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## 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 15<sup>th</sup> 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 15<sup>th</sup> 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 16<sup>th</sup> century, leaving the structures to deterioration caused by time and, in more recent times, by the strong fires that affected Mount Serra. [GP, AA]

### 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 15<sup>th</sup> 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. 1- The position of Rocca della Verruca fortress in relation to the ancient topography (from Google Earth, Image © 2022 Terra Metrics, modified)



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 16<sup>th</sup> 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 Breccie 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 trilitic 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 metasilites, 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 ashlar and in the trilitic lintel) (Fig. 5), in the first construction phase of the gabled building (in large regularly hewn ashlar 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 ashlar 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 ashlar, 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 the 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  $2\theta = 3-70^\circ$ , 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

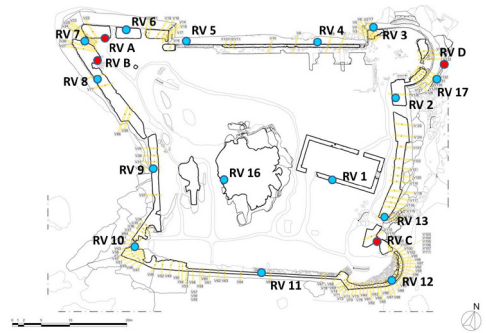


Fig. 8- Localisation of the samples: in blue, the bedding mortars; in red, the bricks (graphic elaboration by Silvia Rescic)

calcium silicates) and will give an estimation of the firing temperature. [FF, SR]

## 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 ( $> 2 \text{ mm}$ ) (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 ( $100\text{-}300\mu\text{m}$ ) and a relatively abundant binder (with a binder/aggregate ratio of  $1/2\text{-}1/3$ ) (Fig. 10). The mortars of the 16<sup>th</sup> century circular bastions on the east side show an aggregate with a medium unimodal grain size ( $400\text{-}500\mu\text{m}$ ) 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. 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. 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)

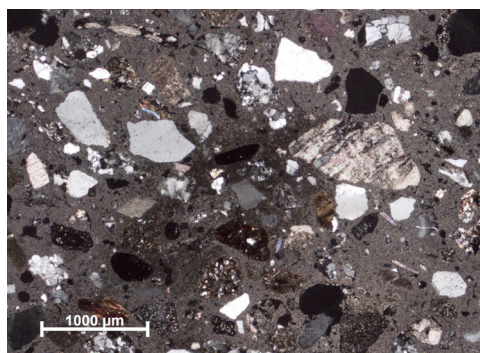


Fig. 11- Brick with a quite abundant framework of fine grain size and random presence of argillaceous rock fragments; image at the optical microscope in thin section, crossed polarized light (photo by Silvia Rescic)

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  $\mu\text{m}$ ) 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

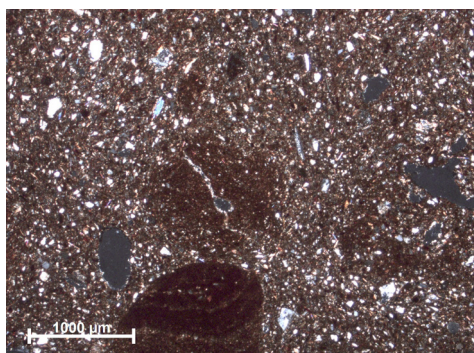


Fig. 12- Bedding mortar of the 16th century circular bastions with a medium grained unimodal aggregate (image at the optical microscope in thin section, crossed polarized light) (photo by Silvia Rescic)

into large, regular blocks had considerable skills. The quartzites 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 Liveto Terme) belonging to the Rhaetavacula contorta Limestone Formation and the Monti Pisani Marble Formation. As regards the conservation conditions of these materials, the stone ashlar 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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