Petrographic study of *pietra ollare* mills from Garda Civic Museum in Ivrea (To)

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Article

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ABSTRACT

An archaeometric study of Roman age pietra ollare mills preserved at Pier Alessandro Garda Civic Museum of Ivrea (Piemonte, NW Italy) was performed, to enhance the historical stone employed in the ancient *Eporedia* (current Ivrea) and to make more available the archaeological heritage of this city. The petrographic analysis and the study of their mineral composition with the electronic microprobe allowed to attribute a local provenance to the millstones studied. In particular, two millstones resuted garnet chloritoschists, that showed petrographic characteristics similar to pietra ollare of Aosta Valley, while a third millstone consisting of a jadeite micaschist probably comes from the high pressure rocks of the Eclogitic Micaschist Complex of the Sesia-Lanzo Zone.

The analyses of these materials is part of diagnostic-conservative and fruition project of the municipality of Ivrea, in collaboration with Soprintendenza Archeologia, belle arti e paesaggio per la Città metropolitana di Torino, the Municipality of Ivrea and the Fondazione Guelpa.

KEY WORDS: cultural heritage, Ivrea, Pietra ollare, petrography, provenance.

INTRODUCTION

The Pier Alessandro Garda Civic Museum, located in Piazza Ottinetti in the heart of Ivrea (Piemonte, NW Italy), preserves an important archaeological section in stone finds.

Starting from 2018, the Department of Earth Sciences of the University of Turin made a collaboration with the Museum, to find a petrographic characterization, no less important than the historical one, to some finds from the archaeological section. The systematic study of the documentation, the analyses of the finds, the comparison with findings from other sites translates into a reasoned interpretation of the past, from prehistory to the flourishing of ancient *Eporedia* (Gabucci et al., 2014).

In this work an attempt was made to answer the problem of the geological origin of the raw materials by carrying out a petrographic characterization of three mills dating back to the Roman age and preserved at the P.A. Garda Civic Museum of Ivrea.

The study and classification of pietra ollare in the field of Earth Sciences is connected with archaeological investigations for the historic provenance of these materials; the archaeometric methodology in this case can be a good tool for applying the scientific methodologies to cultural heritage. Defining the sites of origin of the raw materials of archaeological artifacts is one of the most pursued objectives in archaeometric studies (Riccardi et al., 2018).

The general term pietra ollare is a word with petrographic and economic meaning: as a whole, the rock is mainly made up of a soft mineral in which single isolated sub-millimeter crystals of a hard mineral are set. This type of rock fully satisfies the purpose for which it was used in the past: to powder grain and other seeds for food purpose.

From an economic point of view, this term indicates different lithotypes (generally pietra ollare refers to all green stones of metamorphic origin) which have quite different composition, color and appearance, but which have some peculiar physical and chemical characteristics (Fantoni et al., 2018). The constituents are largely silicates chemically stable to atmospheric agents, and, above all, to foods used by man; they have a high thermal refractoriness, and therefore a good resistance to thermal shock and bad heat conduction; they are homogeneous rocks with very low porosity (they absorb very little liquid) even when they have a foliated texture; the main minerals that make up these rocks have a very low hardness (from 1 to 4 on the Mohs scale) which favors fast and detailed processing with metal tools, both by hand and on the lathe. Finally, they show resistance to acids and bases (Mannoni et al., 1987; Mini, 2015). The term therefore has a meaning linked to certain thermal and mechanical characteristics present in some materials used for more than two millennia (Mannoni et al., 1987).

Mineralogical-petrographic analyses, on the other hand, make it possible to distinguish the lithotypes included in the pietra ollare category. They mostly belong to ophiolite complexes, deriving from the Alpine metamorphism of rocks that were previously part of the oceanic crust outcropping in the internal sector of the Alpine chain (Fantoni et al., 2018).

This term therefore includes numerous lithologies (Mannoni & Messiga, 1980; Mannoni et al., 1987; Santarrosa, 1999; Castello & De Leo, 2007), including chloritoschists. These rocks consist mainly of chlorite, accompanied by other minerals in smaller quantities. For example, in the Western Alps, in the low-temperature reaction zones between serpentinites and rodingite veins, or with encasing rocks, there is always a band of chloritoschists which formed by metasomatic processes, at temperatures below 500°C, at the expense of serpentinized ultrabasic rocks (Bortolami & Dal Piaz, 1968; Dal Piaz, 1967; Dal Piaz, 1969). This reaction zone shows an enrichment in Ca, a loss of Si and a significant decrease in the alkali content (Riccardi et al., 2018). The most abundant mineral is chlorite, often associated with diopside, garnets, talc and amphiboles (Dal Piaz, 1967, 1969).

The classifications proposed in the 1980s and still adopted for the pietra ollare of the Western Alps are those reported by Mannoni & Messiga (1980) and Mannoni et al. (1987), in which at least 11 lithotypes are proposed (Groups A-L). A classification of Alpine pietra ollare was proposed by Gallo (in Santarrosa, 1999) who integrated the first classification with 3 other petrographic types (Groups M-O).

HISTORICAL FRAMEWORK AND PREVIOUS STUDIES

The city of Ivrea (ancient *Eporedia*) is a municipality on the Metropolitan City of Turin and is located nearby of the entrance to the Aosta Valley at the foot of the Western Alpine Chain. Starting from the July 1, 2018 Ivrea became part of the 54th Italian UNESCO World Heritage Site thanks to its historical-archaeological monuments of great interest and industrial architecture (UNESCO, 1972). During the numerous archaeological phases of excavations important stone artifacts dating back to the Roman age have been found, now preserved at the Pier Alessandro Garda Civic Museum.

The Civic Museum, after long restoration and staging of the collections, in January 2014 was reopened to the public, which was thus able to regain of a significant historical and cultural heritage.

Thanks to the availability of the Museum to sample minimal quantities of stone material, three Roman millstones were studied

Fig. 1 - The P.A. Garda Civic Museum roman pietra ollare collection.

(Fig. 1), with the aim of reconstructing their geological provenance for diagnostic and conservation purposes. From a petrographic point of view, these findings are two garnet chloritoschists and one jadeite micaschist. The number of samples considered for this work and the size of the relative thin sections is small since, being these archaeological finds, it was not possible to carry out further sampling.

For better undestanding the probably geological provenance of the pietra ollare the geological map of the Western Alps is shown (Fig. 2), with the four main domains (Southalpine, Austroalpine, Pennidic, and Helvetic-Dauphinois) separated by major tectonic contacts and characterized by a homogeneous paleogeographic origin and geological history (Dal Piaz, 1992). (Fig. 2). In general, Alpine pietra ollare derives from the lower Penninic units called Piemonte Zone in literature (Dal Piaz, 1999), essentially largely made up of metamorphic rocks re-equilibrated under conditions of high pressure and low temperature (eclogitic *facies*) derived from tectonic slices of oceanic crust (metabasites) or, to a lesser extent, upper mantle (serpentinites).

In order to take more detailed for the provenance of these materials, history of commercial route and crossroads of Ivrea is also shown from historical-archaeological point of view. Data from literature (Cortelazzo, 2007 and Cortelazzo, 2013) reported that Ivrea in the past was a centre where important quantities of goods, including millstones. Arrived here, they were stored in what early medieval documents identify as the *communis molarius*, a real state workshop, defining a trade organization with a monopolistic imprint. There were warehouses, supply centers in which to buy the millstones, mercatores, i.e., intermediaries with the quarrymen (Grillo, 1993; Rivolin, 1993). It is probable that, even in Roman times, there was this type of trade and commercial

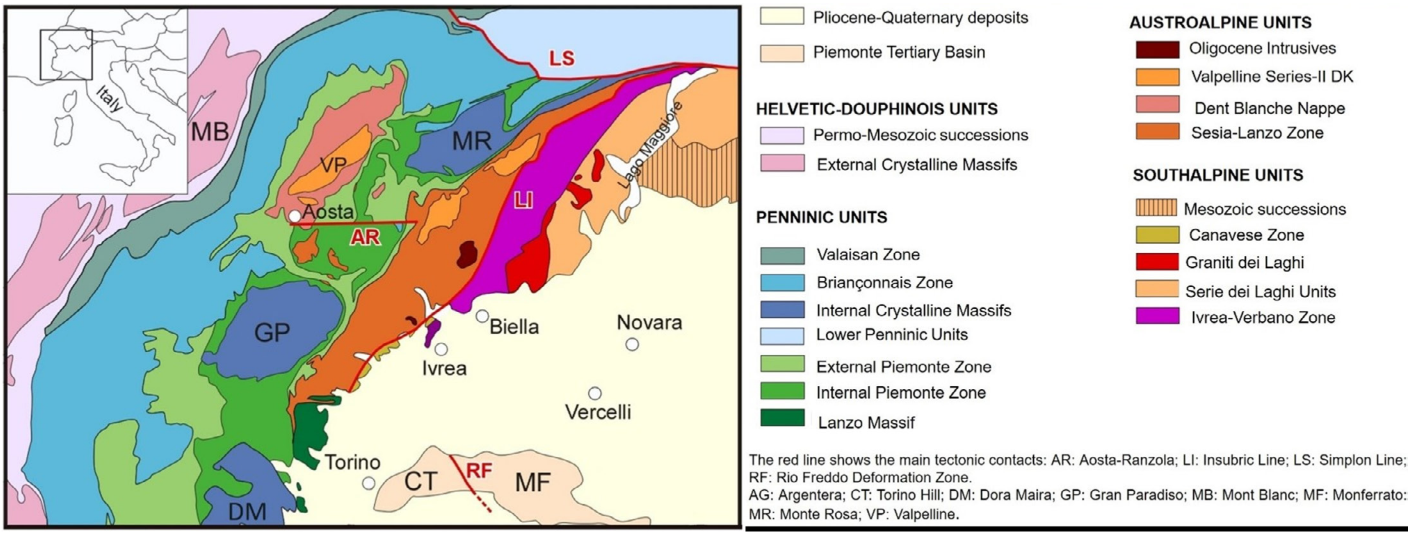

Fig. 2 - Tectonic sketch map of Piemonte Region (modified by Gambino et al., 2019).

exchanges in Ivrea. This hypothesis could be confirmed by the report of the discovery of millstones of Aosta Valley in chloritoschist with garnet, which came to light in the archaeological area of the Roman city of *Octodunum* (Martigny, Valais-CH) (Pellissier, 2000; Cortelazzo, 2018). this would attest to a commercial direction already in Roman times.

MATERIALS AND METHODS

The studies were carried out on three archaeological finds. Macroscopic investigations (variation in texture and mineralogical composition) were conducted directly on the artifacts, through the use of the DINO-Lite converter microscopy, a portable wireless digital instrument that allows to zoom up to 220x and capable of acquiring high-resolution images and videos. Subsequently, thanks to a minimum amount of sampling for each finding, the study in thin section was carried out. The petrographic analyses of the samples were performed using optical microscopy (Olympus STREAM 2.4.3). Mineral composition phases were acquired using a scanning electron microscopy (JEOL JSM-IT300LV) equipped with an energy dispersion X-ray spectrometer (EDX), with an SDD (Oxford Instruments Silicon Drift Detector), hosted at the Department of Earth Sciences of Turin. The acquisition conditions were: acceleration voltage 15 kV, counting time 50 s, process time 5 µs, beam current 800 pA, working distance 10 mm. Measurements were performed under high vacuum conditions. The spectra acquired with EDX were corrected and calibrated both in energy and in intensity thanks to the measurements on a Cobalt standard introduced into the vacuum chamber with the samples. Oxford INCA Energy 300 microanalysis suite was used for the acquisition of spectra and recognition of the elements; a ZAF program for the quantification of the spectra was used. The complete resulting quantitative analysis was obtained by comparing the spectra with reference standards, using natural oxides and silicates from Astimex Scientific Limited®. The MINSORT software was used for the recalculation of the analyses (Petrakakis & Dietrich, 1985). The mineral compositions were expressed as atoms per unit of formula (a.p.u.f.). The mineral acronyms used in the text were taken from Whitney and Evans (2010).

For the determination of the geological origin of these finds, in addition to the petrographic characterization, which allows to define the paragenesis of the mineralogical phases, it was decided to make a comparison with the geochemical database produced by Da Prà et al. (2019) for the main Aosta Valley pietra ollare extraction sites, geographically not far from the archaeological site of the city of Ivrea. The classification of Mannoni et al. (1987), Castello & De Leo (2007) e Mariano Gallo (in Santarrosa, 1999) were considered. Further informations collected by Castello (2016a, 2016b, 2018a, 2018b) are also compared for this study.

RESULTS

Petrographic analysis

The first sample analyzed (MN 440) represents a millstone of generic geographical origin from the Ivrea area (Fig. 3a). From a petrographic point of view (Fig. 3b) it is a garnet bearing chloritoschist.

Under optical microscope (Fig. 3c and Fig. 3d) the sample consists of quite fresh chlorite (Chl) (70% vol.) of ripidolitic composition, strongly pleochroic on the green and organized in submillimetric lamellae generally oriented according to schistosity planes; Chl represents the most abundant mineralogical phase, which surrounds large garnet (Grt) porphyroblasts (25% vol.), grown in large euedral crystals that are clearly visible even to the naked eye, fractured, free of zoning and containing inclusions, with almandinic composition (Fig. 3e). Sodium-calcic amphibole (Amp) (3% vol.) also occurs. It shows a pattern of pleochroism varying from light green to indigo blue, of winchitic-barrositic composition, organized in isolated crystals and showing zoning composition, indicating conditions of high pressure (HP). Rare poikilitic albite (Ab) also occurs in very small crystals (1% vol.) in equilibrium with chlorite. As accessory phases (1% vol.) allanitic epidote (Aln),

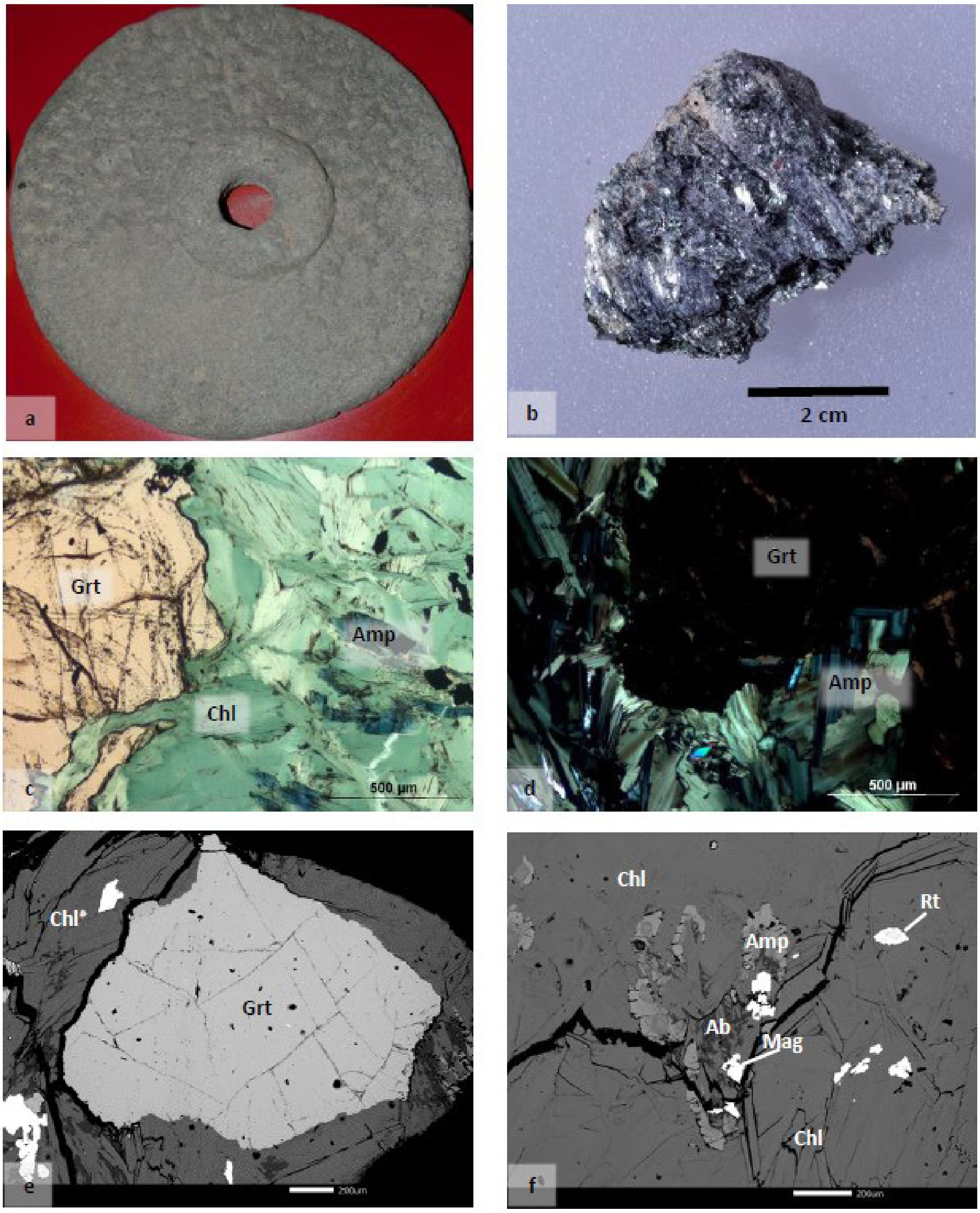

Fig. 3 - a) Roman pietra ollare mills with a very compact appearance and well preserved from a diagnostic-conservative point of view; b) macroscopic photograph of the sample MN 440: note the schistose structure defined by Chl; c) Grt-Amp association surrounded in a chlorite matrix, optical microscope photograph by crossed polarized light (X Pol.); d) Grt crystal, a mineral of high hardness, surrounded by a Chl matrix with a much lower hardness, optical microscope photograph (by X Pol.); e) Grt porphyroblast surrounded by Chl, SEM-BSE image; f) Amp Na-Ca with albitic microinclusions and wrapped in Chl, SEM-BSE image. Grt: garnet; Chl: chlorite; Amp: amphibole; Ab: albite; Mag: magnetite; Rt: rutile.

zircon (Zrn), ilmenite (Ilm), magnetite (Mag) and rutile (Rt) occur (Fig. 3f).

The second sample (MN 441) is represented by a millstone of unknown provenance (Fig. 4a). It is a rock made up of light-colored lamellar minerals that gives the rock a whitish-vitreous color (Fig. 4b). By optical microscope it is recognized a foliate fabric, consisting of white mica (Wm) (70% vol.), quartz (Qz) (26% vol.), and a high-relief mineral (4% vol.), with evident cleavage at 90 degrees, elongated prismatic dress, straight extinction, interference colors corresponding to I red – brown order, which has been interpreted as jadeite (Jd) (Fig. 4c and Fig. 4d).

Due to the small amount of material taken, it was not possible to carry out measurements with the electron-microprobe.

In this specific case, quartz and jadeite acted as hard minerals surrounded in a soft white mica matrix, giving the artefact the same technological meaning as the more common “pietra ollare”. This rock therefore does not fit into the lithological classifications of the literature, but its physical properties are suitable for making millstones.

The last find (MN 443) represents another example of a Roman millstone from the city of Ivrea (Fig. 5a). From the macroscopic point of view it is a rock with foliated texture, characterized by the presence of phyllosilicate minerals which gives the sample the typical greenish color of pietra ollare mills; garnet porphyroblasts of plurimillimetric dimensions were recognized (Fig. 5b). The foliated structure defined by the abundant presence of chlorite (90% vol.) of ripidolitic composition (see chapter of mineral chemistry) can be recognized; it forms a felt of isoriented lamellae to give a marked schistosity, locally deformed and folded by late ductile deformational phases (Fig. 5c and Fig. 5d). In order of abundance,

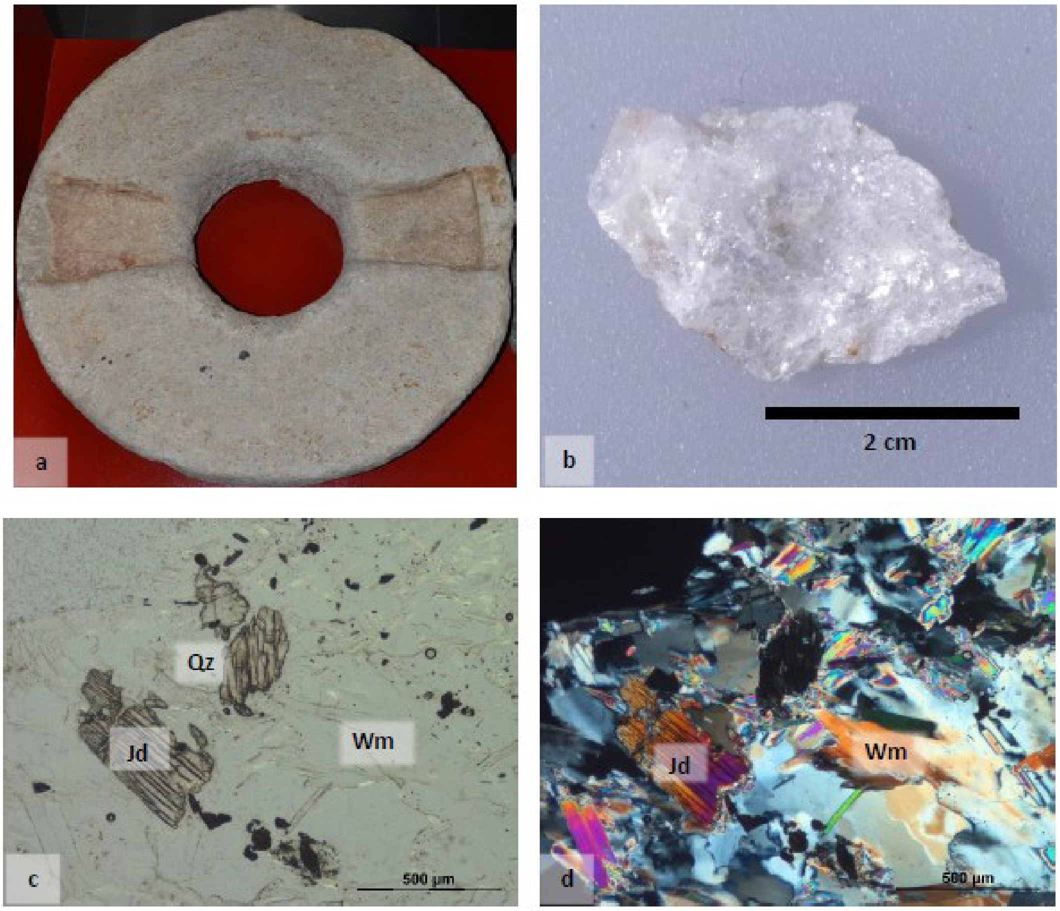

Fig. 4 - a) Roman stone millstone; b) macroscopic photograph of the MN 441 sample in which, from a first macroscopic recognition, white lamellar and others minerals with a vitreous appearance are visible; c) Wm-Jd association, optical microscope photograph by plane polarized light (// Pol.); d) Wm matrix in which jadeitic crystals are embedded, optical microphotograph, X Pol. Qz: quartz; Jd: jadeite; Wm: white mica.

associated with chlorite relict Fe-chloritoid (Cld) (6% vol.), partially replaced by chlorite and pistacitic epidote (Ep) (2% vol.) with nucleous of allanite organized in small granules idiomorphs in equilibrium with chlorite occur. Zircon (1% vol.) and ilmenite (1% vol.) as accessory minerals are present in small masses or aggregates, often included within the chloritoid (Fig. 5e and Fig. 5f). The thin section obtained by sampling the find did not show the presence of Grt porphyroblasts.

Table 1 summarized the main characteristics and minerals present in each sample.

MINERAL CHEMISTRY

All the main mineralogic phases present in the chloritoschist samples MN 440 and MN 443 were analyzed with the SEM-EDS electron microprobe. Section MN 441 was not analyzed because it went out during the processing steps for the microprobe (polishing and scratching), due to its small original grain-size.

For the chlorite the analyses were calculated on the basis of 28 oxygens and were projected on the classification diagram of Hey (1954). Representative analyses are reported in the Table 2.

The composition of the individual crystals is homogeneous within the samples and falls mainly in the field of ripidolite (Fig. 6a).

From the compositional point of view, it is possible to observe the absence of Ti, Mn and Cr, a predominance of Al VI over Al IV and homogeneous values of X Mg ranging from 0.603 to 0.625 atoms per unit of formula (a.p.u.f.) (Tab. 2).

The data of the samples MN 440 and MN 443 (Fig. 6a) were compared with those obtained for the compositions of the chlorites contained in the pietra ollare of the archaeological finds from the site of Saint Martin de Corléans (Ao) (Da Prà et al.

Table. 1 - Main features and mineral assemblage of the three millstones. Chl: chlorite; Grt: garnet; Cld: chloritoid; Ep: epidote; Amp: amphibole; Ab: albite; Wm: white mica; Qz: quartz; Jd: jadeite; Zrn: zircon; Ilm: ilmenite; Mag: magnetite; Rt: rutile.

SAMPLE	GRAIN	TEXTURE	Chl	Grt	Cld	Ep	Amp	Ab	Wm	Qz	Jd	Zrn	Ilm	Mag	Rt
MN 440	Coarse	Anisotropic	x	x		x	x	x				x	x	x	x
MN 441	Fine	Anisotropic							x	x	x				
MN 443	Coarse	Anisotropic	x	x	x	x						x	x		

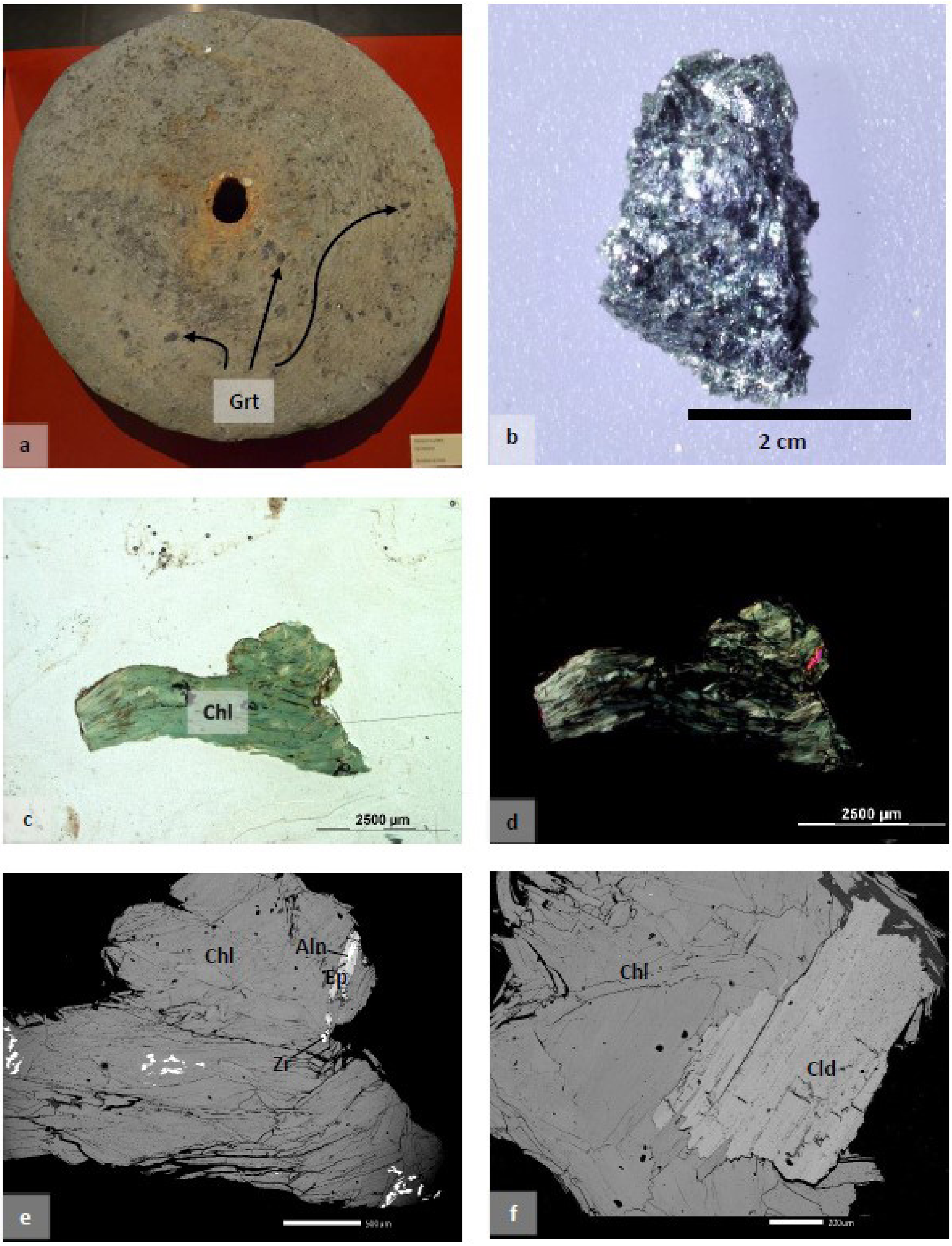

Fig. 5 - a) photograph of the archaeologic find in which the euhedral crystals of Grt (highlighted by the black arrows) of millimeter-plurimillimetric dimensions are already visible; note also how this millstone is much more altered than the MN 440 sample; b) macroscopic photograph of the MN 443 sample; c) Mg-Chl crystals which define the main foliation, optical microphotograph (//Pol.); d) same photograph at X Pol.; e) Chl elongated lamellae with ilmenite inclusion, SEM-BSE photograph; f) Chl-Cld association, SEM-BSE image. Grt: garnet; Chl: chlorite; Aln: allanite; Zr: zircon; Ep: epidote; Cld: chloritoid.

2019) (Fig. 6b). Value of X Fe total are from 3.492 to 3.720, while data of chlorites of Da Prà et al., 2019 has value of X Fe ranging aorung 3.000 and 5.000. The comparison of these data suggests that the analysed chlorites plot between Valmerianaz and Ayas field (Aosta Valley), characterized by a ripidolitic composition.

Chlorite is the only phase present in both sections, so a comparison among them can be made. The chemical analyses of amphibole and garnet, only present in section MN 440, are also reported respectively in Table 3 and Table 4.

As can be seen from the classification diagram used in Fig. 7, the composition of the single crystal of the garnet of the MN 440 sample, verified through cross-sections of microanalysis points, is homogeneous between the core and the rim and therefore without compositional zoning. It shows a particular composition, as the spessartinic molecule is almost absent and the almandine molecule content is greater than 70%. The analyses of garnet (Fig. 7) were compared with those obtained for the compositions of the garnets contained in the pietra ollare of the archaeological finds from the site of Saint Martin de Corléans (Ao) (Da Prà et al., 2019). The comparison of these data suggests that the analysed pietra ollare MN 440 plot in Valmerianaz field (Aosta Valley), characterized by an almandinic composition. Therefore, analyses with garnets from Valmerianaz (Fig. 8) were compared: the compositions are very similar, with strong enrichment in Fe end-member, although the component in Mn differs slightly.

Table 2 - Mineral chemistry of chlorite in MN 440 and MN 441 pietra ollare, based on 28 oxygens. Acronyms represent percentage weight of oxide and the values of the various elements making up the mineralogical phases are to be considered expressed in atoms per unit of formula (a.p.u.f.).

CHLORITE									
SAMPLE	MN 440						MN 443		
ANAL.	1	2	3	4	5	6	1	2	3
SiO_2	27.49	27.92	27.36	26.87	26.94	26.61	27.65	27.10	26.89
Al_2O_3	20.05	20.36	20.48	21.01	21.52	21.94	20.04	21.11	21.27
FeO	21.32	20.52	21.23	21.68	20.97	21.25	21.03	21.19	21.24
MgO	19.15	19.19	18.94	18.44	18.57	18.19	19.28	18.59	18.59
	******	******	******	******	******	******	******	******	******
Total	88.01	87.99	88.01	88.00	88.00	87.99	88.00	87.99	87.99
Si	5.626	5.681	5.595	5.511	5.500	5.443	5.649	5.541	5.501
Al IV	2.374	2.319	2.405	2.489	2.500	2.557	2.351	2.459	2.499
Al VI	2.463	2.564	2.531	2.589	2.679	2.731	2.473	2.627	2.630
Fe	3.649	3.492	3.632	3.720	3.581	3.635	3.593	3.623	3.634
Mg	5.844	5.821	5.774	5.641	5.651	5.546	5.872	5.667	5.671
Z	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Y	11.956	11.877	11.937	11.950	11.911	11.913	11.939	11.916	11.934
Xmg	0.616	0.625	0.614	0.603	0.612	0.604	0.620	0.610	0.609

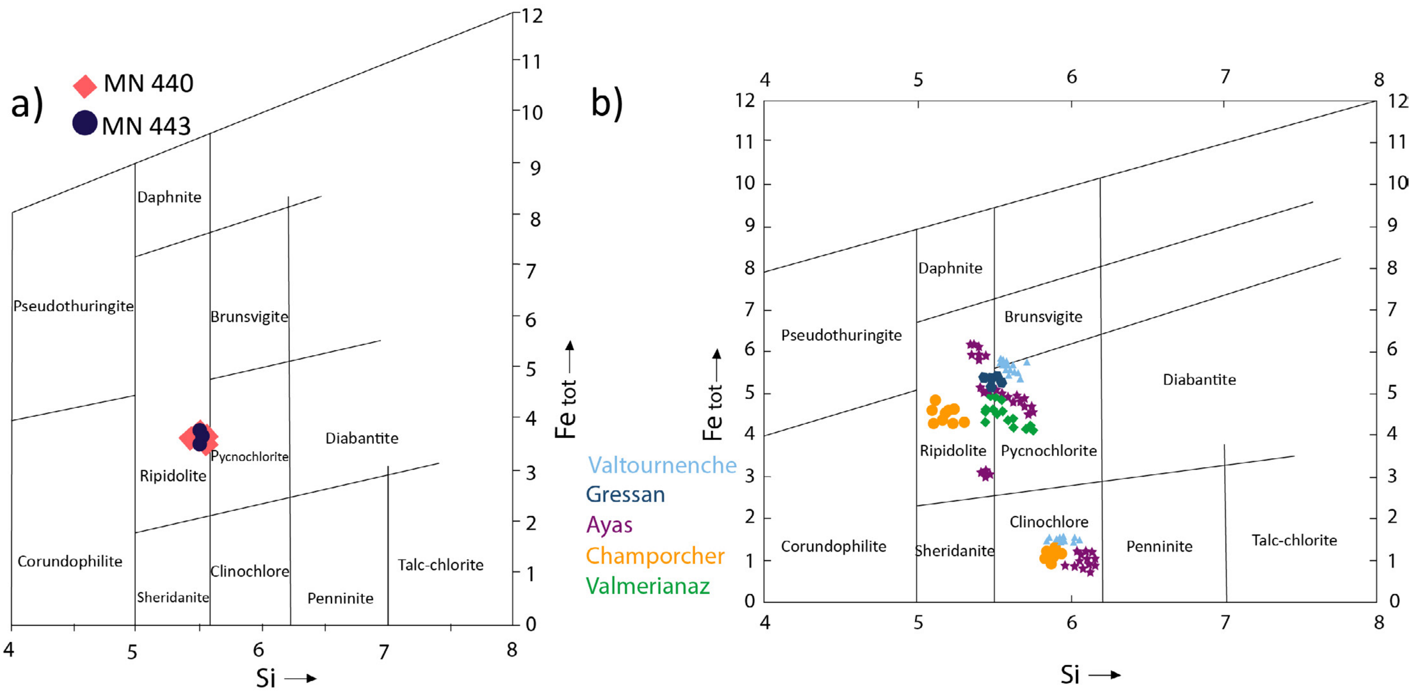

Fig. 6 - a) Chlorites classification diagram (modified from Hey, 1954) for the Eporedian pietra ollare; b) Chlorites classification diagram about pietra ollare mills of the archaeological finds from the site of Saint Martin de Corléans (Ao) (modified from Da Prà et al., 2019).

Table 3 - Mineral chemistry of amphibole in MN 440 pietra ollare, based on 23 oxygens. Acronyms represent percentage weight of oxide and the values of the various elements making up the mineralogical phases are to be considered expressed in atoms per unit of formula (a.p.u.f.).

AMPHIBOLE									
SAMPLE	MN 440								
ANAL.	1	2	3	4	5	6	7	8	9
SiO_2	46.73	46.95	48.12	49.25	53.31	49.91	54.10	55.83	55.69
TiO_2	0.30	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al_2O_3	10.88	11.01	8.04	7.57	5.61	7.03	6.47	7.77	8.13
FeO	19.38	19.41	19.43	18.24	16.42	18.60	17.07	16.43	16.43
MgO	9.23	9.09	10.63	11.27	12.60	11.07	11.03	9.85	9.75
CaO	7.77	7.62	8.92	8.98	6.85	8.53	5.15	2.19	2.21
Na_2O	3.70	3.62	2.86	2.70	3.21	2.86	4.20	5.93	5.79
	******	******	******	******	******	******	******	******	******
Total	97.99	97.99	98.00	98.01	98.00	98.00	98.02	98.00	98.00
Si	6.768	6.787	6.974	7.096	7.498	7.189	7.608	7.930	7.906
Al IV	1.232	1.213	1.026	0.904	0.502	0.811	0.392	0.070	0.094
Al VI	0.625	0.662	0.347	0.381	0.427	0.382	0.680	1.231	1.267
Ti	0.033	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe^{3+}	1.088	1.112	1.105	0.995	1.134	0.999	1.017	0.000	0.000
Mg	1.993	1.959	2.297	2.421	2.642	2.378	2.312	2.086	2.064
Fe^{2+}	1.260	1.235	1.251	1.203	0.796	1.242	0.991	1.683	1.669
Fe^{2+}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.269	0.281
Ca	1.206	1.180	1.385	1.386	1.032	1.316	0.774	0.334	0.335
Na	0.794	0.820	0.615	0.614	0.968	0.684	1.226	1.397	1.384
Na	0.246	0.195	0.189	0.142	-0.091	0.115	-0.080	0.236	0.211
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Xmg	0.613	0.613	0.648	0.668	0.768	0.657	0.700	0.517	0.514

DISCUSSION

The pietra ollare mills make an aspect of great interest due to their geological origin. The wide distribution in the Po Valley of the millstones, established by the historical and archaeological bibliography, must also be supported by the petrographic characterization for their geological origin. If it is certainly not possible to attribute a millstone found in an archaeological site of Italy, in particular those in granatiferous chloritoschist, to a precise quarry, the outcrop area of this particular rock, exploited for the production of millstones, would seem to be limited to a particular sector of the north-western Alps in Aosta Valley (in particular in the central part of the right orographic slope of the Dora Baltea River, with afferent lateral valleys) (Cortelazzo, 2018).

The optical microscopy analyses of the samples MN 440 and MN 443, combined with the mineral-chemical analyses, made it possible to carry out a further comparison with the data known in the literature on the compositions of archaeological finds in pietra ollare, in order to try to determine their origin. In particular, the

Table 4 - Mineral chemistry of garnet in MN 440 pietra ollare, based on 12 oxygens. Acronyms represent percentage weight of oxide and the values of the various elements making up the mineralogical phases are to be considered expressed in atoms per unit of formula (a.p.u.f.). Alm: almandine; sps: spessartine; pyr: pyrope; grs: grossular; anr: andradite.

GARNET						
SAMPLE	MN 440					
ANAL.	1	2	3	4	5	6
SiO_2	37.48	37.44	37.16	37.26	37.47	37.35
Al_2O_3	20.34	20.46	20.59	20.41	20.48	20.71
FeO	33.33	33.38	33.90	33.60	33.29	33.30
MnO	0.44	0.34	0.00	0.00	0.00	0.00
MgO	1.81	1.94	2.11	2.32	2.48	2.71
CaO	6.60	6.45	6.25	6.41	6.27	5.93
	******	******	******	******		******
Total	100.00	100.01	100.01	100.00	99.99	100.00
Si	3.011	3.006	2.896	2.990	3.001	2.989
Al IV	0.000	0.000	0.014	0.010	0.000	0.011
Al VI	1.926	1.936	1.936	1.920	1.933	1.943
Fe	2.239	2.241	2.278	2.255	2.230	2.229
Mn	0.030	0.023	0.000	0.000	0.000	0.000
Mg	0.217	0.232	0.253	0.278	0.296	0.323
Ca	0.568	0.555	0.538	0.551	0.538	0.509
Z	3.011	3.006	3.000	3.000	3.001	3.000
Y	1.998	1.999	2.003	2.002	2.000	2.002
X	2.982	2.989	3.002	3.001	2.998	3.002
alm	0.727	0.729	0.737	0.724	0.722	0.723
sps	0.010	0.008	0.000	0.000	0.000	0.000
pyr	0.073	0.078	0.084	0.092	0.099	0.108
grs	0.154	0.154	0.146	0.143	0.146	0.140
anr	0.036	0.031	0.034	0.041	0.033	0.030
Xmg	0.091	0.096	0.103	0.113	0.120	0.130

works of Mannoni et al. (1987), Castello (2016 a, 2016b, 2018a, 2018b), Castello & De Leo (2007) and Mariano Gallo (in Santarrosa, 1999) were considered: the comparison seems to confirm the Aosta Valley provenance for these two finds. The 2 millstones correspond to the '' G '' group of Mannoni et al. (1987) (coarse grain green chloritoschists with Chl, ±Tlc, ±Ep, Ap-Ttn, Grt, Cld and Opq and low hardness) and to the '' G '' group of Castello & De Leo (2007) (coarse grain green-grey chloritoschists with Fe-Mg chlorite, Grt, Cld, Ep and Zrn, without talc) and may come from the Valmerianaz or from the Ayas Valley .

The hypothesis of Aosta Valley origin of the millstones MN 440 and MN 443 examined in this work come from the comparison with data of Castello (2018), and Da Prà et al. (2019). From a geological point of view, the rocks described may belong to areas in which

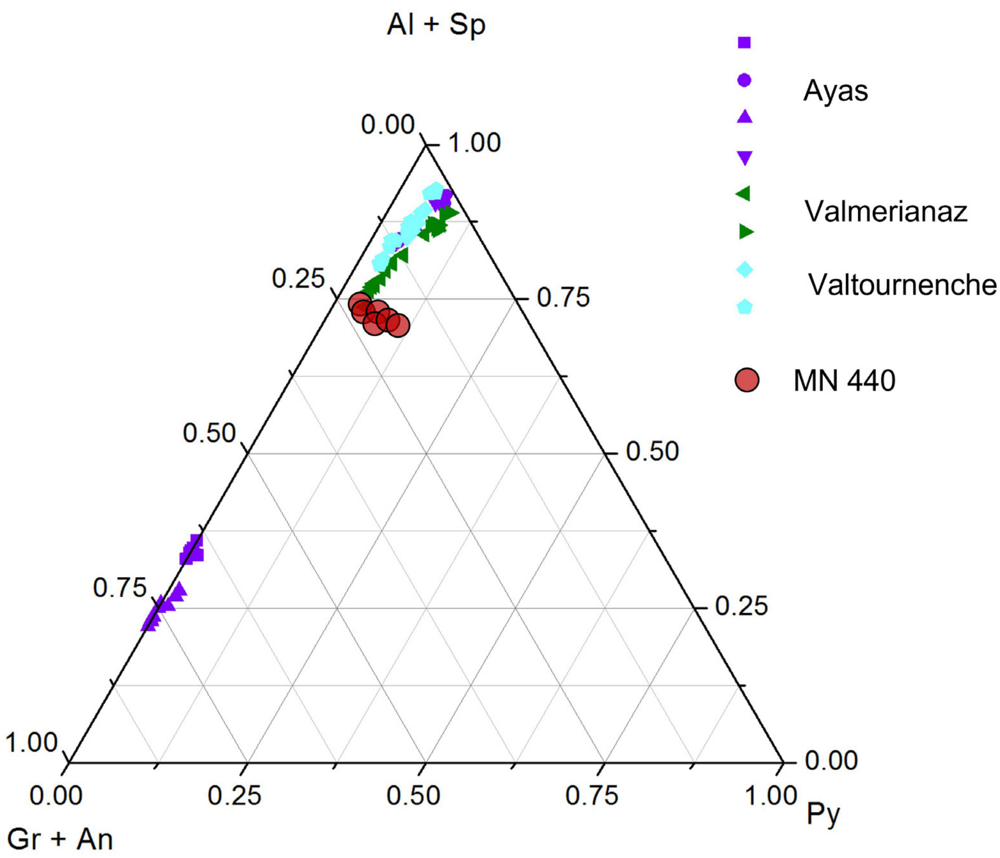

Fig. 7 - Garnet classification diagram, modified by da Prà et al., 2019: the sample MN 440 plots near the Valmerianaz field. Al: almandine; Sp: spessartine; Gr: grossular; An: andradite; Py: pyrope.

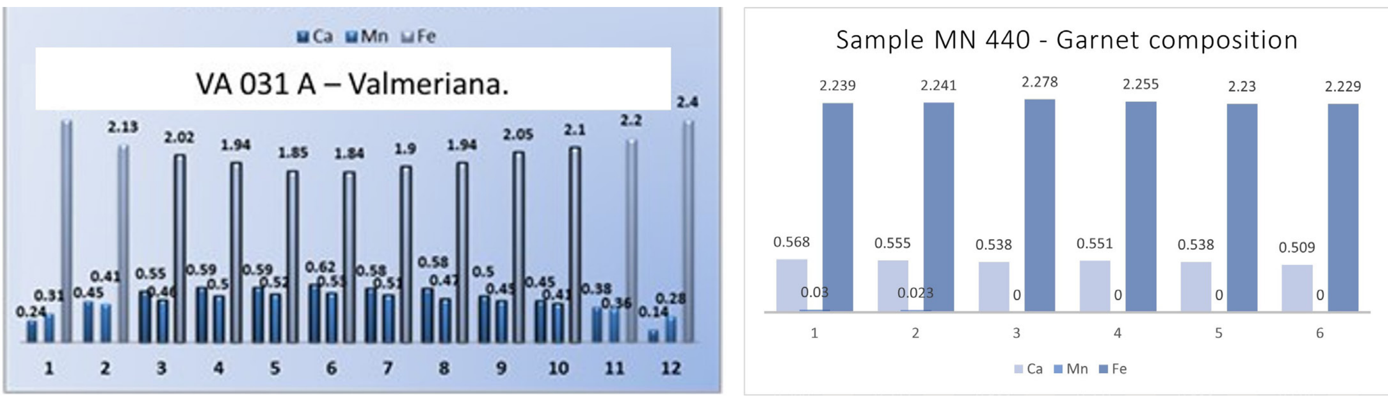

Fig. 8 - Compositional profiles of garnet from Valmerianaz (on the left, modified by Da Prà et al., 2019) and of the sample MN 440 (on the right) which show the contents of the calcium atoms (Ca), manganese (Mn) and iron (Fe) cations calculated on the basis of 12 oxygens per unit formula. As can be seen the values of Ca and Fe are similar.

coarse-grained chloritoschists with a more or less schistose texture, in which chlorite is associated with minerals such as garnets ranging in size from mm to cm, amphibole (generally sodium-calcium), chloritoid, epidote (allanitic), opaque like magnetite and ilmenite, and accessory minerals such as apatite, titanite, zircon, rutile, quartz and albite. This paragenesis is typical of the pietra ollare sampling from the Piemonte Zone, consisting of the remains of the Liguria-Piemonte Ocean and its sedimentary cover that crops out along the entire length of the Western Alps and in particular in the central part of the Aosta Valley.

Also, the association Chl-Ab-Ep of MN 443 sample, can be considered as paragenesis of low pressure and low temperature, developed during the second Alpine metamorphic event, in greenschist *facies*.

Similar characteristics were not found in other outcrops of the Western Alps, such as for example in Val di Viù, Valle Ossola and Valsesia, Val Malenco, Valchiavenna, Val Bregaglia, Valtellina or in the Valais (Riccardi et al., 2018; Gattiglia et al., 2018; Fantoni & Stainer, 2018; Poletti Ecclesia & Tassinari, 2018; Girlanda & Pfeifer, 2018; Cavallo & Guerra, 2018; Guglielmetti, 2018; Pfeifer

& Serneels, 1988; Pfeifer et al., 1993; Pfeifer et a., 2011; Kissing et al., 2016), where the lithotype is fine-grained and the paragenesis different from that of *Eporedia* samples. Again Castello (2018), divides the chloritoschists used as pietra ollare into two main types: massive fine-grained chloritoschists with chlorite-garnet-diopside-tremolite-epidote-apatite-titanite-carbonate paragenesis, outcropping in the Champorcher and Champdepraz area, and chloritoschists with coarse grain, marked schistosity and intense green colour, characterized by a (Fe-Mg) chlorite-garnet-(Na-Ca) amphibole-chloritoid paragenesis, even of large dimensions, which could be attributable to Mannoni et al. (1987) "G type" and found in the Valemerianaz quarries. Furthermore, the presence of coarse-grained chloritoschist with garnet and chloritoid in the Aosta Valley used as pietra ollare through millstones had already been highlighted by Gastaldi (1871, 1876) and taken up again by De Mortillet in 1899.

Finally, for what concern the sample MN 441, the petrographic characteristics allow to identify the rock as jadeite-silver micaschist from the Sesia-Lanzo Zone, a geological unit of the Austroalpine Domain, that consists of continental crust rocks involved in the Alpine subduction (Dal Piaz et al., 1972; Dal Piaz, 1999) in eclogitic conditions.

MN 441 sample is formally a millstone not in pietra ollare s.s., but considering the definition of Mannoni et al. (1987) the rock has all the functions of pietra ollare s.l. (soft rock with hard minerals embedded which therefore fully satisfies the purpose for which it was used in the past: to reduce grain and other seeds for food into powder).

CONCLUSION

The minero-petrographic study of three pietra ollare mills from the Roman age made it possible to determine the geological provenance of these materials found in the archaeological excavations of ancient *Eporedia* (current Ivrea, NW Italy). The analyses are part of a diagnostic-conservative and fruition project of the Museo Civico P.A. Garda, where the millstones are kept. The petrographic characterization allowed to determine the geological domain, and in some cases the geological unit.

Through the archaeometric approach was possible to define that:

- Two millstones (MN 440 and MN 443) are chloritoschists with garnet, belonging to the Piemonte Zone; the electron-microprobe analysis of chlorite allowed to establish a ripidolitic composition; the millstone (MN 441) is a micaschist with jadeite from the Sesia-Lanzo Zone.
- The data were compared with the previous geological bibliography which allows to attribute an essentially Aosta Valley provenance of the MN 440 and MN 443 materials, as well as for the vast majority of coarse-grained chloritoschist with garnet pietra ollare.

The geological origin of these materials and the conspicuous historical-archaeological bibliography in this regard, suggests that *Eporedia* (current Ivrea, NW Italy) in Roman times could have been a center of some importance, with routes and exchanges with other cities of the Empire, such as *Augusta Praetoria Salassorum* (current Aosta).

The data presented in this paper are of a preliminary and partial nature, precisely because the material taken derives from the sampling of archaeological artifacts, and the outcrops of the chloritoschist in the Aosta Valley still need to be partially studied and analysed. In the future, a detailed archaeometric and geochemical study is planned in order to be able to define the supply sites with more certainty and consequently correlate the quarries with the artefacts, in order to determine with more precision the geological origin of the material itself.

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