MINERAL-PETROGRAPHIC AND PHYSICAL-MECHANICAL CHARACTERIZATION OF HYBLEAN LIMESTONES

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Since the antiquity, in Eastern Sicily different varieties of Hyblean limestones have been employed in constructive activities (walls, farms, villas, civil and religious architectures), due to the easy availability, workability and extractivity of stones.

After the earthquake of 11th January 1693, which destroyed the major part of Eastern Sicily, an intense reconstruction building activity took place in different urban cities of the Val di Noto (Ragusa, Modica, Scicli, Noto, Siracusa, etc.), allowing to the Sicilian architecture to reach a splendid and autonomous flowering of Baroque forms because of the ability of the local architects and workers and to the easy workability of local stones. The numerous baroque monuments and buildings of Eastern and Western Sicily have been recognised as Cultural Heritage by the UNESCO for their exceptional historical and artistic interest.

Observing the conservation state of these monuments, it is evident that carbonate rocks employed are characterized by different type of degradation and/or alteration.

It is known that degradation depends on the intrinsic characteristics of the materials (mineralogical composition, textural features) and on external factors as the implementation, the conditions of exposure to the atmospheric agents, the rate of environmental pollution and the previous restoration works.

For this reason, we carried out a study on the mineral-petrographic and physical-mechanical features of the carbonate stones used in historical Baroque monuments of the Val di Noto with the purpose of underlining the compositional and textural differences. These characteristics were related to the weathering types both reproduced in laboratory through accelerated ageing tests and directly observed on the monuments. In this study, we used stone parameters that have an influence on durability and depend only upon pore structure: connected porosity, the water absorption coefficient by capillarity, the saturation coefficient. We also used stone parameters with an influence on strength: flexural strength, uniaxial compressive strength, Young's dynamic modulus and ultrasound wave velocity. Analytical methodologies carried out are: thin section microscopic analysis, determination and grain size distribution of the insoluble residue, mineralogical analysis through X-ray diffractometry, mercury intrusion porosimetry, colorimetric analysis, determination of water absorption coefficient by capillarity (UNI EN 1925), determination of water absorption at atmospheric pressure (UNI EN 13755), determination of the open porosity through hydrostatics balance, determination of the drying index (NORMAL 29/88), determination of the resistance to the crystallization of the salts (UNI EN 12370), measure of the speed of sound propagation (NORMAL 22/86), determination of uniaxial compressive strength (UNI EN 1926), determination of flexural strength under concentrated load (UNI EN 12372), determination of the elastic modulus to uniaxial compressive strength (UNI 9724/8-92).

The laboratory analyses were carried out on specimens (n° 467) belonging to five geological formations outcropping in the Eastern and Western Hyblean Plateau for a total of ten sites of sampling. The geological formations examinated are the *Climiti Mountains Formation (Melilli white limestone)*, the *Carrubba Mountain Formation (Lumachelle limestone)*, the *Pleistocene Bench (giuggiulena or ochred*

calcirudite), the *Palazzolo Formation (yellowish and pale cream limestone)* and the *Ragusa Formation (Ragusa, Modica and Scicli limestone)*. The materials have been sampled in historical quarries because they represent the most likely extraction sites of the materials used in historical Baroque monuments of the Val di Noto. The major part of stones object of the study is not currently extracted or used as exception of the Palazzolo Formation limestone. This last one has been in fact quarried both in historical and in recent quarries.

Briefly summarizing, the results of studies conduced so far showed that:

The *Pleistocene ochred calcirudite* from a petrographic viewpoint can be classified as biosparite or grainstone with a grain-supported texture (Fig. 1) formed by fragments of algae, foraminifers and bryozoans shells. The intergranular space is filled with sparry calcite. The porosity determined by optical microscopy is 30-40% and the mean pore diameter is about 1-2 mm whereas the porosity determined by mercury intrusion porosimetry is markedly inferior (11%). This characteristic influences the mobility of

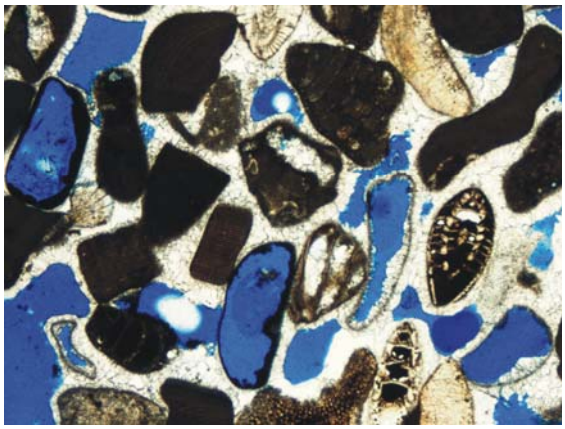

Fig. 1 - Grain supported texture (2.5 x).

the fluids inside the material, in fact, during tests of water absorption by capillarity and by total immersion all the samples produced a "sponge effect" saturating (shortly after 1 minute in the capillarity test) and releasing part of the water for gravity very quickly.

The principal effect of such characteristics is that the material does not degrade during the test of salt crystallization because are not present evident pore of small dimensions ($\phi < 0.1$ mm) and there are not therefore conditions for the development of high pressures of crystallization. From a mechanical standpoint this limestone records low values of uniaxial compressive and flexural strength.

The *Lumachelle limestone*, from a petrographic viewpoint can be classified as biosparite or packstone and shows good petrophysical and mechanical characteristics: high values of uniaxial compressive and flexural strength, high ultrasonic wave velocity, low coefficient of water absorption by capillarity, mean weight loss after salt crystallization test around 17%. Most common types of weathering are selective weathering, granular disgregation and sometimes detachment around shell pile (Fig. 2).

Fig. 2 - Selective weathering and detachment around shells pile.

The *Melilli white limestone*, classified as wackestone or biomicrite, shows high values of water adsorption coefficient by capillarity, high values of porosity, open porosity and coefficient of imbibition. The mean weight loss after salt crystallization test is about 27% and the common

weathering types are flaking, produced by detachments of small, thin, stone flakes parallel to the stone surface, granular disgregation and selective weathering around the accumulation of worms' pipe. From a mechanical viewpoint, they have a middle degree of compactness testified by high ultrasonic wave velocity, high values of uniaxial compressive and flexural strength and elastic modulus.

From a petrographic standpoint the *Palazzolo Formation limestones* can be classified as biomicrite or wackestones.

It is possible to recognize within such formation two different lithofacies: pale cream limestones, represented by the samples quarried near Cassibile (Cassibile historical quarry) and Palazzolo Acreide town (Camelio modern quarry) and yellowish limestones quarried near Ancient Noto (Leone historical quarry) and Noto town (Porcari modern quarry). The first lithofacies is more compact and has a percentage of insoluble residue inferior to 3%; the second results less compact and shows 3% great insoluble residue. In detail, the pale cream limestone displays better mechanical properties than the yellowish one. Indeed it has, higher ultrasound wave velocity, higher values of uniaxial compressive and flexural strength and elastic modulus. (Index of a great compactness and a great specific weight). From a physical point of view the pale cream limestone displays values of the parameters determined (porosity, water absorption coefficient by capillarity, open porosity, coefficient of imbibition, weight loss after salt crystallization test) better then to yellowish one.

Both lithofacies show as principals types of weathering a selective weathering (loss of material takes place around "skolithos") (Fig. 3) and chromatic alteration.

Fig. 3 - Loss of material around "skolithos" during II-VI-XV salt crystallization cycle.

Ragusa Formation limestones can be all classified as biomicrite or packstones. The limestone quarried around Scicli town is the most resistant to the crystallization salt test (mean weight loss is about 34%) that is probably related to the better textural characteristic and to the higher degree of compactness testified by higher ultrasonic wave velocity. The Modica limestone exhibits petrographic features similar to those of the Scicli and Ragusa limestone, although it suffered a higher mean weight loss (64%). During the test of salt crystallization a progressive flaking of the samples occurred parallel to the stratification and it shows a higher percentage of insoluble residue (about 7%). From a physical-mechanical viewpoint the Ragusa limestone is the cheapest within the Ragusa Formation.

The analytical techniques, employed in this study, enabled the characterization of Hyblean limestones used in historical Baroque monuments of Val di Noto and the identification and correlation with their degradation forms.

It is determined therefore that the principal causes of degradation types, with the exception of the ochred calcirudite, are pressures produced by the salt crystallization. This determines nevertheless in the different material forms and different intensity of degradation tied up to the intrinsic characters of the rocks. In fact salt weathering, quantified by the percentage of weight loss after salt crystallization ($Na_2SO_4 \cdot 10H_2O$) is dependent on textural features such as heterogeneities, type and dimension of pores, percentage of insoluble residue, stratification, etc.

Opportune mineral-petrographic and physical-mechanical investigations are therefore necessary in order to perform the correct choice of materials adequate to the architectural site, either for the construction of new buildings or substitutions during the restoration.

Future studies will be focused on the material pore network and changes in physical-mechanical properties of this in response to salt crystallization tests.