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Mineralogical-petrographic characterisation and provenance of "Porta Nuova" stones: A XVI century gate in Ravenna (Italy)

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Abstract. — Porta Nuova in Ravenna (Northern Italy) is one of the most beautiful gates of ancient Ravenna walls, built in the XVI century (1580-1585). Through the centuries, the door underwent several restoration events, the most important in 1653. A recent architectural survey has revealed that the Door is currently undergoing both structural deterioration and bad conservation of stone materials. Therefore, the Door has been subjected to laboratory investigation for the purpose of collecting data useful for restoration. This work presents a detailed mineralogical-petrographic, diffractometric and electron microscopy investigation of Porta Nuova stones, which brought to a classification of both natural and artificial materials.

The results indicate the presence of different ornamental stones, which represent materials recovered from monuments of Roman age. The widespread material is the white Pietra d'Istria in the four varieties Orsera, "vacuolar", "nodular" and "facies liburnica". The red "marble" Rosso Ammonitico Veronese is also present to create a beautiful chromatic effect. The valuable architectural components such as the Composite capitals and the columns drums are carved in *Marmor Proconnesium* and *Marmor Troadense*, respectively. Peculiar is the use of Pietra di Prun in the capitals' astragals and of Trachite dei Colli Euganei in the small pillars supporting the upper hinges of the main door.

The hanging wall façade is built with recovery bricks of different size and chromatic shades. Characteristic phases (e.g. gehlenite, analcime, cristobalite) detected by diffractometric analysis confirm that bricks derive from high temperature firing of the mixture in furnaces. Bricks surface grinding ("*sagramatura*") was a common feature.

Original lime bedding mortars and finishing plaster mortars with fine sand framework have been distinguished in the hanging wall. A late micro-conglomeratic finishing plaster mortar has also been detected, likely ascribed to a restoration intervention after the second World War.

Riassunto. — Porta Nuova in Ravenna (Nord Italia), costruita nel XVI secolo, è una delle più belle porte dell'antica cinta muraria della città di Ravenna. Nel corso dei secoli la porta ha subito numerosi interventi di restauro, il più importante dei quali avvenne nel 1653. I rilievi effettuati sulla porta hanno consentito di effettuare la mappatura architettonica dei conci lapidei. Le indagini mineralogico-petrografiche, diffrattometriche e in microscopia elettronica eseguite sui campioni di lapidei naturali ed artificiali hanno permesso di effettuare la classificazione petrografica

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e di raccogliere elementi necessari per operare un intervento di restauro. I risultati indicano la presenza di differenti tipologie di pietre ornamentali che in parte rappresentano materiale recuperato da monumenti di età romana. Il materiale maggiormente utilizzato è la candida Pietra d'Istria nelle varietà Orsera, vacuolare, nodulare e nella facies liburnica. E' anche presente il marmo Rosso Ammonitico Veronese che crea un gradevole contrasto cromatico. Gli elementi architettonici più importanti come i capitelli Compositi ed i rocchi delle colonne sono scolpiti in *Marmor Proconnesium* ed in *Marmor Troadense*, rispettivamente. Una particolarità è rappresentata dalla Pietra di Prun utilizzata come astragalo interposto fra colonne e capitelli e dalla Trachite dei Colli Euganei come sostegno dei cardini della porta.

Il paramento murario è stato realizzato con mattoni di recupero di diverso modulo e colore. L'individuazione diffrattometrica di fasi caratteristiche come gehlenite, analcime e cristobalite conferma che i mattoni sono stati sottoposti a cottura in fornaci ad elevata temperatura. La tecnica della "sagramatura" è stata impiegata per rettificare la superficie parietale.

Le malte originali di allettamento e di stuccatura con stilatura sono caratterizzate da un impasto di sabbia fine e calce. In interventi di restauro eseguiti dopo la seconda Guerra Mondiale, sono state effettuate stuccature utilizzando impropriamente malte cementizie grossolane.

Key words: *Porta Nuova, ornamental stones, petrography, provenance*.

Introduction

Porta Nuova in Ravenna (Northern Italy) is considered one of the most beautiful gates of Ravenna. Porta Nuova has been the object of an interdisciplinary study, which realized an architectural survey of the gate, mapping ashlars stones and drawing thematic maps. This has been realized by means of mesoscopic analysis of the materials, implemented by optical-petrographic, diffractometric and electron microscopy studies which brought to a classification of both natural and artificial stone materials and to a preliminary evaluation of their deterioration degree. To date, there was no detailed petrographic investigation of Porta Nuova materials, which had been generically identified only by macroscopic observations as "marbles" and "granites".

In the framework of this study, a representative number of samples of both natural (ornamental) and artificial (bricks, mortars) stones was taken for laboratory analysis, with the aim of characterising all the materials and attributing provenance to active and/or ancient quarries for the stone materials used to build Porta Nuova. As demonstrated by recent studies (e.g. Lazzarini *et al.,* 2007), the information obtained (provenance, mineralogical-petrographic characterisation and state of conservation) is of primary importance for monument restoration and conservation. Moreover, provenance studies will not only make it possible to define the best materials for restoration, but also offer insights into ancient trading and importation of stone materials.

History and Architecture of the Gate

Porta Nuova stands on the south side of the town, at the end of Via di Roma and at the beginning of the road that leads to Classe and Rimini. It is considered one of the most beautiful gates of Ravenna and allows the access to the city from the south. It is commonly accepted that Giovanni Pietro Ghisilieri built it between 1580 and 1585 where antiquely stood the Door, which led to the Basilica of San Lorenzo in Cesarea. The new Door took the name of Porta Nuova and was also called Gregoriana in honour of Pope Gregorio XIII (1502-1585). It was decorated with rich marbles taken from Porta Aurea, a triumphal arch dating back to II cent. A.C. considered the main gate to the city during Roman age. Porta Aurea had been demolished in 1582 with the purpose of obtaining building stones. Lately, Porta Nuova underwent restoration by Cardinale Legato Stefano Donghi in 1653, probably following a Bernini design. The restoration of the door was carried out in the occasion of excavation of the shipway Pamphilio, which connected the city to the old harbour Candiano and was called, as well as the Door, “Pamphilio” in honour of Pope Innocenzo X, from the Pamphili family, pope from 1644 to 1655. The two memorial plaques at the façade sides nowadays remember that huge work. After Italy unity, it was also called Porta Garibaldi, from the name of the road starting from the door itself.

The brick-made front is inter-divided by two grey granite semi-columns with Composite capitals, leaning on basements at the main fornix’s sides and supporting a marbled entablature and flanked by two pilaster strips with Tuscan capitals. To crown the attic, flanked by two cornucopias, there is Pope Innocenzo X’s coat of arms consisting of a dove with a branch of olive in its beak as a symbol of peace; three lilies crossed by poles are sculptured over the dove. Above the entablature there’s a jutting cornice with the inscription “INNOCENTIO X PONT OPT MAX MDCLIII”, surmounted by the attic, bearing the inscription “PORTA PAMPHILIA” at the centre. The wrought iron lunette under the main arch was recovered after the demolition of Porta Alberoni.

In the origin Porta Nuova was part of the town walls representing a passage for vehicles and for the steam engine connecting Ravenna to Forlì (called “*tramvai*”). Only in the XX century it was isolated in order to realize more passages for vehicles. The main front is formed by three passages (Fig. 1): the one in the centre is a round arch; the smaller lateral ones, opened in the XX century, were closed at the beginning of the XXI century.

Materials and Methods

Identification and sampling of Porta Nuova materials were both based on macroscopic evidence such as colour, grain-size and consistency, and on different alteration products and deterioration degree of the monument. Only removed fragments, small pieces from hidden portions and/or from the monument cracks caused by deterioration, previous restorations and damages were taken during the diagnostic examination prior to restoration. On all samples of ornamental stones, bricks and mortars of the monument the following examinations were carried out: thin section petrographic analyses, SEM-EDX observations and X-Ray diffraction (XRD) analysis.

The thin sections were observed under the polarising microscope to determine and describe the petrographic parameters, i.e. structure, texture, grain size and mineralogical association. Such petrographic observations were compared with those reported in the specific literature and with reference samples from active quarries.

SEM-EDX observations were carried out using a Scanning Electron Microscope (SEM) Philips 515B fitted with an EDAX DX4 microanalytical device.

Mineralogical data of the materials were obtained by X-ray Diffraction (XRD). Analyses were performed by using a computer-controlled Philips PW 1710 diffractometer with the following operative conditions: CuKα radiation, 40kV and 30mA, 0.02° (2Θ) step size, counting time of 1 s/step. All powder samples were prepared by side loading of an aluminium holder to obtain a quasi-random orientation. The mineralogical identification was based on comparison with JCPDS data.

Results and Discussion

Ornamental Stones

The full list of samples of ornamental stones and artificial materials sampled and analysed in this study is reported in Tab. 1. A brief description of the stone location within the door architecture (cf. also Fig. 1), and mesoscopic and microscopic descriptions of the materials is reported hereby for each lithotype. A reconstruction of provenance

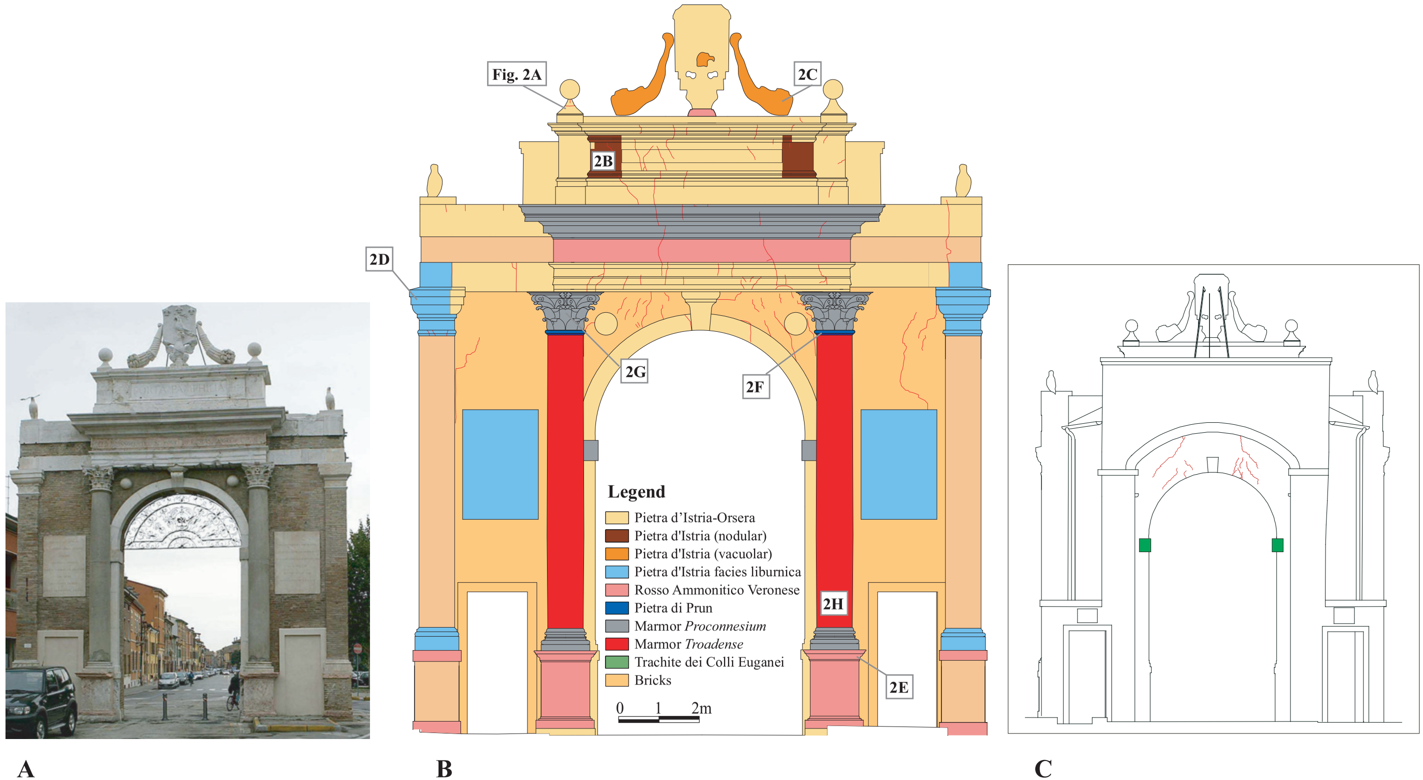

Fig. 1– A) General view of Porta Nuova (Ravenna, Italy); Schematic sketch of Porta Nuova, front view (B) and back view (C) with location of ornamental stones described in detail in Fig. 2. On the door back side (C) only two ornamental stones have been mapped, the rest are bricks.

has also been attempted as to formulate hypotheses on the source of the materials at the time of Porta Nuova building and/or during subsequent restoration.

The use of *Pietra d'Istria* is widespread in the Door. The detailed petrographic investigation under optical microscope allowed recognising four different stone types within this lithotype. Pietra d'Istria-Orsera (Fig. 1) is a stylolitic variety employed in the main architectonic frames of the gate (TABLE 1; e.g. spheres at the top of the attic, Fig. 2A). This compact white-ivory-coloured limestone shows stylolitic joints, laminations and conchoidal fracture. The grainsize is fine with micritic peloids set in an intragranular micritic cement, rare bioclasts and microcavities with plagues filled by clear sparry calcite (Fig. 3A). On the basis of its textural and compositional characters and following the most common classification systems for carbonate rocks (Folk, 1959, 1962; Dunham, 1962) the rock is a mudstone. The second type of Pietra d'Istria (nodular), found only in the right and left sides of the frame of the attic inscription (Fig. 1; Fig. 2B), is a micritic limestone, light yellow-ivory coloured, less compact as due to the occurrence of pseudo-nodular levels divided by yellowish patinas. The rock is classified as carbonatic mudstone. A third variety employed in the fruits and stalk of the two cornucopias (Fig. 2C) is a porous, vacuolar and light yellow-ivory limestone. The texture is isotropic with fine grain size and oriented fractures. The dominant grains are micritic peloids, supporting microfossil bioclasts, red algae with laminar structure and echinoderm plaques (monocrysts). The intergranular cement is microsparite, whereas the intragranular cement is orthosparite locally forming druses (Fig. 3B). The rock is classified as a fine-grained grainstone (Dunham, 1962) with peloids. The stone Pietra d'Istria-Orsera together with the two nodular and vacuolar types described above all belong to the Lower Cretaceous geological level mined in the Istrian peninsula near Orsera (Velić *et al.,* 2003; Vlahović *et al.,* 2005). A further type of stone is a biocalcarenitic (grainstone, Dunham, 1962) Pietra d'Istria found in the Tuscan capitals, pilasters over Tuscan capitals (Fig. 2D) and memorial plaques at the columns sides. It is a compact calcarenite, microgranular, and white-ivory coloured. The texture is anisotropic with alternation of mm-size undulated laminas of different grain size and composition. Within the fine-grained lamina the grains are mainly constituted by peloids of dense micrite (fecal pellets), associated to microforaminifers. The early intergranular cement is clear recrystallized microsparite. The coarse-grained laminas are formed by foraminifer bioclasts, echinoderm plaques, fecal pellets, micritic intraclasts. The inter- and intra-granular cement is clear sparite, either coarse when syntaxial over echinoderm bioclasts, or fine (microsparite) (Fig. 3C). The textural, compositional characters of the rocks and the bioclasts association (miliolids, ataxophragmidae and other foraminifera, along with the green alga *Thaumatoporella*) point towards a depositional environment of lagoon or platform of Upper-Cretaceous-Paleocene age. All these characters well reconcile with an identification of the stone as Pietra d'Istria-facies liburnica (Ogorelec *et al*., 2001).

Rosso Ammonitico Veronese is employed in the entablature frieze and columns pedestals (Fig. 2E), in the eagle tail and claws. It a rosy limestone with conchoidal fracture characterised by cm-sized nodules. At the microscopic scale the rock presents anisotropic structure with stylolitic joints.

Calpionellids, "Protoglobigerine" (foraminifera) and remnants of pelecypods shells (*filaments*) are all set in a matrix formed by micritic peloids. The intergranular cement is given by either dusty micrite or by clear microsparite plaques. Widespread is the crystallisation of rhomboidal dolomite crystals as well as intense oxidation by iron hydroxides, which give the rock the characteristic red colour

Table 1

Classification, location, description and composition determined by optical microscopy of samples (ornamental stones, bricks and mortars) taken from the door.

Sample	Classification	Location
L1	Pietra d'Istria (nodular)	attic inscription left side frame
L2	Pietra d'Istria Orsera	left sphere pedestal
L3	Pietra d'Istria Orsera	left sphere
L4	Pietra d'Istria (nodular)	attic inscription left side frame
L5	Pietra d'Istria (vacuolar)	left cornucopia fruits
L6	Pietra d'Istria (vacuolar)	left cornucopia stalk
L7	Pietra d'Istria Orsera	eagle wing
L8	Rosso Ammonitico Veronese	eagle tail and claws
L10	Pietra d'Istria Orsera	attic frame
L11	Pietra d'Istria Orsera	attic base
L12	Pietra d'Istria Orsera	attic inscription
L13	Rosso Ammonitico Veronese	entablature frieze
L14	Rosso Ammonitico Veronese	entablature frieze
L15	Marmor proconnesium	band of the entablature frame
L16	Marmor proconnesium	left Composite capital volute
L17	Marmor proconnesium	left Composite capital acanthus leaf
L18	Pietra d'Istria Orsera	architrave band
L19	Pietra di Prun	left Composite capital astragal
L20	Pietra d'Istria (facies liburnica)	left Tuscan capital collar
L21	Pietra d'Istria (facies liburnica)	left Tuscan capital upper pilaster
L22	Pietra d'Istria Orsera	dressed stone at the left of the keystone
L23	Pietra d'Istria Orsera	hemisphere at the left of the keystone
L24	Pietra d'Istria Orsera	keystone
L25	Marmor troadense	right column upper drum
L26	Trachite dei Colli Euganei	pillar supporting the left hinge
L27	Trachite dei Colli Euganei	pillar supporting the right hinge
L28	Pietra d'Istria (facies liburnica)	right memorial plaque
L29	Pietra d'Istria (facies liburnica)	left memorial plaque
L30	Marmor troadense	left column upper drum
L31	Marmor troadense	right column upper drum
L32	Marmor troadense	right column lower drum
L33	Marmor proconnesium	right column plinth
L34	Rosso Ammonitico Veronese	right column pedestal
L35	Pietra d'Istria Orsera	keystone
LT1	Red Brick	Hanging wall
LT2	Yellow Brick	Hanging wall
LT3	Yellow Brick	Hanging wall
LT4	Rose Brick	Hanging wall
LT5	Rose Brick	Hanging wall
LT6	Rose Brick	Hanging wall
M1	conglomeratic plaster mortar	Hanging wall
M2	bedding mortar	Hanging wall
M3	finishing plaster mortar	Hanging wall
M4	finishing plaster mortar	Hanging wall
M5	conglomeratic plaster mortar	Hanging wall
M6	finishing plaster mortar	Hanging wall
M7	bedding mortar	Hanging wall
M8	finishing plaster mortar	Hanging wall
M9	finishing plaster mortar	Hanging wall
M10	finishing plaster mortar	Eagle

"Mineral abbreviations after Kretz (1983), except Anor (Anorthoclase). Other abbreviations: Lim: limestone; Che: chert; Gp: gypsum; Gra: granite; Gne: gneiss; Ser: serpentinite; She: shells; Cp: cocciopesto".

Table 1
Continued...

Description	Composition
micritic, stylolitic, nodular, white	micritic and sparitic Calcite
micritic, stylolitic, white	micritic and sparitic Calcite
micritic, stylolitic, white	micritic and sparitic Calcite
micritic, stylolitic, nodular, white	micritic and sparitic Calcite
micritic, vacuolar, white	micritic and sparitic Calcite
micritic, vacuolar, white	micritic and sparitic Calcite
micritic, stylolitic, white	micritic and sparitic Calcite
micritic, nodular, rose	micritic and sparitic Calcite, Dolomite
micritic, stylolitic, white	micritic and sparitic Calcite
micritic, stylolitic, white	micritic and sparitic Calcite
micritic, stylolitic, white	micritic and sparitic Calcite
micritic, nodular, rose	micritic and sparitic Calcite, Dolomite
micritic, nodular, rose	micritic and sparitic Calcite, Dolomite
saccharoidal, white, bluish veinlets	Calcite, Dolomite
saccharoidal, white, bluish veinlets	Calcite, Dolomite
saccharoidal, white, bluish veinlets	Calcite, Dolomite
micritic, stylolitic, white	micritic and sparitic Calcite
micritic, nodular, rose	micritic and sparitic Calcite
microgranular, white	micritic and sparitic Calcite
microgranular, white	micritic and sparitic Calcite
micritic, stylolitic, white	micritic and sparitic Calcite
micritic, stylolitic, white	micritic and sparitic Calcite
micritic, stylolitic, white	micritic and sparitic Calcite
phaneritic, grey-purplish	Pl+Kfs+Bt+Hbl+Qtz+Mag+Ap+Ttn+Zr
porphyritic, grey-yellowish	Anort+Sa+Pl+Bt+Px+Mag+Ap+Zr
porphyritic, grey	Anort+Sa+Pl+Bt+Px+Mag+Ap+Zr
microgranular, white	micritic and sparitic Calcite
microgranular, white	micritic and sparitic Calcite
phaneritic, grey-purplish	Pl+Kfs+Bt+Hbl+Qtz+Mag+Ap+Ttn+Zr
phaneritic, grey-purplish	Pl+Kfs+Bt+Hbl+Qtz+Mag+Ap+Ttn+Zr
phaneritic, grey-purplish	Pl+Kfs+Bt+Hbl+Qtz+Mag+Ap+Ttn+Zr
saccharoid, white, bluish veinlets	Calcite, Dolomite
micritic, nodular, rose	micritic and sparitic Calcite, Dolomite
micritic, stylolitic, white	micritic and sparitic Calcite
microgranular, vacuolar, red	Qtz+Pl+Kfs+Ms+Bt
microgranular, vacuolar, yellow	Qtz+Pl+Kfs+Bt
microgranular, vacuolar, yellow	Qtz+Pl+Kfs+Bt
microgranular, vacuolar, rose	Qtz+Pl+Kfs+Ms+Bt+Gneiss fragments
microgranular, vacuolar, rose	Qtz+Pl+Kfs+Ms+Bt
microgranular, vacuolar, rose	Qtz+Pl+Kfs+Ms+Bt
micro-conglomeratic, dark grey	Lim+Che+She+Cp+Qtz+Cal+Fsp+Mca
granular, vacuolar, light beige	Lim+Che+Gne+Ser+She+Qtz+Fsp+Mca
granular, vacuolar, light beige	Lim+Che+Gne+Ser+She+Qtz+Fsp+Mca
granular, vacuolar, light beige	Lim+Che+Gne+Ser+She+Cp+Qtz+Fsp+Mca
micro-conglomeratic, dark grey	Lim+Che+Gra+She+Qtz+Cal+Fsp+Mca
granular, vacuolar, light beige	Lim+Che+Gra+Gne+She+Cp+Qtz+Fsp+Mca
granular, vacuolar, light beige	Lim+Che+Gne+Ser+She+Cp+Qtz+Cal+Fsp+Mca
granular, vacuolar, light beige	Lim+Gp+She+Cp+Qtz+Fsp+Mca
granular, vacuolar, light beige	Lim+She+Cp+Qtz+Fsp+Mca
granular, vacuolar, light beige	Lim+Che+She+Cp+Qtz+Cal+Fsp+Mca

"Mineral abbreviations after Kretz (1983), except Anor (Anorthoclase). Other abbreviations: Lim: limestone; Che: chert; Gp: gypsum; Gra: granite; Gne: gneiss; Ser: serpentinite; She: shells; Cp: cocciopesto".

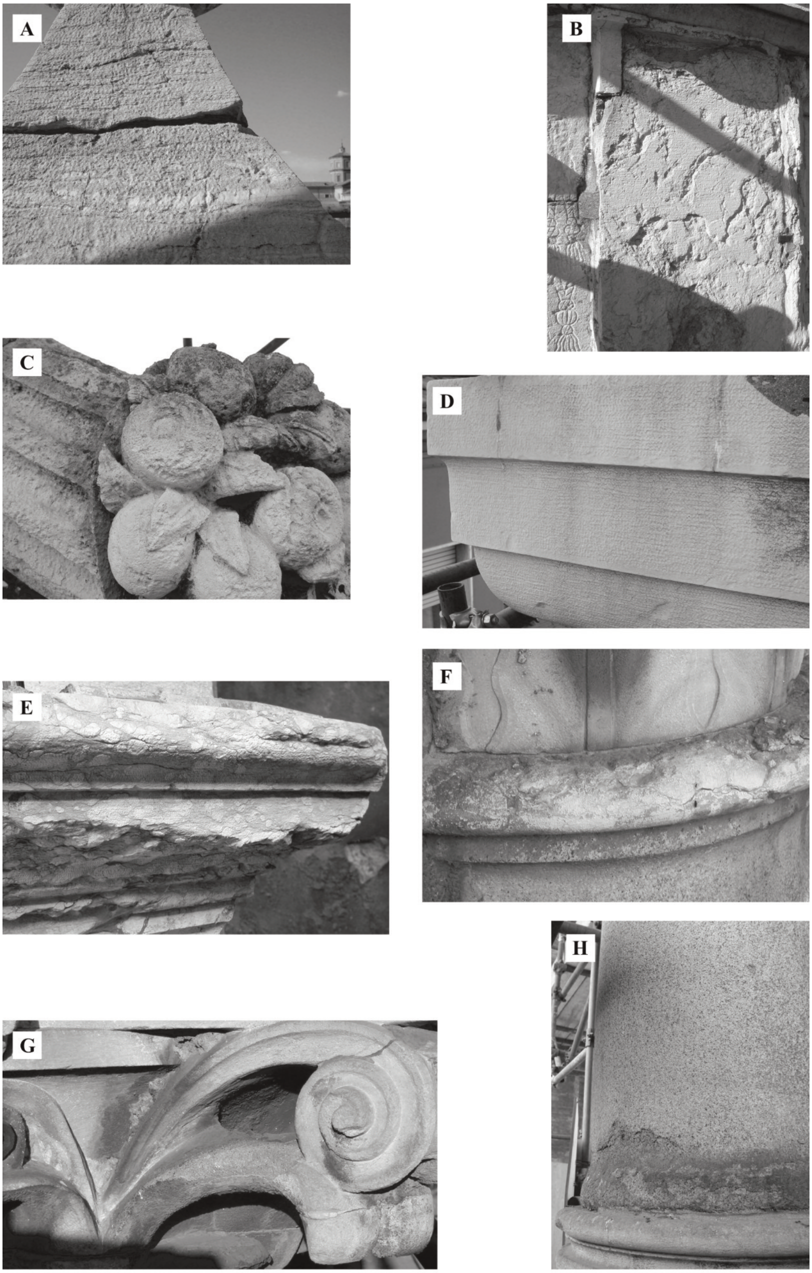

Fig. 2 – Macrophotographs of ornamental stones as indicated in Figure 1: A) Pietra d'Istria, sphere pedestal at the top of the attic; B) Pietra d'Istria-nodular, left side of the frame of the attic inscription; C) Pietra d'Istria-vacuolar, cornucopias' fruits; D) Pietra d'Istria-facies liburnica, Tuscan capital; E) Rosso Ammonitico Veronese, column pedestal; F) Pietra di Prun, capital astragal; G) *Marmor Proconnesium*, Composite capital; H) *Marmor Troadense*, column drum.

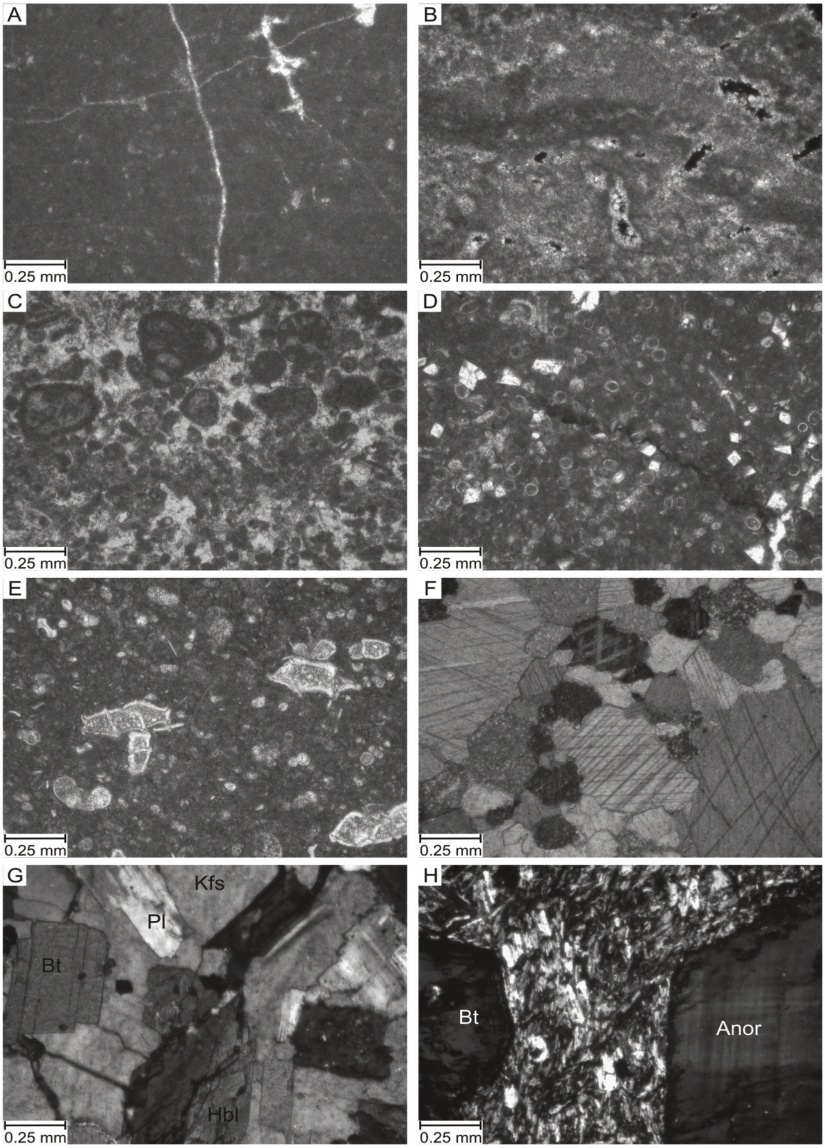

Fig. 3 – Optical photomicrographs (polarized light) of ornamental stones: A) Pietra d'Istria, fine-grained micritic limestone with peloids and calcite veins (sample L7, NX); B) Pietra d'Istria-vacuolar, fine-grained limestone with peloids, showing laminar structure and druses (L6, NX); C) Pietra d'Istria-facies liburnica, biocalcarenitic grainstone with foraminifers shells and sparry cement (L21, N//); D) Rosso Ammonitico Veronese, calclutite with Calpionella shells, euhedral dolomite crystals and oxidised stylolitic joints (L13, N//); E) Pietra di Prun, micritic calclutite with foraminifers shells (*Marginotruncana bicarenata*) (L19, N//); F) *Marmor Proconnesium*, calcite marble with heteroblastic polygonal texture (L33, NX); G) *Marmor Troadense*, quartz monzonite with poikilitic K-feldspars (Kfs) and euhedral plagioclase (Pl), biotite (Bt) and hornblende (Hbl) (L31, NX); H) Trachite dei Colli Euganei, porphyritic texture with anorthoclase (Anor) and biotite (Bt) phenocrysts set in a trachitic groundmass (L26, NX).

(Fig. 3D). The rock is classified as sandy calclutite (wackestone, Dunham, 1962) and attributed to Upper Jurassic (Dogger-Malm) (Préat *et al*., 2006; Barbieri and Grandesso, 2007).

Pietra di Prun, found in the capitals astragals at the base of the Composite capitals above the granite columns (Fig. 2F), is a rosy nodular limestone with conchoidal fracture presents anisotropic structure with stylolitic joints. It is constituted by abundant small size foraminifers (*Globigerina*) associated to bigger size foraminifers (i.e., *Marginotruncana bicarenata*), which allow attributing a Tironian (Upper Cretaceous) age (Ogg *et al.,* 2008). *Globigerina* specimens are set in a matrix-cement formed by dusty micrite; *Globotruncana* specimens are filled by recrystallized calcite (Fig. 3E). The rock is classified as micritic, in part marly, calclutite (mudstone) and attributed to the Upper Cretaceous Scaglia Rossa Formation, known as Pietra di Prun (Stefani *et al*., 2007).

Marmor Proconnesium has been employed in the band of the entablature frame, in the two Composite capitals (Fig. 2G) and in the two central columns plinths. The rock is a white metamorphic marble with bluish veinlets. The microscopic investigation evidences an isotropic heteroblastic polygonal texture with calcite crystals (up to 0.5 cm) associated to submillimetric crystals. Grain contacts vary from polygonal with triple points to irregular (Fig. 3F). Dolomite occurrence has been detected by diffractometric analysis (Fig. 5A; Table 2). The compositional and textural characters of the rock leave no doubt on the classification as *Marmor Proconnesium*, of the island of Proconnesus, modern Marmara (Turkey) (Waelkens, 1989; Ward-Perkins, 1992).

Marmor Troadense is employed in the central columns drums (Fig. 2H). It is a phaneritic plutonic rock, with grey-purplish colour and medium-coarse grain size. The hypidiomorphic granular texture is made up of poikilitic K-feldspar (orthoclase), embedding idiomorphic crystals of zoned plagioclase, biotite and hornblende (Fig. 3G). Opaque minerals and allotriomorphic quartz crystals also occur in the interstices. The rock is classified as quartz-monzonite from Troas, Turkey (Galetti *et al*., 1992; Birkle and Satir, 1995; Ponti, 1995), following the QAPF modal classification of plutonic rocks (Le Maitre and IUGS, 2002).

Trachite dei Colli Euganei was sampled from the small pillars supporting the upper hinges of the main door (cf. back view in Fig. 1). One of the pillars is grey-coloured, whereas the other one presents a grey-yellowish colour. The rock is characterised by porphyritic texture and medium-coarse grain size with idiomorphic anorthoclase with thin sanidine rims, plagioclase, biotite with opaque rims and less abundant pyroxene (pale green augite) (Fig. 3H). Common accessory minerals are apatite, zircon, magnetite and ilmenite. The groundmass is made up of idiomorphic tabular or xenomorphic sanidine oriented along the flux direction. On the basis of the mineralogical composition, the rock is classified as trachite (Le Maitre and IUGS, 2002). This rock is characteristic of the Veneto Oligocene magmatism in the Colli Euganei area, near Padova (Piccoli *et al*., 1981; De Pieri *et al*., 1983; Capedri *et al*., 2000).

Bricks

The hanging wall is built with recovery bricks of different chromatic shades ranging from red to rose to yellow as a result of the different concentration of iron oxides. The mixture is heterogeneous with a sandy frame from fine to very fine made up of quartz, plagioclase, K-feldspar, muscovite, hematized biotite and bricks fragments (*cocciopesto*) (Figs. 4A-B). Neo-forming minerals derived from the mixture have also been recognized by XRD investigation: among these pyroxene, gehlenite, analcime (wairakite) and cristobalite (Fig. 5B; Table 2).

TABLE 2
Mineralogical composition determined by X-ray diffraction.

Sample	Qtz	Cal	Dol	Pl	Kfs	Gp	Ms	Chl	Anl	Gh	Cpx	Crs
L4	+	++++				+						
L5	+	++++				++						
L15	tr.	++++										
L16	+	++++				+						
L17	+	++++				+						
L28	tr.	++++				+						
L29	+	++++										
L33		++++	+									
LT1	++	++				tr.				++	++	
LT2	++	++							+	++	+++	++
LT3	+++	+				tr.			tr.	++	+++	++
LT4	++++	++		+		tr.			tr.	++	++	
LT5	+++	++				tr.				++	+++	
LT6	+++	++		+		tr.				++	++	
M1	+++	++++	tr.	tr.								
M2	+++	+++	tr.	++	+		+	tr.				
M3	+++	+++	tr.	++	+		+	tr.				
M4	+++	+++	+	++	+		tr.	tr.				
M5	+++	++++		+	+	tr.	+					
M6	+++	+++	tr.	+	+	tr.	+	tr.				
M7	+++	+++	+	+	+	tr.	++	+				
M8	++	+++				++++						
M9	++	++++	+	+	+	+						

Qtz: Quartz; Cal: Calcite; Dol: Dolomite; Pl: Plagioclase; Kfs: K-feldspar; Gp: Gypsum; Ms: Muscovite; Chl: Chlorite; Anl: Analcime-Wairakite; Gh: Gehlenite; Cpx: Clinopyroxene; Crs: Cristobalite. ++++ = very abundant; +++ = abundant; ++ = average presence; + = present; tr. = traces

On some of the bricks a residual very thin layer of lime plaster ("*sagramatura*") with sand formed by quartz, K-feldspar, micas and *cocciopesto* fragments have also been detected (Fig. 4C). This technique ("*sagramatura*") was commonly used for grinding the bricks surface. Fissures and macro pores are partially filled by recrystallized calcite and gypsum (Fig. 4D).

Mortars

In the hanging wall different kinds of mortars have been identified (cf. TABLE 1). Samples have been classified according to the binder characteristics and to the aggregate composition (Rossi Manaresi *et al.,* 1985). On this basis, original lime bedding mortars (Fig. 4E) and finishing plaster mortars (Fig. 4F) have been distinguished.

Light beige lime bedding mortars are made up of fine-medium sandy aggregate, *cocciopesto* fragments and binding lime. The medium-fine sandy aggregate is characterized by monocrystalline quartz, K-feldspar, plagioclase,

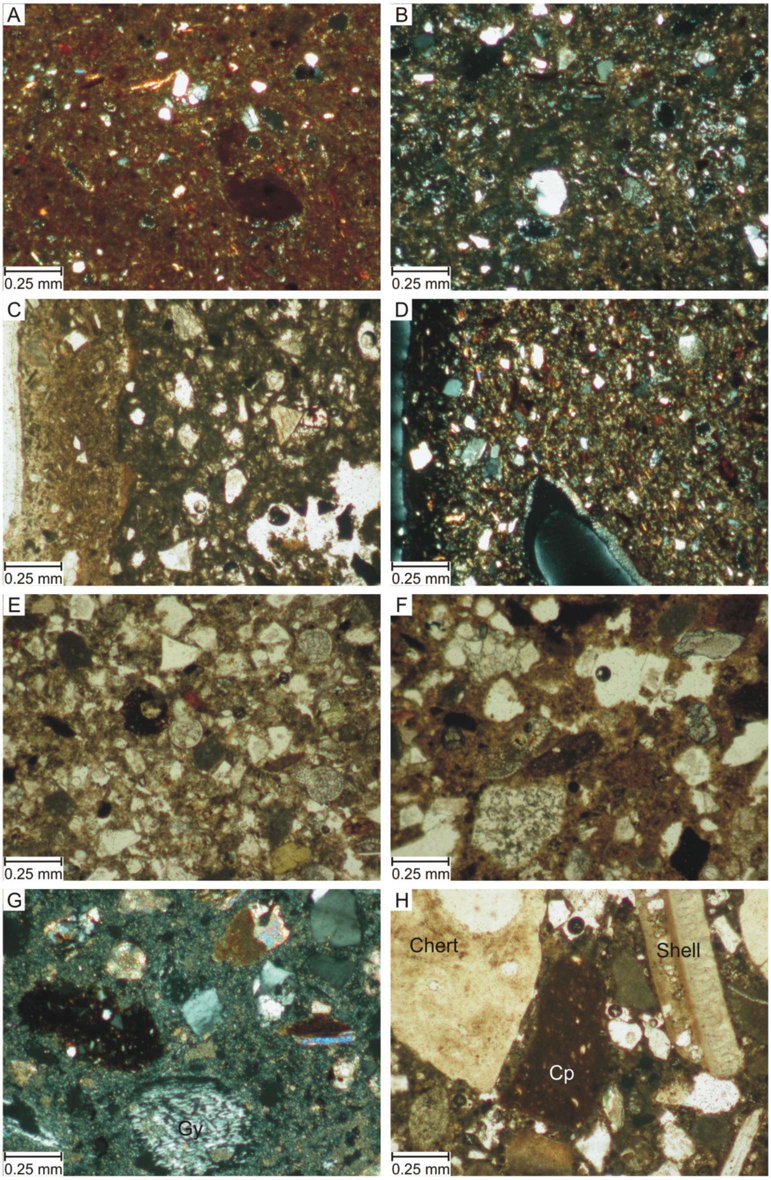

Fig. 4 – Optical photomicrographs (polarized light) of bricks and mortars. A) Red brick with quartz-feldspar-phyllosilicates plus *cocciopesto* frame in a fine-grained reddish groundmass with scattered vacuoles (sample LT1, NX); B) Yellow brick with quartz-feldspar sandy frame in brown vacuolar groundmass (LT2, NX); C) Yellow brick showing a thin layer of lime plaster ("*sagramatura*", left) (LT3, N//); D) Rose brick rich of quartz-feldspar fragments and macropores with calcite rims and a thin lime plaster (left) (LT6, NX); E) Lime bedding mortar, sand frame with scattered foraminifers shells and *cocciopesto* (M7, N//); F) Finishing plaster mortar, similar to 4E (M4, N//); G) Finishing plaster mortar with crystalline gypsum (Gy) fragment (M8, NX); H) Micro-conglomeratic plaster mortar with chert, *cocciopesto* (Cp) and shells fragments (M1, N//).

calcite, phyllosilicates (muscovite and chlorite), dolomite, gypsum (Fig. 5C; TABLE 2) and polycrystalline fragments of carbonatic rocks, cherts, gneissic rocks, serpentinites, shell and foraminifer fragments (Fig. 4E).

Finishing plaster mortars with binding lime are quite similar in colour and composition to the bedding mortars (4F), but are characterised by the presence of gypsum determined by XRD. A particular variety is represented by a finishing plaster mortar, which also contains fragments of natural crystalline gypsum (Fig. 4G).

Furthermore, finishing plaster mortars realized during further restoration interventions are also present. These are represented by micro-conglomeratic dark grey-coloured plaster mortars. The petrographic observation allowed identifying a micro-conglomeratic component bearing carbonatic rocks, aplitic granites, rounded cherts, calcite crystals, quartz, microcline, phyllosilicates and bioclasts (shell fragments and foraminifers remains). These coarse sands and micro-conglomerates are found along the fossil coastlines of Fosso Ghiaia, south of Ravenna. *Cocciopesto* fragments are also present (Fig. 4H). SEM-EDX investigation revealed that a mixture of lime and cement serves as binding.

CONCLUDING REMARKS

The purpose of the investigation was to make a basic mineralogical and petrographic characterisation of materials used to build Porta Nuova, thus providing useful data for restoration works. The combined mineralogical-petrographic, diffractometric and electron microscopy investigation of Porta Nuova stones brought to a classification of both natural and artificial materials.

The results indicate the presence of different ornamental stones which were not identified by previous surveys: Pietra d'Istria in the four varieties Orsera, "vacuolar", "nodular" and

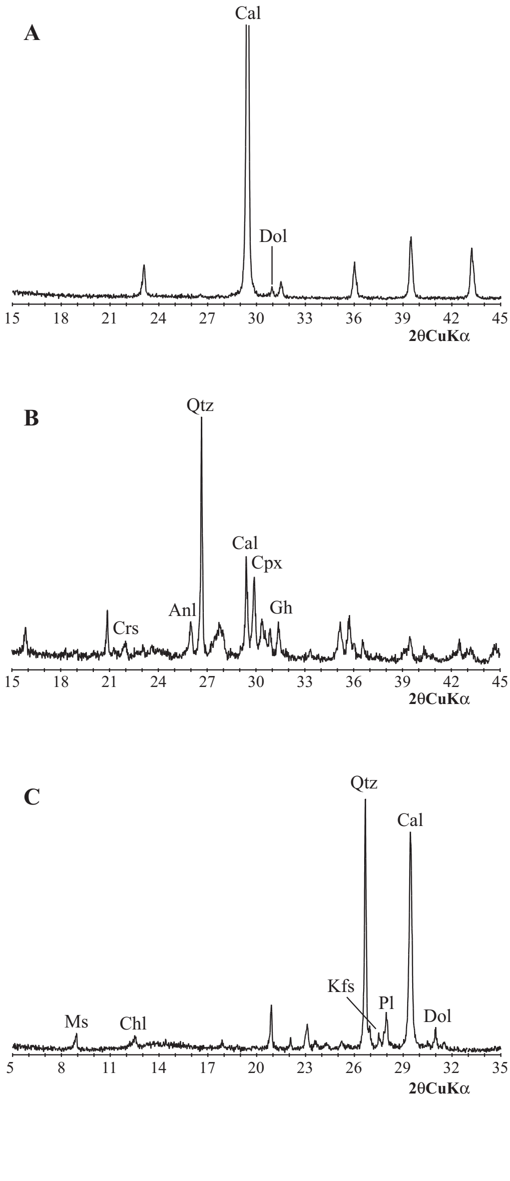

Fig. 5 – X-ray diffraction patterns. A) *Marmor Proconnesium* (sample L33); B) XRD pattern of brick sample LT2; C) XRD pattern of mortar sample M7. The main peaks corresponding to the identified minerals were labelled. Cal: calcite; Qtz: quartz; Dol: dolomite; Pl: plagioclase; Kfs: K-feldspar; Anl: analcime; Ms: muscovite; Chl: chlorite; Cpx: clinopyroxene; Gh: gehlenite; Crs: cristobalite.

"facies liburnica", Rosso Ammonitico Veronese, *Marmor Proconnesium*, *Marmor Troadense*, Pietra di Prun and Trachite dei Colli Euganei. All these ornamental stones belong to the historical materials imported since the Roman age in Ravenna from the Veneto-Istrian and Greek-Turkey areas. Pietra d'Istria was massively employed by Romans, Byzantines and Longobards. Since the XIV century, it represents a widespread ornamental stone employed in Venice and in all the cities of the north Adriatic, among which Ravenna. Rosso Ammonitico Veronese was commonly employed during Paleo-Christian age in Ravenna both for basilica doors and for Byzantine mosaic pieces and polychrome tarsia of the *opus sectile*. Pietra di Prun has been widely employed in architecture in all the territories belonging to the Serenissima Republic of Venice. *Marmor Proconnesium* and *Marmor Troadense* represent two of the most famous and widely used marbles of the ancient world, in particular during the Byzantine Empire (Walker, 1985; Attanasio, 2003). In particular, *Marmor Troadense* was mined in Turkey since the IV C. BC with widespread diffusion in the Roman age in most of the ancient cities of the Mediterranean basin where it was especially employed for the realization of columns and pillars (Lazzarini, 1987). In the following centuries common was the recovery of *Marmor Troadense* columns for new monuments or for restoration purposes. Trachite dei Colli Euganei has been employed as ornamental stone since the Roman age for the realization of columns, millstones and for road paving (e.g. Roman roads Flaminia and Emilia). Taking into account the demolition of the Porta Aurea Arch (occurred in 1582) and of other buildings of Roman age, it is likely that most of the ornamental stones used to build Porta Nuova were re-employed from former buildings.

The hanging wall façade is built with recovery bricks. Characteristic secondary phases (e.g. gehlenite, analcime, cristobalite) detected by diffractometric analysis confirm that bricks derive from high temperature firing of the mixture in furnaces. Original lime bedding mortars and finishing plaster mortars with fine sand framework have been recognised in the hanging wall. A late micro-conglomeratic finishing plaster mortar has also been detected, likely ascribed to one of the several restoration interventions.

We suggest that the results of this study (nature of ornamental stones, bricks and mortars) may be of primary importance and should be considered as a starting point for forthcoming restoration. It is also hoped that the data presented here may prove useful for future comparisons with other types of ornamental stones in historical buildings in Ravenna and in other cities connected to the Roman-Byzantine-Venetian trade.

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