techniques.

1. Introduction

This study is part of a research project which purpose is to understand the heritage value of the Verruca fortress and its state of conservation in view to envisage adequate measures aimed at the conservation and enhancement of this historical architecture. Archaeological investigations aimed at identifying the stratigraphic wall units and the building's evolution phases were carried out together with a laser scanner and photogrammetry survey integrating with high quality drone images. These data were integrated with investigations on structural issues, reporting information on the presence of lesions and masonry deformations that allowed to obtain a picture of the mechanisms of the instability (Pancani & Bigongiari, 2020). This research examines the building materials of the fortress with a particular focus on the composition of the artificial stone materials (bricks, bedding mortars). The results will be useful from the historical point of view and for the future conservation intervention. Indeed, the characterization of bricks and mortars can have considerable potential in the archaeological studies of masonries because these materials contain a lot of technological information, starting from the raw materials to arrive at the 'recipe' of their realization. Their study contributes to the characterization of the masonries even when they are realized with the same stone materials and with similar processing and finishing. [GP, AA, FF, SR]

2. Geographical and historical notes

The Rocca della Verruca fortress is located in the eastern part of the Pisan Mountain on the summit of the homonymous mountain at 537 m.

a.s.l. Its position was strategic because it allowed to control the lower Arno valley and a large part of the seacoast. Indeed, in the Middle Ages the coastal line was much closer to Pisa. This allowed to control the presence of the pirates which in the early Middle Ages had caused serious damage to the Pisan economy and settlements (Dall'Antonia et al. 2001). Moreover, from the fortress it was possible to control the entire network of lakes and rivers, around the Bientina depression, which allowed the connection with Lucca, no longer present today (Ceccarelli Lemut, 2008) (Fig. 1).

The Verruca fortress appears for the first time in the imperial diploma of Henry II of 1020, listed in the possessions of the imperial monastery of San Salvatore di Sesto, closely linked to the Marquis Ugo of Tuscany (Kurze, 1989).

The birth and development of the Verruca fortress are related to the events of the nearby monastery of San Michele founded in 996 in the place of a chapel dedicated to the saint, attested since 861 and owned by the Aldobrandeschi family. The archaeological excavation was conducted since 1996 allowing to discover the entire site (Francovich & Gelichi, 2003).

The fortress remained under the Pisan rule until the 15th century, when it was besieged by the Florentines and conquered with the entire Pisan territory. With the Florentine takeover, the fortress was inspected by renowned architects, such as Giuliano da Sangallo and Leonardo da Vinci (Pedretti, 1972), who planned to improve its defensive structure with the insertion of circular towers and pentagonal bastions, as it was the case of the other castles conquered during the wars. The modernization of the defences was attributed to Luca del Caprina and Giuliano da Sangallo (Taddei, 2007), despite the absence of documents attesting their work. Studies comparing designs, models and surveys of civil and military architectures made by Sangallo have been carried to verify the belonging of some of the Verruca structures to the master's design intentions (Frommel et al. 2018).With the period of peace established by the Florentines and the increasingly less strategic importance of this defensive position, the Verruca fortress was gradually abandoned starting from the 16th century, leaving the structures to deterioration caused by time and, in more recent times, by the strong fires that affected Mount Serra. [GP, AA]

Fig. 1 - The position of Rocca della Verruca fortress in relation to the ancient topography (from Google Earth, Image © 2022 Terra Metrics, modified)

3. The structure of the fortress

Although seriously damaged by historical vicissitudes, it is evident that today's structures are not all belonging to the same construction phase: there is not a unitary project, but as it is usual in the medieval period, the buildings were only redesigned in part to be adapted to the new defensive needs. The Verruca was a watchtower, in visual relationship with a system of surrounding towers, and was fortified with the intention of resisting the typical assaults of the Middle Ages, with high walls and battlements, where the shooting units were positioned. The medieval fortress had walls surrounding the tower. With the process of modernization, the walls of the fortress were rebuilt and probably enlarged by adapting the wall sections to the resistance necessary to deflect the blows of the artillery. Only the portions of masonry around the access door and the battlements to the west are attributable to typical characteristics of the medieval period and can be considered part of the original walls (Pancani & Bigongiari, 2020). The rest of the walls is the result of an enlargement obtained with the construction of embankments. As it is usual for the enceinte of the 15th century defences, against them there was a system of barrel-vaulted galleries. The construction techniques of the fortress walls are of different types, a first one typical of the medieval period and a second of the modern expansion. The oldest structures have a greater attention to the processing of regular and homogeneous construction elements, while the new portions have irregular elements and the almost total absence of horizontal wall texture. The characteristic inclined scarp, which allowed the architectures to resist the blows of the firearms,

Fig. 2 - Fortress mesh with texture, only photogrammetry (photo by Giovanni Pancani)

appears regularly on the northern side and in the pentagonal bastions; there is no trace of it on the southern side, where the wall rises vertically.

At present, the plan is quadrilateral with two round corner towers on the east side, the result of 16th century renovations, and two sharp-edged bastions on the west side (Fig. 2).

The entrance, which is reached by a steep staircase carved into the rock on the east side, still retains traces of the hinges and locking devices and allows entry into the fortress. Inside, the underground structures such as the cistern, the access corridors to the lateral towers and a gabled building (identified as a firehouse), which is missing its roof, are still well preserved. The two largest sides of this structure show an entrance with a monolithic lintel and, on the south side, two splayed windows. In addition, remains of a donjon are present in the rocky peak in the centre of the fortress. The perimeter walls no longer have the battlements (in some places the remains can be glimpsed), but on the inside some of the stone corbels that served as supports for the patrol walkway are still visible. These walls in some places reach considerable height, well over 4 metres (Benvenuti, 2004). [GP, AA]

4. Geological setting

Mount Verruca, on which the fortress stands, forms the nucleus of an anticline structure and is part of the Monte Pisano chain, a mountain system that reaches 900 metres in height and separates Pisa and Lucca. This mountain is part of the "Middle Tuscany Ridge", a geological alignment that represents the deepest part of the structural edifice of the Northern Apennines, in which it is possible to observe the basement of the Tuscan metamorphic units, consisting of relicts of the ancient European Hercynian chain. Three tectonic units have been recognised in Monte Pisano, which can be traced back to the deformation of the continental margin of the Adria plate (Carosi et al. 2006): the Monte Serra, the Santa Maria del Giudice and the Falda Toscana Tectonic Units. The Monte Serra Tectonic Unit and Santa Maria del Giudice Tectonic Unit are composed of Triassic silicoclastic deposits (Verruca Formation) discordant on Hercynian and post-Hercynian successions (Phyllites and quartzites of Buti, San Lorenzo Shales and Brecce di Asciano), and Triassic-Cenozoic carbonate deposits; these two successions were affected by metamorphism in Green Schists facies and are separated by the "Faeta fault zone", a band of tectonic faults approximately 2 km thick.

The Falda Toscana Tectonic Unit crops out in the Monti d'Oltre Serchio and, sporadically, on the south-western slopes of the Monte Pisano: only locally it is affected by a very low metamorphic grade.

In particular, the summit of Mount Verruca is constituted by the basal member of the Verruca Formation (Middle Triassic age, belonging to the Monte Serra Tectonic Unit) which crops out in vertically arranged layers. This member consists of poorly graded polygenic meta-conglomerates with a matrix-supported to clast-supported texture (traditionally called 'Verrucano') and subordinately of coarse meta-arenites.

The clasts, consisting of sericitic quartzites, reddish quartziferous porphyry, phyllites, white quartz and purplish-pink quartz, show a good degree of rounding, poor grading, and grain size from below

Fig. 3 - The northeast round bastion which clings directly to the conglomeratic rock of the mountain peak (photo by Fabio Fratini, 2022)

Fig. 4 - A fire mouth with the hole and lintel made of Verrucano conglomerate (photo by Fabio Fratini, 2022)

Fig. 5 - The trilithic lintel of the gateway made of Verrucano conglomerate (photo by Fabio Fratini, 2022)

1 cm to about 20 cm. The matrix, locally purplish because rich in hematite, consists of quartz, chlorite, and sericite. At the base of the summit, the Violet Schists member crops out. These are violet quartzitic phyllites with interlayers of pink, white or rarely grey or light green quartzites. In the area surrounding the Verruca peak, the Formation of Phyllites and Quartzites of Buti (belonging to the Palaeozoic basement), consisting of an alternation of medium-fine-grained grey quartzitic meta-sandstones and greenish grey or purplish phyllites and metasiltites, and the Monte Serra Quartzite Formation (Upper Triassic age) (Monte Serra Tectonic Unit) consisting of greenish grey to pinkish grey to purplish quartz meta-sandstones, can be also observed.

5. Stone buildings materials

Many of the rocks described in the previous paragraph were used to build the fortress, which clings directly to the conglomeratic rock of the mountain peak (Fig. 3).

In particular, the meta-conglomerate was used in the fire mouths (for the hole and as lintel and threshold) (Fig. 4), in the gateway (in large regularly hewn ashlars and in the trilithic lintel) (Fig. 5), in the first construction phase of the gabled building (in large regularly hewn ashlars and in the lintels of the openings). It was also used sporadically in the perimeter walls in small blocks. Indeed, these walls, as well as the donjon, were predominantly made of small, roughly hewn ashlars of grey to green - purple quartzite from the other geological formations present in the area surrounding the peak (Fig. 6). Quartzite, in small, regularly hewn ashlars, was also used in the second construction phase of the gabled building. Also, in quartzite (in the light green variety) is the threshold of the gateway to the fortress in which the trace of a hinge is visible (Fig. 7).

Other materials include quartziferous phyllites (violet to grey green) used as roof slabs of the gabled building, which now form the collapse layer inside the building, and elements of local white Monte Pisano marble, present as the threshold of some of the small windows of the same building. [FF, SR]

6. Materials and methods

Among the materials used in the construction of the fortress there are also bricks and bedding mortars. The bricks in particular have been used in the basement of the north-east tower, in the construction of many of the vaults of the underground rooms, in the construction of the splayed openings of the fire mouths and in thre numerous renovations of the perimeter walls to fill in the gaps (see Figg. 3-4).

Bricks and bedding mortar were sampled according to the different construction phases. Their position is reported in Fig. 8. The following investigations were carried out:

- the mineralogical composition was determined on the ground samples using a PANalytical X'PertPRO diffractometer with CuK1 = 1,545 Å radiation, operating at 40 KV, 30 mA, investigated range 2θ =3-70°, equipped with an X' Celerator multidetector and High Score data acquisition and interpretation software;
- the petrographic study was carried out on thin section (30 microns thick) observed under a

transmitted polarised light optical microscope (ZEISS Axioscope. A1 equipped with a camera (5-megapixel resolution).

Regarding the mortars, there are many characteristics to investigate, as the amount and type of binder, the grain size and composition of the aggregate, the type of lime lumps. This makes it possible to differentiate them, to confirm different construction phases and to identify new ones. Concerning the binder, the study of lumps gives information about the kind of carbonate stone that was burnt to produce the lime (Pecchioni, E., Fratini, F. & Cantisani E., 2014; Pecchioni et al. 2014; Scala et al. 2021). As for the bricks, the amount and kinds of framework (use of a lean or fat earth) can be recognized. The mineralogical analysis via x ray diffraction will give information about the possible use of a marly clay (presence of calcium silicates) and will give an estimation of the firing temperature. [FF, SR]

Fig. 6- The small, roughly hewn ashlars of grey to green-purple quartzite constituting most part of the perimeter walls (photo by Fabio Fratini, 2022)

Fig. 7- The threshold of the gateway to the fortress made of a light green variety quartzite with the trace of a hinge (photo by Fabio Fratini, 2022)

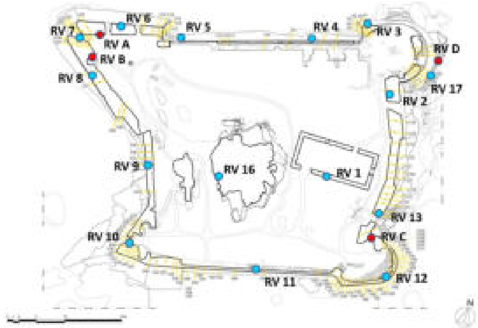

Fig. 8- Localisation of the samples: in blue, the bedding mortars; in red, the bricks (graphic elaboration by Silvia Rescic)

7. Results

The mineralogical-petrographic study of the bedding mortars shows that all of them were made with an air hardening lime binder without the addition of hydraulic additives. From the manufacturing point of view, it also appears that this lime was adequately purified from under burnt limestone fragments as evidenced by their absence in the mixtures. Compositionally, the aggregate does not show differences and consists of crystal clasts of quartz and calcite, lithic fragments of quartzite, quartz-micaschists, and micritic limestones. There are, however, differences in terms of the mixing recipe among the different construction phases. The earliest mortars (first phase of the gabled building [sample RV1], core of the jamb of the gateway [sample RV 13]) show a mixture with little amount of binder and a fairly coarse-grained aggregate (> 2 mm) (Fig. 9).

The mortars of the north, west, south, and east sides walls and of the sharp-edged bastions of the west side have a fine-grained unimodal aggregate (100-300µm) and a relatively abundant binder (with a binder/aggregate ratio of 1/2-1/3) (Fig. 10). The mortars of the 16th century circular bastions on the east side show an aggregate with a medium unimodal grain size (400-500µm) and an abundant binder (binder/aggregate ratio of 1/2) (Fig. 11).

Overall, it can be stated that all the bedding mortars, both medieval and more recent, were carefully prepared with adequate aging and selection of lime putty as evidenced by the

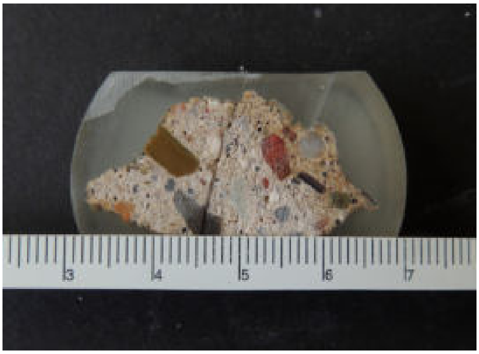

Fig. 9 - Cross section of a bedding mortar of the earliest building phases, with a fairly coarse-grained aggregate (photo by Silvia Rescic)

Fig. 10 - Cross section representative of the bedding mortar of the north, west, south, and east sides walls characterized by a fine-grained unimodal aggregate (photo by Silvia Rescic)

low amount of lumps. Furthermore, the more recent mortars show a particular selection of the aggregate grain size.

Regarding the origin of the raw materials to produce mortars, the lime was most likely produced close to the outcrops of the carbonate rocks found at the base of the mountain (current localities of Caprona and Uliveto Terme). These carbonate rocks belong to the Rhaetavicula contorta Limestone Formation (Upper Triassic age) of the Falda Toscana Tectonic Unit) and to the Marble Formation of the Monti Pisani (Lower Jurassic age) of the Monte Serra Tectonic Unit. The aggregate also seems to come from the plain at the base of the mountain because it shows the presence of marble and limestone fragments, lithotypes that do not outcrop in the vicinity of the fortress.

The bricks show mixtures of homogeneous appearance with a quite abundant framework of fine grain size (50-200 µm) and a scarce presence of argillaceous rock fragments (Fig. 12). As for the groundmass, some bricks show a not birefringent aspect while others are birefringent, indicating in this case a lower firing temperature but still starting from the same raw materials which are the clayey sediments of the alluvial plain at the base of the mountain.

Regarding the conservation condition of these materials, there are no particular problems. The Verrucano conglomerate is a rock of high cohesion, difficult to shape due to its heterogeneity. The stonemasons that in the Middle Ages shaped them

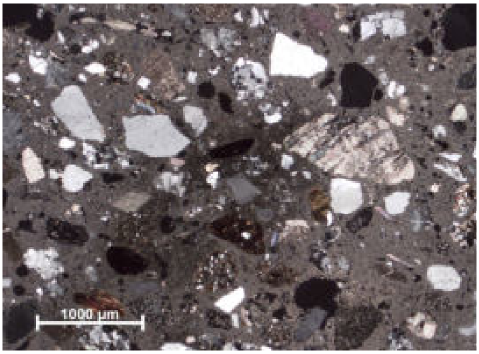

Fig. 11 - Brick with a quite abundant framework of fine grain size and random presence of argillaceous rock fragments; image at the optical microscope in thin section, crossed polarized light (photo by Silvia Rescic)

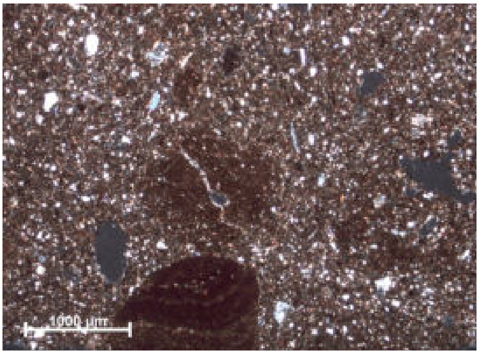

Fig. 12 - Bedding mortar of the 16th century circular bastions with a medium grained unimodal aggregate (image at the optical microscope in thin section, crossed polarized light) (photo by Silvia Rescic)

into large, regular blocks had considerable skills. The quarzites also show good durability. Only the finer and schistose varieties may show exfoliation phenomena. They were certainly easier to work than conglomerate due to their homogeneity and oriented texture, which facilitated their splitting into regular surfaces. As for bricks and mortars, both show considerable cohesion. This is explained by a careful production process with raw materials free of soluble salts. Furthermore, concerning the mortars, the petrographic study has revealed noteworthy recrystallization phenomena in the binder matrix, a process that contributed to increase their cohesion. [FF, SR]

8. Conclusions

The building materials used in the Rocca della Verruca fortress reflect the nature of the rocks outcropping in the surroundings. In fact, given its perched position, difficult to reach even today (almost two hours' walk from the plain below), it was necessary to exploit the local stone resources. Thus, in the perimeter walls and in the internal buildings it is possible to recognise rocks belonging to the Verrucano formation, the Violet Schists, the Buti Phyllites and the white marble of Monte Pisano. As for the artificial stone materials, the bricks were produced by firing the clayey sediments of the alluvial plain at the base of Mount Verruca while the bedding mortars, both medieval and more recent, are made of a local aggregate, from the plain at the base of the mountain, consisting of quartz, quartzite, quartz-micaschists, sparitic and micritic limestones. The lime binder was produced from the carbonate rocks outcropping at the base of the mountain (current localities of Caprona and Uliveto Terme) belonging to the Rhaetavicula contorta Limestone Formation and the Monti Pisani Marble Formation.As regards the conservation conditions of these materials, the stone ashlars do not show any specific problem of decay, as they are made of rocks of good cohesion and durability. Likewise, concerning bricks and bedding mortars, the care in the selection of the raw materials and processing ensured a good durability. [GP, AA, FF, SR]

Author contributions

Authors' contributors are indicated by the initials of their names at the end of each paragraph: GP (Giovanni Pancani); AA (Andrea Arrighetti); FF (Fabio Fratini); SR (Silvia Rescic).

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Volume pubblicato nel mese di marzo 2023

PISA UNIVERSITY PRESS

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