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The grey marble of Porta Praetoria (Aosta, Italy): a minero-petrographic characterisation and provenance determination

Alessandro Borghi[1*], Lorenzo Appolonia[2], Laura Fiora[1] and Alessandro Zoja[1]

[1] Dipartimento di Scienze Mineralogiche e Petrologiche – Università di Torino, via Valperga Caluso, 35 – 10125 Torino, Italy
[2] Servizio Laboratorio Ricerche e Beni Archeologici – Sovrintendenza Regionale Valle d'Aosta – Aosta, Italy

Abstract. — The provenance determination of the ancient stone materials results the main insight archeometric application in the archaeological field, even if it can result difficult to reach when the studied material consists of white or coloured marbles.

A petrographic application on grey marbles, using a scanning electron microscope equipped with a electronic microprobe system, is here reported. The marbles of Porta Praetoria (Aosta, Italy), manufactured by the Ancient Romans in the Republican Age, are studied. According to historical documents, two types of marble may have been used: the marble coming from Villeneuve or from Aymaville villages (Aosta Valley). Both marble varieties occur as lenses interbedded in Upper Piedmont Zone, an ophiolitic unit belonging to Penninic domain of the Western Alps.

The sample from the Porta Praetoria is constituted by a grey marble, characterized by calcite and dolomite levels of different grain size, which reflect different grey tonality and confer to the rock a typical veined appearance ("bardiglio" variety). Minor silicate minerals, concentrated in the dolomite layers, are also present. In particular, this marble is characterized by the contemporaneous presence of three dioctahedral micas, with the potassic mica enriched in the celadonitic end-member as crystallized at high pressure metamorphic conditions. In additions, phlogopite and Mg-chlorite are also present. Comparable paragenesis is shown by the Aymaville marble, whereas the marble from Villeneuve resulted devoid of phlogopite and Mg-chlorite. Therefore, on the basis of petrographic and microchemical features, it may be suggested that the grey marble used for the edification of the Porta Praetoria in Aosta comes from the village of Aymaville, located in the right side of the central Aosta Valley.

Riassunto. — In questo lavoro viene presentato uno studio petrografico di una varietà di marmo di notevole significato archeometrico, impiegato per alcune importanti costruzioni storiche della città di Aosta.

I materiali presi in esame sono il Marmo di Aymavilles e la Pietra di Villeneuve, entrambi appartenenti alla Zona Piemontese dei Calcescisti e delle Pietre Verdi.

Lo studio svolto ha portato alla caratterizzazione petrografica ed all'identificazione della provenienza del marmo grigio utilizzato dai Romani per rivestire la Porta Praetoria all'ingresso di Aosta. In particolare è stato svolto un confronto petrografico e minero-chimico tra il materiale proveniente dalle cave storiche e alcuni frammenti provenienti dal marmo che orna la porta.

Il materiale utilizzato per l'edificazione della Porta Praetoria risulta costituito da un marmo grigio listato caratterizzato dall'alternanza regolare di livelli centimetrici di colore grigio chiaro e scuro. In particolare la paragenesi risulta costituita,

* Corresponding author, E-mail: Alessandro.borghi@unito.it

oltre che da calcite e dolomite, da alcuni silicati (fengite, paragonite, margarite, flogopite e Mg-clorite), che hanno permesso l'attribuzione di questa pietra ornamentale al Marmo di Aymaville, caratterizzato dalla medesima associazione mineraralogica.

Key words: *Porta Praetoria, grey marble, petrography, Piedmont Zone.*

1. Introduction

The determination of provenance of the marbles used in the antiquity represents an important tool from both scientific and archaeological point of view. Indeed, it provides important information on the rock material for restoration of ancient artefacts and may provide insight on the economic life and trade possibilities of a given country during a particular historical age. When the lithological material consists of silicate rocks its identification is rather suitable. Instead, when the artefact consists of white or grey marbles, their identification and provenance does not represent an easy task (Mariottini, 1998). However, in the last years, petrographic and geochemical approaches allowed to obtain some qualitative and quantitative parameters as grain size, grain boundary shape of carbonatic crystals, isotopic composition, compositions of accessory minerals, which provide to obtain a precise characterization of the marble (Lazzarini, 2004; Capedri *et al.*, 2004).

In this paper a multianalytical study to identify the site of provenance of the grey marble used in Aosta (Aosta Valley, Northern Italy) for the important historical construction of the "Porta Praetoria" built by the Ancient Romans, is reported.

This study is a petrographic and minero-chemical comparison between some fragments of the Porta Praetoria marble and samples coming from abandoned quarries of marbles outcropping along the Aosta Valley. The studied lithological varieties were the Aymavilles Marble and the Villeneuve Stone, which are considered the possible source of the employed stone, on the basis of historical documentation (Bortolaso and Appolonia,1992).

2. The Porta Praetoria

Augusta Praetoria was a Roman town founded as a military camp in the 25 b.C. and its site is today occupied by the modern town of Aosta. Prominent remains of the Roman age are still visible and include an almost complete circuit of walls with a city gate named "Porta Praetoria", still today in excellent state of conservation.

The Gate, constructed for pre-eminent military function, shows a typical rectangular plant and it is constituted by a double facade made of enormous blocks of "puddinga", a quaternary rock of fluvial origin. The Eastern facade is composed by three barrel-vaults, that reach in the middle a height of 9 meters, measured from the ancient street level. Inside the gate, a large courtyard of crews (19,20 m × 11,85 m) is constrained by the two facades and the two flanking towers.

It is nearly sure that in the Roman Republican age the currently visible Gate was adorned with facings of dimensional stones: it is, indeed, successive to the construction of one previous gate, much simpler and poor.

The eastern facade is covered with grey marble slabs, while blocks of the same material have the task to support the arched of the three barrel-vaults (Fig. 1). This marble is characterized by calcite and dolomite levels, of different grain size, which reflect different grey tonality, conferring to the rock a typical veined appearance ("bardiglio" variety) (Fig. 2). The chromatic contrast with the travertine used in order to cover the entire town-walls building is also emphasized by the presence of adorned cornices of white marble. For this last marble, a source provenance from Carrara or Paros (Greece) has been supposed by Mirti *et al.* (1997) on the basis of chemical and isotopic analyses.

3. The Aymavilles Marble and Villeneuve Stone

3.1 Geological setting

From the geological point of view, the Villeneuve Stone and Aymavilles Marble belong to the Piedmont Zone.

The Piedmont Zone crops out all along the arc of the Western Alps (Fig. 3) and represents the relicts of the Mesozoic ocean separating the European

Fig. 1 – Eastern facade of Porta Praetoria, showing the cover with grey marble slabs and white marble cornice.

Fig. 2 – Detail of grey marble of Porta Praetoria. Dark and light layering draws isoclinal folds.

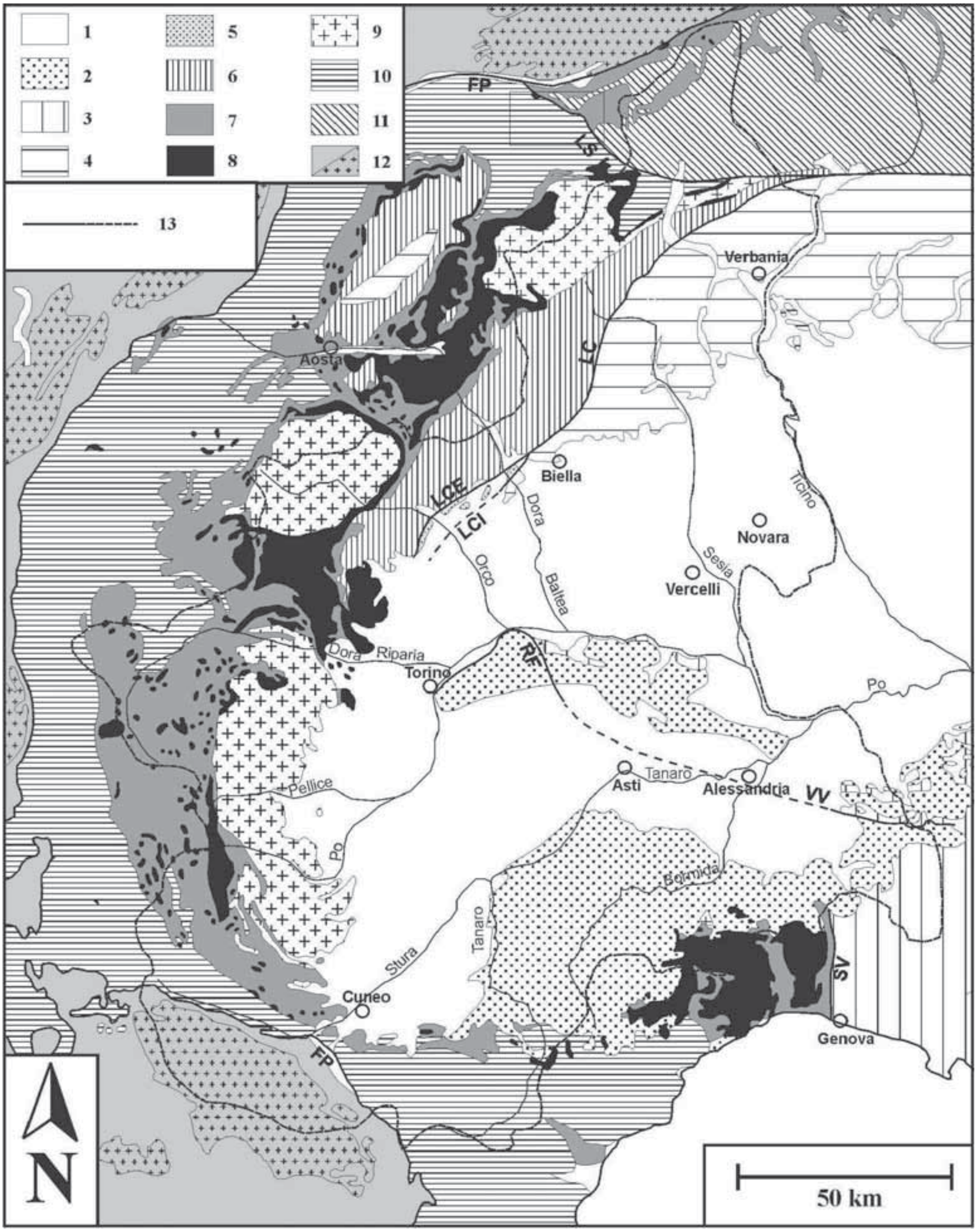

Fig. 3 – Tectonic sketch map of the Western Alps. 1: Post-orogenic continental and marine terrigenous deposits of Plio-Pleistocene to Quaternary age. 2: Late orogeny fore-deep turbiditic deposits of Oligo-Miocene age (Monferrato, Torino Hill, Ligure-Piedmont Tertiary basin) 3: Appenine chain; 4: South-Alpine Domain; 5: Canavese Zone; 6: Austroalpine Domain; 7: Upper Piedmont Unit; 8: Lower Piedmont Unit; 9: Internal Crystalline Massifs; 10: Briançonnais Zone; 11: Lower Penninic Unit; 12: Helvetic Domain. 13: Tectonic Lines: FP: Penninic Front, LS: Simplon Fault; LCE: External Canavese Line; LCI: Internal Canavese Line; SV: Sestri Voltaggio Line, RF: Rio Freddo Line, VV: Villalvernia Varzi Line.

and Apulian continental paleomargin (e.g. Dal Piaz, 1999, with references therein).

As result of the Alpine orogenesis, the Piedmont Zone consists of several tectonic units recording a polyphase metamorphic history. They may be distinguished into two major ophiolitic units according to their tectonic positions, lithological association and grade of the metamorphic overprint.

The lower Piedmont unit is dominated by mafic and ultramafic ophiolites which display an oceanic affinity, such as the internal Ligurian units in the northern Apennines, and an eclogitic metamorphic imprinting (Ernst and Dal Piaz, 1988).

The upper Piedmont unit mainly consists of metasediments with minor metabasites, showing a first metamorphic event developed under blueschist facies conditions, followed by a strong greenschist facies metamorphic overprint (Ernst and Dal Piaz, 1988).

In the Aosta Valley the upper Piedmont Zone is named Tsatè Nappe by Marthaler (1984). It is composed by carbonate and terrigenous calcschists alternating with tabular beds of greenschist facies metabasalts of oceanic origin (prasinites), with relics of blueschist facies conditions. Some olistoliths and tectonic slices of ultramafic rocks are also present (e.g. Marthaler and Stampfli, 1989). Exotic sheets of continental origin discontinuously occur near the base of the upper Piedmont Zone, both in the North (Dal Piaz, 1988) and the South of the Aosta- Ranzola fault system (Elter, 1971, 1972). These sheets consists of quartzite schists followed by dolostones and marbles (Middle-Late Triassic), slope breccias with dolomite fragments (Jurassic) and basinal marble and calcschists (Cretaceous). The Villeneuve and Aymaville marbles belong to one of these carbonate sheets outcropping South of Aosta – Ranzola fault, west of the Mt. Emilius klippe (Elter, 1971, 1972, Caby, 1981)

3.2 Villeneuve Stone

The Villeneuve Stone crops out in the North of Villeneuve village, on the right side of the Dora Baltea Stream, in the central portion of the Aosta Valley (Fig. 4). The stone consists of a grey marble, marked by the presence of silicate-bearing layers. It is characterized by an intercalation of light and dark levels (“bardiglio” variety). The rock is

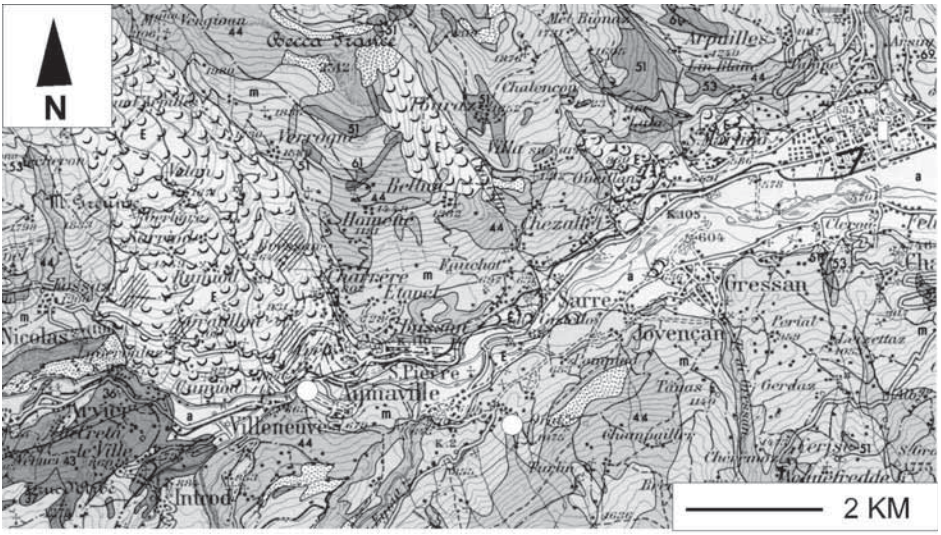

Fig. 4 – Geological Map of central Aosta Valley (from Elter, 1987). Location of Villeneuve Stone and Aymaville Marble quarry and of Porta Praetoria are reported. The grey level n. 44 represents the calcschists of the Upper Piedmont Zone. The white circles indicate the site quarry of Villeneuve and Aymanvilles marbles. The white square indicates the position of the Porta Praetoria in Aosta city.

compact, with a granoblastic microtexture and a fine grain size. Sometimes, it passes gradually to a calcschist when the silicate content increases. The Villeneuve Stone shows a regional schistosity, which in the quarrying area is directed to NW. Evidences of the ancient quarry activity are still preserved. In particular, along the North Est slope over the cemetery of Villeneuve village, the remnants of a quarry active up to the seventies of the twentieth century, are visible.

3.3 Aymavilles Marble

The Aymavilles Marble is macroscopically similar to the Villeneuve Stone, even if it results more fractured and characterized by some calcite veins that cut across the mineralogical layering. The peculiar features of Aymavilles Marble is the presence of a marked layering defined by varied grey levels of carbonate composition (Fig. 5). Frequently the contact between light and dark grey levels draws isoclinals folds, whose axial plane foliation, of transpositional origin, represents the main regional foliation.

At Pesse locality, near Aymavilles village (Fig. 4), three different quarries are still visible. The quarry at more elevated altitude represents the larger site of extraction. Here the regional schistosity shows a dipping of 10-15° toward N-NW, with a little attitude at "franapoggio" of marble bedding, forming a structural setting suitable for quarrying activity (Fig. 6). In the surrounding area, discharged irregular blocks represent the residual material extracted in the 40's of the twentieth century.

Sampling and analytical methods

Four samples were selected as representative rocks of the Aymaville marble (AP 1 and 2) and the Villeneuve Stone (AP 3 and 4). They are banded rocks, with marble layers mainly consisting of calcite ± dolomite which alternate at silicate-bearing layers consisting of calctie + dolomite + quartz + micas and other phyllosilicates. Samples were cut both orthogonal and parallel to the maximum extensional direction. Three samples, of few cubic centimeters, coming from the pilaster of the central and right barrel vault of the "Porta Praetoria", collected during the recent restoration of the monument, were cut from the fresh fractured side and used for preparing petrographic thin sections.

A careful petrographic analysis, performed by light and electronic microscope, was carried out to define the mineralogical assemblage and

Fig. 5 – Aymaville Marble outcrop at Pessa Alta quarry. Calcite (light) and dolomite (dark) levels, of different grey tonality are distinguishable.

Fig. 6 – Pessa Alta quarry.

the microstructural features of "Porta Praetoria" marble and to compare then it with Villeneuve Stone and Aymaville Marble. Electron microprobe analyses were performed with an EDS-SEM system of Oxford Instruments. Natural silicates and oxides were used as standards. The accelerating voltage was 15 KV and the dwell time 50 s. A ZAF data reduction program was used. All the analyses were recalculated using the MINSORT computer program of Petrakakis and Dietrich (1985). The mineral compositions are expressed as atoms per formula unit (a.p.f.u.). Unless otherwise specified, the mineral symbols are from Kretz (1983). Microprobe analyses allowed to define the chemical composition of mineral phases occurring in the "Porta Praetoria" fragments and to compare them with the rock-forming minerals of Villeneuve and Aymaville marbles.

4. Petrographic features

4.1 Porta Praetoria Marble

This marble is characterized by the repeated intercalation of carbonate layers showing a different grain size and containing minor silicate minerals. The mineralogical assemblage is the same in both the fine (below 50 micron) and the coarse (around 500 micron) grain size domains and consists of carbonates (calcite + dolomite) with minor quartz, white micas, phlogopite, chlorite and accessory minerals as pyrite, zircon, graphite and apatite (Fig. 7a).

Carbonates are the most abundant mineralogical phases in the rock (around 80%). Both calcite and dolomite are present. The latter, well identified by electron backscattered images (BSE), is concentrated in the fine grain size layers, where it partially replaces the original calcite (Fig. 7b). These portions correspond to the dark grey levels on the hand sample.

Calcite is the most abundant carbonate (60%) of the rock and is concentrated in the coarse levels. It occurs as granoblasts showing irregular grain boundary (from sutured to embayed), with a homogeneous size (around 500 micron). It shows a pervasive poly-synthetic twinning, displaying acicular shape which suggests a later solid-state deformation origin (Fig. 7c). Another evidence of intracrystalline deformation is the undulate extinction. Sometime a dimensional preferred orientation of grains is also evident. These features implies that calcite crystals (re)crystallized under syn-kinematic conditions.

Quartz occurs as isolated granoblasts with a medium to fine grain size, showing rounded boundaries. It is characterized by undulated extinction and, sometime, subgrain aggregates due to syn-kinematic recrystallization. It is present in a 5 – 10 vol. % and is more abundant in the fine grain layers.

White mica occurs as isolated flakes homogeneously distributed in the rock. The percentage of white mica ranges between 5 and 10 vol. %. BSE images and electron microprobe analyses allow to distinguish three different dioctahedral mica varieties: phengite (K end-member), paragonite (Na end-member) and margarite (Ca end-member). The potassic white mica resulted the most abundant, followed by paragonite and margarite. It is present in both fine grain and coarse grain domains. Paragonite occurs

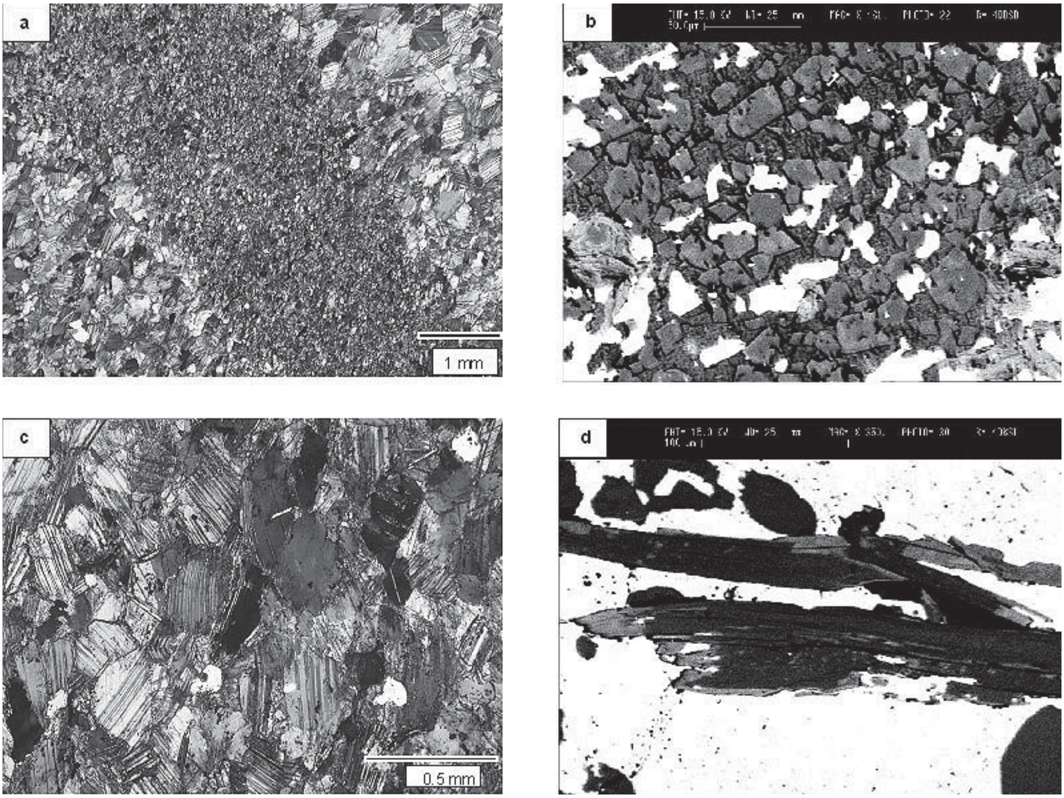

Fig. 7 – Microstructures and mineralogical assemblages in the studied grey marbles: a) Coarse and fine grained carbonatic levels in the Porta Praetoria marble. Light microscope, crossed pol. b) Prismatic crystals of dolomite (grey) grown on calcite crystals (light) in the fine grained levels. BSE image. c) Detail of calcite crystals in the coarse grained levels. Each crystal shows lobate grain boundary, poly-synthetic twinning, undulate extinction and evidence of intracrystalline deformation. Light microscope, crossed pol. d) Paragonite lepidoblast (dark) showing a coronitic overgrown of margarite (light). BSE image. e) Irregular distribution of phengite (ph) and phlogopite (phl) acicular crystals and rounded quartz (qtz) in the calcite rich levels of Porta Praetoria marble. BSE image. f) Intergrowth microstructures of paragonite (dark) and Mg-chlorite (black) flakes in the calcite – dolomite levels. BSE image. g) Fine-grained pseudomorphs after lawsonite in the Villeneuve Stone. The pseudomorphs consist of phengite + margarite + paragonite + dolomite + calcite + graphite symplectite. BSE image. h) Phengite (ph) and phlogopite (phl) oriented lamellae in the calcite rich levels of Aymavilles Marble. BSE image.

as large (>200 micron) and isolated flakes, without any preferential orientation. It is present only in the calcite-rich coarse domains. Margarite occurs only as intergrowth lamellae at the rim of paragonite lepidoblasts (Fig. 7d).

Phlogopite and chlorite are also present. Phlogopite occurs as very fine lepidoblasts (maximum size <100 micron) concentrated in the coarse size domains and associated to calcite granoblasts without any preferential orientation (Fig. 7e). Chlorite also occurs in the coarse calcite domain or is associated to paragonite, showing intergrowth microstructures (Fig. 7f).

4.2 Villeneuve Stone

The rock mainly consists of carbonates (calcite + dolomite) with minor silicates (micas and quartz). It shows a well defined layering consisting of large size calcite levels interbedded with fine size levels where calcite is partially replaced by dolomite, where it is around 35 – 40% in vol. Some later quartz veins cross-cutting the compositional layering are also present.

In the coarse levels, calcite is the most abundant (> 90%) mineral, with minor amounts of micas and quartz, which occur as isolated crystals included in the calcite matrix. Also in the coarse layer, isolated crystals of dolomite, widespread in the carbonate matrix, are visible. The silicate minerals are preferentially concentrated in the dolomitized layers.

In the Villeneuve Stone, three dioctahedral mica varieties are also present (10 – 15%). The prevalent mica is the potassic variety, which occurs as small lepidoblasts (100 micron in size) homogeneously distributed in the rock. It shows a preferred dimentional orientation. Large crystals of paragonite, in the calcite rich level, are also present. Finally, margarite occurs preferentially associated at lozenge shaped pseudomorphoses developed at the expense of original lawsonite porphyroblasts, now completely overprinted by a fine grained mineralogical association of muscovite + margarite + paragonite + dolomite + calcite + graphite (Fig. 7g). Margarite represents a typical product of the lawsonite breakdown, which probably happened by the following de-hydration reaction: lawsonite + Kaolinite = margarite + quartz + H_2O reported by Frey *et al.* (1982) and Chatterjee *et al.* (1984). Actually, kaolinite flakes are found associated to potassic mica. The occurrence of margarite instead of epidote in the pseudomorphoses after lawsonite imply low temperature conditions, in agreement with literature, which suggest for the External Piedmont Zone blueschist facies conditions at T lower than 500 °C (Ernst and Dal Piaz, 1988).

4.3 Aymavilles Marble

The microstructure of Aymavilles marble is characterized by a well developed layering defined by the regular intercalation of fine grained (lower than 50 micron) and coarse grained (around 500 micron) levels. The boundary between different grain size domains is sharp. The rock mainly consists of carbonate minerals (> 90%), with a subordinate presence of silicates as micas, quartz, phlogopite and chlorite. Apatite, zircon, graphite and pyrite occur as accessory minerals.

Among carbonate minerals, BSE images allow to distinguish calcite and dolomite. Calcite is more abundant than in Villeneuve Stone and occurs as polygonal aggregates of granoblasts showing prismatic grain boundary. The grain size is quite homogeneous, with a maximum grain size around 500 micron. Single calcite crystals show polisynthetic twinning and undulose extinction, which reflect the large amount of ductile deformation suffered by the rock under syn-kinematic conditions. Dolomite is present in the fine grained levels, where it partially replaces the original calcite. Quartz occurs as granoblasts, showing rounded grain boundary with a medium to fine grain size. It shows undulate extinction and subgrain boundary development due to recovery processes. The amount of quartz is lower than 5% vol.

White mica shows an heterogeneous grain size (from hundreds to lower than 50 micron) and an homogeneous distribution in the rock. The amount of white micas (5 – 10%) is considerably lower respect to the Villeneuve Stone, and comparable with that one observed in the Porta Praetoria marble. In the Aymavilles marble the three dioctahaedral micas varieties were also observed by BSE images. The potassic mica, which occurs as lepidoblasts in both the coarse and the fine grained domains, is the most abundant. It shows a preferred dimensional orientation (fig. 7h). Large crystals of paragonite occurs as isolated large grains in the calcite layers. Sometimes, very small phlogopite crystals (< 50 micron) are founded in the calcite rich levels (Fig. 7h). Finally, Mg-chlorite is also present, as single crystals associated to paragonite.

5. Mineralchemistry

5.1 Phengite

Potassic mica resulted the most common mica occurring in the analysed marbles. It is marked by an high celadonitic substitution, which implies a crystallization under high pressure conditions typical of the first metamorphic event of Alpine age. All phengite crystals show the same minerochemical features, independently by the sample provenance.

Both Aymavilles and Villeneuve micas plot in the same field along the muscovite celadonite tie – line as shown in Fig. 8, where representative analyses of Porta Praetoria micas are also reported. In particular, the single mica crystals show a compositional zoning with a Si content decreasing from the core (Si = 3.70 atoms p.f.u., on the basis of 11 oxygen) towards the rim (Si = 3.35 atoms p.f.u.), reflecting a partial re-equilibration during the decompressional stages of the metamorphic evolution.

The potassic mica, grown in correspondence of lawsonite pseudomorphs, is characterized by a lower celadonitic substitution (Si content ranges between 3.30 and 3.20 atoms p.f.u.), which suggests a crystallization occurred at lower pressure conditions.

In addition, the analysed micas exhibit a value of the octahedral sum ($Mg + Fe^{2+} + Al^{VI} + Ti$) slightly more elevated than the theoric value of 2.000 atoms p.f.u. Therefore, mica shows a limited trioctahedral substitution, as generally reported in literature for micas of paraderivated origin (Guidotti, 1984). In particular, in the analysed mica the octahedral site is only occupied by Al^{VI} and Mg cations, while Ti and Fe resulted below detection limit. Ti content is generally related to temperature values, and his absence implies that during the metamorphic peak low temperature conditions were reached.

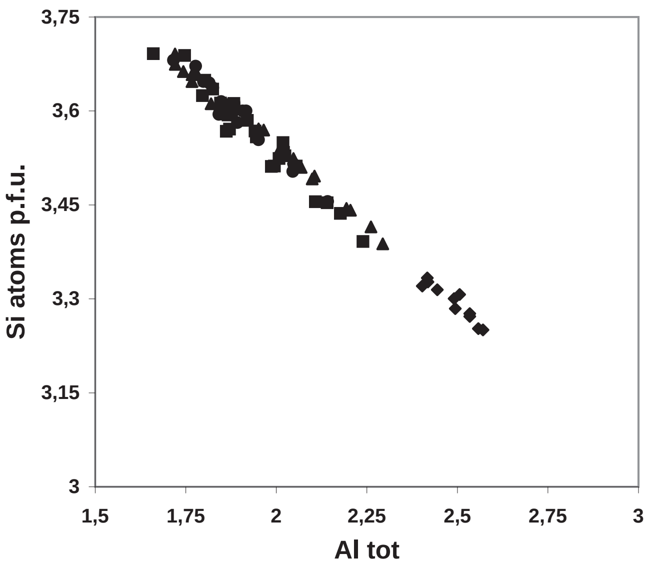

Fig. 8 – Si / Al tot classification diagram for the potassic dioctahedral micas. Data plot along the joint muscovite - celadonite. Square = Porta Praetoria mica; circle = Aymavilles Marble mica, triangle = Villeneuve Stone mica, diamond = mica from lawsonite pseudomorphs.

Instead, the lack of Fe^{2+} implies that in the tschaermakitic substitution [Si + (Mg, Fe^{2+}) = Al^{IV} + Al^{VI}], occurred during the high pressure metamorphic conditions, Al^{VI} was substituted only by Mg, in agreement with the chemical system CMASH which characterizes the carbonatic system at which the studied samples belong. The good linear correlation between Mg and Al^{VI} contents (Fig. 9) attests the presence of only Mg in the double cationic substitution of the high pressure potassic mica.

Finally, potassic mica is marked by a low amount of paragonite and margarite substitution, (<10%), confirming the low temperature conditions at which it developed.

5.2 Paragonite

Paragonite is less abundant than potassic mica, even if it occurs homogeneously widespread in all the analysed samples. Paragonite shows a light excess of Si content respect to the theoric value of stoichiometric formula (4.000 atoms p.f.u., on the basis of 22 oxygen), coupled with a light deficit of Al^{IV}. This fact is real and not the result of an analytical error, as the sum of the octahedral site is always around the theoretical value of 4.000, implying that the total amount of quantified Al is stoichiometrically correct. Sometime the Al^{VI} is slightly substituted by Mg, while Fe^{2+} and Ti are below detection limit.

Paragonite shows a partial substitution with the potassic and, above all, the calcium mica. The margarite molecule is <20%, with an average value of 5%, while the muscovite molecule is <8%.

5.3 Margarite

The calcic mica is only present in the pseudomorphs after lawsonite in the Villeneuve Stone or grown at the rim of paragonite mica in the Aymaville Marble and in the Porta Praetoria samples.

Margarite shows a slight defect of the octahedral site sum respect to the theoric value of 4.000 atoms p.f.u. on the basis of 22 oxygen, while the Si content is always lower than the theoric value of 4.000, because it is partially replaced by Al^{IV}.

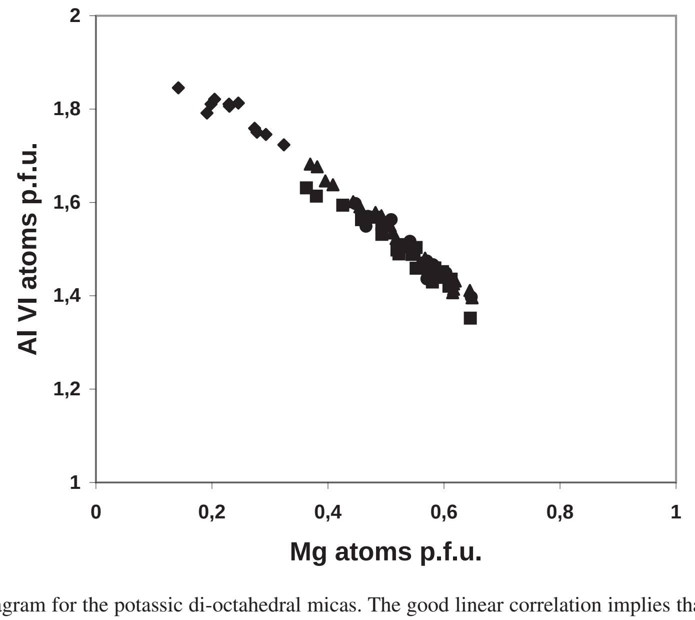

Fig. 9 – Al^{VI} / Mg diagram for the potassic di-octahedral micas. The good linear correlation implies that all octahedral Al is replaced by Mg cation. Square = Porta Praetoria mica; circle = Aymavilles marble mica, triangle = Villeneuve Stone mica, diamond = mica from lawsonite pseudomorphs.

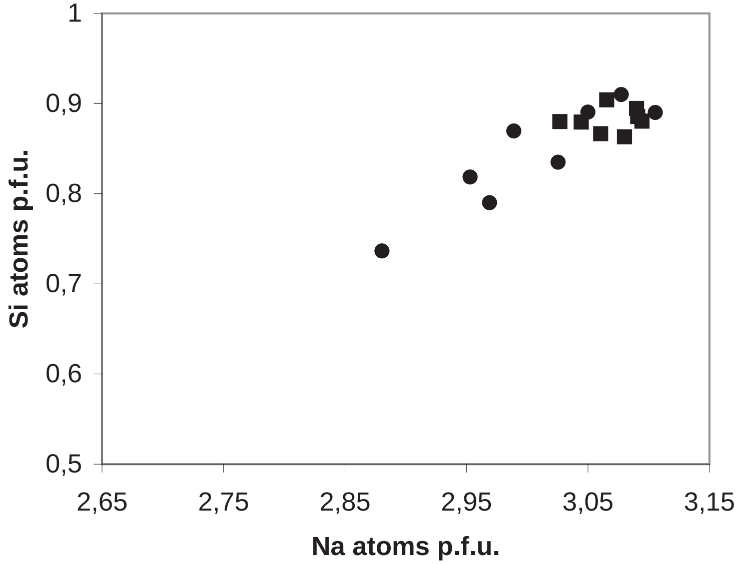

Fig. 10 – Si / Na diagram for margarite. The good linear correlation is related to the margarite – paragonite solid solution. Square = Porta Praetoria marble; circle = Villeneuve Stone.

This fact is related to the partial substitution of margarite molecule by the paragonite (between 20 and 40%) and, subordinately, by the muscovite (<10%) end-members. Indeed, in the interlayer site the Ca content is always lower than the theoric value of 4.000 a.p.f.u., as Ca is partially replaced by Na and K. In Fig. 10 the good linear correlation between Ca and Al^{IV} contents, related to the double cationic substitution Ca + Al^{IV} = Na + Si, which defines the margarite – paragonite solid solution, is displayed.

5.4 Other minerals

The phlogopite occurring in the Porta Praetoria samples and in the Aymaville Marble results quite homogeneous. It is marked by pure Mg end-member (i.e. Fe content was <0.050 a.p.f.u., on the basis of 22 oxygen). The eastonitic substitution resulted more extended, as the Al^{VI} content ranges between 0.130 and 0.331 a.p.f.u. Also chlorite occurring in the Aymaville Marble and in the Porta Praetoria samples resulted a pure Mg end-member (Fe content was always lower than 0.100 atoms p.f.u., on the basis of 28 oxygens). Si content ranges between 5.75 e 5.92 atoms p.f.u. On the classification diagram of Hey (1954) the analysed chlorite plots in the field of clinoclore.

Finally, some crystals of calcite and dolomite belonging to the Porta Praetoria samples were analysed. Calcite resulted always stoichiometrically pure, with a content of Mg lower than 3%. Instead, dolomite resulted partially substituted by calcite. The Mg content, ranging between 0.87 to 0.97, is lower than the theoretical value of 1.000, (calculated on the basis of 2.000 atoms p.f.u). On the contrary Ca is always over the value of 1.000, ranging between 1.01 and 1.07. A low content of Fe (0.01 – 0.04 atoms p.f.u.) was also detected. Comparing results were obtained for both Aymavilles and Villeneuve marbles

6. Conclusion

Marbles were widely used in Roman times in sculpture and architecture. Beside coloured marbles, white and grey varieties were particularly appreciated and selected for prominent buildings and for use in statuary and architectural sculpture.

TABLE 1 – *Representative electron microprobe analyses and atomic proportions of phengitic mica based on 11 oxygens. PP: Porta Praetoria sample; AY: Aymavilles Marble; VIL: Villeneuve Stone. bdl = below detection limit.*

	Phengite											
ANAL.	PP	PP	PP	PP	PP	PP	AY	AY	AY	VIL	VIL	VIL
SiO2	53.97	54.90	54.71	53.70	55.39	55.77	53.75	55.95	55.95	55.06	54.88	55.14
TiO2	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Al2O3	26.79	24.29	23.88	25.96	24.52	24.72	25.04	23.82	23.42	24.16	23.86	24.44
FeO	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
MgO	4.77	5.60	5.62	5.04	5.38	5.66	5.43	5.98	6.16	5.93	5.84	5.80
CaO	bdl	bdl	0.59	0.44	0.34	bdl	0.41	bdl	bdl	0.39	0.97	0.60
Na2O	0.25	bdl	bdl	0.29	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
K2O	9.98	9.59	9.88	9.51	10.02	10.18	9.53	9.88	9.83	9.64	9.83	9.44
	******	******	******	******	******	******	******	******	******	******	******	******
Total	95.77	94.38	94.69	94.93	95.64	96.32	94.15	95.64	95.35	95.18	95.39	95.43
Si	3.512	3.612	3.605	3.524	3.607	3.605	3.554	3.637	3.647	3.600	3.595	3.594
Al IV	0.488	0.388	0.396	0.476	0.393	0.395	0.446	0.363	0.353	0.400	0.406	0.407
Al VI	1.567	1.495	1.459	1.532	1.490	1.489	1.505	1.462	1.446	1.462	1.436	1.471
Mg	0.463	0.549	0.552	0.493	0.523	0.545	0.535	0.579	0.599	0.578	0.571	0.564
Ca	–	–	0.042	0.031	0.024	–	0.029	–	–	0.027	0.068	0.042
Na	0.033	–	–	0.038	–	–	–	–	–	–	–	–
K	0.829	0.805	0.831	0.796	0.833	0.840	0.804	0.820	0.818	0.805	0.821	0.785
Z	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Y	2.030	2.044	2.011	2.025	2.012	2.034	2.040	2.041	2.045	2.040	2.006	2.034
X	0.861	0.805	0.873	0.864	0.856	0.840	0.833	0.820	0.818	0.832	0.889	0.827

In particular, the Villeneuve Stone and Aymavilles Marbles represent two important historical material stones, which were used by Ancient Romans in the edification of Augusta Praetoria (the modern town of Aosta). These marbles were selected for their peculiar grey colour, with irregular light and dark compositional layering, which well contrasted with the white colour of travertine and pure marbles. The most important use consists in the covering of the Porta Praetoria, showing an excellent state of preservation.

The petrographic and mineral chemistry study of some fragments of the Porta Praetoria grey marble, compared to Aosta Valley marbles, allowed to reconstruct its minero-petrographic features and to define its provenance. Indeed, the Porta Praetoria grey marble is characterized by a peculiar metamorphic paragenesis, defined by the contemporaneous presence of the three dioctahedral micas (phengite, paragonite and margarite) other than phlogopite and Mg-chlorite. This assemblage reflects the metamorphic conditions suffered by this marble during the Alpine orogeny (blueschists facies) and allows to distinguish it by other grey marbles employed in the ancient time. As regard to the provenance of Porta Praetoria grey marble, the comparison with Villeneuve Stone and Aymavilles Marble, allowed to assign it at Aymaville Marble. The latter, indeed, is the only rock in which occur phlogopite and Mg-chlorite, with the same chemical compositions detected in the Porta Praetoria samples, other than the three varieties of white micas.

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TABLE 2 – *Representative electron microprobe analyses and atomic proportions of paragonite (an. 1-6) and margarite (7-12) micas based on 22 oxygens. PP: Porta Praetoria sample; AY: Aymavilles Marble; VIL: Villeneuve Stone. bdl = below detection limit.*

	Paragonite						Margarite					
ANAL.	PP	PP	PP	AY	AY	AY	PP	PP	PP	VIL	VIL	VIL
SiO2	48.01	47.55	48.17	48.70	47.74	47.11	35.34	33.93	36.52	34.76	39.00	35.29
Al2O3	38.00	39.50	39.60	38.82	38.53	39.39	46.69	48.29	45.50	46.28	43.98	45.57
MgO	0.50	bdl	bdl	0.57	0.61	bdl	bdl	bdl	bdl	bdl	bdl	bdl
CaO	0.41	0.78	0.32	0.53	0.75	0.32	9.66	12.32	9.17	9.26	6.60	9.62
Na2O	6.81	6.77	7.25	7.05	7.11	7.38	2.33	1.24	2.17	2.86	3.85	2.61
K2O	0.73	0.90	bdl	0.70	0.47	bdl	0.43	0.29	1.06	bdl	0.49	0.30
	******	******	******	******	******	******	******	******	******	******	******	******
Total	94.47	95.51	95.35	96.38	95.20	94.20	94.46	96.05	94.42	93.16	93.93	93.39
Si	6.160	6.051	6.100	6.131	6.089	6.049	4.681	4.448	4.838	4.662	5.141	4.729
Al IV	1.840	1.949	1.900	1.869	1.911	1.951	3.319	3.552	3.162	3.338	2.859	3.271
Al VI	3.907	3.973	4.010	3.892	3.880	4.009	3.969	3.909	3.941	3.978	3.975	3.926
Mg	0.096	–	–	0.107	0.115	–	–	–	–	–	–	–
Ca	0.057	0.107	0.044	0.072	0.102	0.044	1.371	1.730	1.301	1.331	0.933	1.382
Na	1.694	1.670	1.781	1.722	1.759	1.836	0.599	0.315	0.557	0.743	0.985	0.678
K	0.120	0.147	–	0.113	0.076	–	0.072	0.049	0.179	–	0.084	0.052
Z	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Y	4.003	3.973	4.010	3.999	3.996	4.009	3.969	3.909	3.941	3.978	3.975	3.926
X	1.870	1.924	1.825	1.907	1.937	1.880	2.042	2.094	2.037	2.074	2.001	2.112

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TABLE 3 – *Representative electron microprobe analyses and atomic proportions of phlogopite based on 22 oxygens (an. 1-6) and chlorite (an. 7-12) based on 30 oxygens. PP: Porta Praetoria sample; AY: Aymavilles Marble. bdl = below detection limit.*

	Phlogopite						Chlorite					
ANAL.	PP	PP	PP	AY	AY	AY	PP	PP	PP	AY	AY	AY
SiO2	46.71	46.59	46.09	44.16	46.05	45.34	33.14	32.42	32.98	30.37	32.20	32.02
Al2O3	12.38	12.78	12.46	12.63	12.14	13.32	21.23	23.41	23.20	22.58	21.82	21.71
FeO	bdl	0.23	0.42	1.48	bdl	bdl	bdl	bdl	bdl	bdl	0.40	0.57
MgO	28.65	29.07	27.90	26.76	28.30	27.79	33.19	34.08	33.67	32.14	32.80	32.54
CaO	bdl	0.52	bdl	1.64	0.37	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Na2O	bdl	0.59	0.47	0.43	0.38	bdl	bdl	bdl	bdl	bdl	bdl	bdl
K2O	8.81	8.84	8.53	9.08	8.00	8.67	bdl	bdl	bdl	bdl	bdl	bdl
	******	******	******	******	******	******	******	******	******	******	******	******
Total	96.54	98.61	95.88	96.19	95.26	95.11	87.55	89.91	89.86	85.09	87.21	86.84
Si	6.280	6.172	6.257	6.081	6.268	6.189	6.053	5.781	5.875	5.724	5.924	5.922
Al IV	1.720	1.828	1.743	1.919	1.732	1.811	1.947	2.219	2.125	2.276	2.076	2.078
Al VI	0.241	0.169	0.251	0.130	0.216	0.331	2.623	2.701	2.746	2.738	2.654	2.654
Fe	–	0.025	0.048	0.170	–	–	–	–	–	–	0.061	0.088
Mg	5.743	5.740	5.647	5.496	5.742	5.655	9.040	9.058	8.944	9.031	8.995	8.971
Ca	–	0.073	–	0.242	0.054	–	–	–	–	–	–	–
Na	–	0.151	0.124	0.117	0.101	–	–	–	–	–	–	–
K	1.510	1.494	1.477	1.596	1.390	1.510	–	–	–	–	–	–
Z	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Y	5.984	5.935	5.946	5.797	5.958	5.985	11.662	11.759	11.690	11.769	11.711	11.712
X	1.510	1.718	1.600	1.954	1.545	1.510						

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