THE PIETRA DI CUSANO IN THE HISTORICAL ARCHITECTURE OF CAMPANIA REGION: TECHNICAL FEATURES AND VALORISATION PERSPECTIVES

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INTRODUCTION

The present study brings new information on the lithofacial features, the mineralogical-petrographical and physico-mechanical characters and the weathering phenomena of the Pietra di Cusano or Bryozoan and Lithothamnion Limestones (BLL), commercially known as Perlato Royal Coreno.

The stone crops out over vast areas in central and southern Italy (Campania, Lazio and Abruzzo regions) ad has been widely employed from Roman times (as demonstrated by several findings in the archaeological sites of Minturno, Cassino and Pompei), through the Medieval period (*e.g.*, the bell tower of the Santa Chiara monastery in Naples) to modern times (*e.g.*, the XIX Century Bourbon Bridge on the Garigliano river, near Minturno). BLL are appreciated as a valuable building stone today as well (*e.g.*, the Montecassino Abbey, rebuilt in the 1950s).

The investigated samples were collected from two quarry areas located at Coreno Ausonio (Cava La Valle - Frosinone province) and at Pietraroja (Cava Canale - Benevento province). The selection of the former site is due to the presence of all the commercial varieties; on the contrary material from the latter site was studied for its historical importance, since it represents a stone used for a long time in the architecture of Campania region (Italy).

RESULTS AND DISCUSSIONS

The results of sedimentological, mineralogical-petrographical and physico-mechanical analyses allowed to define the properties of BLL that, although widely employed over several centuries, had never undergone such a systematic investigation.

Sedimentological analysis

Eight lithofacies were identified in the BLL of the Coreno Ausonio district and six in the Pietraroja one on the basis of the textural characters, the relative abundance of the main biogenic components and the rhodolith dimension and shape as observed on polished rock slabs and in thin sections.

By integrating the sedimentological description with the commercial classification used in the Coreno Ausonio district, it was possible to correlate each lithofacies to a specific commercial rock type as defined in the Perlato Royal Coreno Manual (Consorzio per la Valorizzazione del Perlato Coreno, 2002).

The main biogenic components are bryozoans, corallinacean algae, mollusk shells, with minor contribution by serpulids and balanids. Larger benthic foraminifers (*i.e.*, *Amphistegina* sp., *Gypsina* sp., *Elphidium* sp., *Heterostegina* sp.) and planktic foraminifers and echinoid remains are abundant in the matrix.

The recognised lithotypes are given and described in Table 1.

Table 1 - Sedimentological and petrographical characterization of the BBL from Cava Canale and Cava La Valle.

Rock type	**Lithofacies*** (Embry & Klovan, 1971)	**Main macroscopic characteristics**	**Porosity type** (Choquette & Pray, 1970)	**Petrography**
Perlato	Rhodolith rudstone	Large rhodoliths (at least 10 cm in diameter)	Fracture Porosity	calcite, dolomite, quartz.
Mezza Perla	Rhodolith floatstone	Smaller often distinctly elongated rhodoliths than in Perlato	Fracture Porosity	calcite, dolomite, quartz
Perlatino	Rhodolith and oyster rudstone – floatstone	Small rhodoliths and abundant mollusks shells	Fracture Porosity	calcite, dolomite, quartz
Risatino	Red algae and bryozoan grainstone – packstone	Absence of large rhodoliths	Fracture – Intraparticle Porosity	calcite, dolomite, quartz
Botticino	Red algae and bryozoan rudstone	Absence of rhodoliths	Fracture Porosity	calcite, dolomite, quartz
Conchigliato	Bryozoan, coralline algae and mollusk shells rudstone	Rare and small rhodoliths and abundant mollusk shells	Fracture Porosity	calcite, dolomite, quartz
Svirgolato	Bryozoan, oyster and red algae rudstone	Abundant mollusk shells	Fracture Porosity	calcite, quartz
Nocciolato	Bryozoan, coralline algae and mollusk shells rudstone	Abundant bryozoans	Fracture Porosity	calcite, quartz

Among the lithofacies cropping out at Coreno Ausonio, only those corresponding to the commercial varieties Perlato, Mezza Perla, Perlatino, Botticino, Conchigliato and Risatino were recognised also in the Campanian outcrop of Cava Canale (Fig. 1). The specimens from this outcrop exhibit the same texture and lithofacies characters of the analogues of Coreno Ausonio. However, minor differences in the biogenic composition and in the relative abundance of biogenic components were sometimes observed in a single lithofacies both in the same locality and between the two sampled localities (Fig. 1). This indicates that the Coreno Ausonio and the Pietraroja area experienced very similar paleoenvironmental conditions during the deposition of the BBL. All the lithofacies recognized at Cava La Valle and at Cava Canale can be referred to the middle sector of a carbonate ramp, according to the depositional model proposed for the BLL by Corda & Brandano (2003).

Mineralogical and petrographic analyses

Mineralogical and petrographical characterization was performed by means of X-ray powder diffraction, X-ray fluorescence and optical and electron microscopy.

The cold cathodoluminescence microscopy enabled to recognise the calcitic cements filling the fractures and the intraparticle voids of fossils (*i.e.*, Coralline Red Algae and bryozoans) for both Cava La Valle and Cava Canale specimens.

Porosity was studied, for Cava Canale specimens, under UV-reflected light and classified (Table 1) according to the Choquette & Pray classification (1970).

The X-ray powder diffraction pointed out the presence of calcite and, in minor amount, quartz in all the lithofacies. The insoluble residue, obtained only for Cava Canale samples, is essentially constituted by quartz and smectite, kaolinite, illite and rarely titanium oxide and feldspar.

X-ray spectrometric analysis highlights the presence of a minor amount of MgO in the Cava Canale samples than in the Cava La Valle ones.

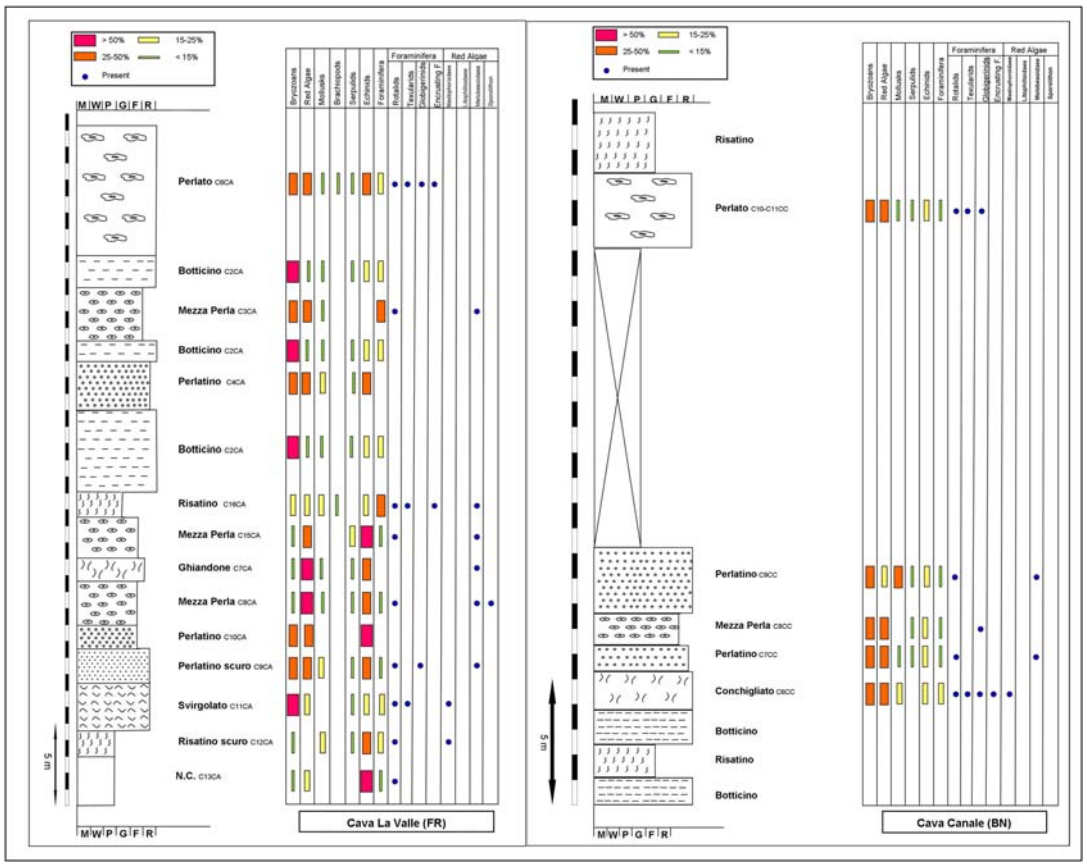

Fig. 1 - Lithological logs for the sites of Cava La Valle (FR) and Cava Canale (BN). M, mudstone; W, wackestone; P, packstone; G, grainstone; F, floatstone; R, rudstone. The relative abundance of the biogenic components and the occurrence of particular taxa of red algae and foraminifers are shown in the table on the right.

Petrophysical analysis

The petrophysical characterization was carried out according to the European-suggested standards (UNI EN, Normal) and ISRM suggestions. Ageing tests were also performed.

The tested lithofacies were Botticino, Mezza Perla and Perlatino both from Cava Canale and Cava La Valle and on Risatino and Perlato sampled in Cava Canale and on Nocciolato sampled in Cava La Valle.

The main physical-mechanical parameters are given in Tables 2 and 3.

Specimens from both the sampling areas gave low porosity, imbibition coefficient and capillarity absorption coefficient values.

BLL from both the sites showed good performance in terms of mechanical strength, as confirmed by the UCS tests and by the ultrasonic velocities.

The experimental data show that the UCS values for all the studied lithofacies are higher for the Cava La Valle samples than for the Cava Canale ones. The difference in the UCS values between the two areas could be linked to the presence in the Cava Canale samples of calcite-filled microfractures, well

visible in cold cathodoluminescence microscopy. These microfractures could act as preferential cracks, even if they do not contribute significantly to open porosity. Besides, the higher UCS values of Cava La Valle samples could be partly due to the major concentration of MgO (Allocca, 2007; Vola, 2009).

The main index properties of the BLL are comparable to the ones of other sedimentary rocks widely employed as ornamental stones throughout the architectural history of the Campania region (Breccia Irpina, Marmi di Mondragone, Marmi di Vitulano, Pietra di Bellona, Pietra di Padula; Allocca *et al.*, 2010).

Table 2 - Petrophysical characterization (mean values) – Cava Canale.

Cava Canale					
Lithofacies	**Perlato**	**Mezza Perla**	**Perlatino**	**Botticino**	**Risatino**
Apparent density (kN/m^3)	26,13	26,06	25,83	26,04	25,43
Bulk density (kN/m^3)	26,33	26,31	26,20	26,47	26,29
Open porosity (%)	0,76%	0,95%	1,41%	1,65%	2,40%
Compattezza	0,99	0,99	0,99	0,99	0,97
Imbibition capacity (%)	0,40	0,37	0,45	0,25	1,10
Capillarity coefficient (g/cm^2·s$^{0.5}$)	4,61E-05	4,78E-05	5,65E-05	3,37E-05	1,97E-04
P-wave dry velocity (m/s)	6126	6113	6057	6090	5495
P-wave wet velocity (m/s)	6354	6298	6237	6221	5725
Uniaxial compressive strength (MPa)	185	160	161	182	162
Brazilian strength (MPa)	8,3	9,8	9,8	9	7,2
Rupture energy (J)	2,61	3,76	3,11	2,65	4,09
Abrasion resistance (mm)	19,19	16,81	16,94	16,88	18
Hardness Rockwell (HR30T)	72,1	73,4	70,5	74,6	70,7
Flextural strength (MPa)	9,81	12,30	11,50	11,98	9,40

Table 3 - Petrophysical characterization (mean values) – Cava La Valle.

Cava La Valle				
Lithofacies	**Mezza Perla**	**Perlatino**	**Botticino**	**Nocciolato**
Apparent density (kN/m^3)	25,88	25,92	25,94	25,97
Bulk density (kN/m^3)	26,33	26,30	26,25	26,46
Open porosity (%)	1,69%	1,44%	1,19%	1,86%
Compattezza	0,99	0,99	0,99	0,98
Imbibition capacity (%)	0,56	0,66	0,50	0,55
Capillarity coefficient (g/cm^2·s$^{0.5}$)	6,79E-05	7,84E-05	6,82E-05	7,5E-05
P-wave dry velocity (m/s)	6137	6141	6010	6123
P-wave wet velocity (m/s)	6337	6311	6219	6266
Uniaxial compressive strength (MPa)	196	188	205	206
Brazilian strength (MPa)	-	-	-	-
Rupture energy (J)	-	-	-	-
Abrasion resistance (mm)	-	-	-	-
Hardness Rockwell (HR30T)	-	-	-	-
Flextural strength (MPa)	-	-	-	-

Weathering phenomena affecting the bell tower of the Santa Chiara monastery (Naples)

The main weathering phenomena affecting the BLL are well visible on all the above mentioned monuments and in particular on the bell tower of the Santa Chiara Monastery, which has been studied as a case history. These are essentially black crusts, efflorescence, stain, detachment, scaling, and rarely exfoliation, pitting and vegetation. Integration (*i.e.* lacks filled up with different materials) and fractures are often observed.

CONCLUSIONS

The present study brings new data on the sedimentological-stratigraphical, mineralogical-petrographical and engineering-geological characters of the BLL Fm. and on the main weathering phenomena involving the stone when used outdoor.

The sedimentological analysis allowed to distinguish in the BLL Fm. eight lithofacies corresponding to as many commercial rock types. It is worth mentioning that the correspondence established in this study between the lithofacies of the BLL and the commercial varieties of the *Perlato Royal Coreno* disclosed some very interesting perspectives. In fact, like any facies model (Walker, 1992), the BLL depositional model (Corda & Brandano, 2003; Civitelli & Brandano, 2005) can be used to make predictions on lithofacies distribution to optimize the exploration both of mature quarrying districts and of areas that have not yet been intensively quarried.

Mineralogical and petrographical studies did not reveal significant differences between the two sampling sites. On the contrary, physico-mechanical test demonstrated a difference between the Cava La Valle and the Cava Canale samples especially regarding the UCS values.

Finally, it must be emphasised that the BLL from both the sites showed good performance in terms of mechanical strength, abrasion resistance and rupture energy. It evidently implies that the rock could be successfully employed for street furnitures and/or with architectural and structural purposes.

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