

Stone Roofing In The Aosta Valley, Italy: Technical Properties And Durability Of Traditional Lithotypes

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Abstract: The Aosta Valley Region has promulgated in 1990 a law to partially finance stone roofs to the owners of houses in the historic centers of the valley, provided that the stone material chosen was suitable for this use. This suitability was certified by physical, mechanical and durability tests. More than twenty years ago, roofing slabs were extracted in north-western Alps mainly from schistose rocks. In recent time instead roofing slabs, according to global market, have an international origin. All the traditional stones tested showed excellent technical features according to the local legislation on roof slates. One of these traditional stones is a phyllite whose trade name is “Porfiroide” having the best physical and mechanical properties compared to the other kinds of traditional stones, but with a high standard deviation in the results of flexural strength performed after the freeze and thaw cycles. In the roofing installed 40 years ago, despite their best technical features, the “Porfiroide” roof slabs show a poor state of conservation with widespread detachments, fractures, growth of mosses and lichens, variations in colours. Otherwise, stones with a lower value of flexural strength and higher water absorption instead show good behaviour in the roofing in situ and also in terms of colour change. Evidently the only characterisation of the stone materials is not sufficient but it must be associated to a on-site verification, comparing each slab to be installed with a reference sample, part of the sample submitted to the tests, and to a control on site of the resistance of the stones to degradation.

Keywords: stone slab; aesthetical variation; mechanical strenght; legal requirements; stone roofing; stone durability;

1. Introduction

The choice of stone as a covering and roofing material depends on the colour and appearance in general, as well as its durability and mechanical strength. Stone roofing has to last for centuries, to be reused several times and to hold to the loading of snow. In addition, the supply of stone slabs coming from nearby areas brings economic and environmental advantages, due to a lower cost, as well as the decreasing of transportations emissions and providing work to local companies and people. Dobszay [1] compared historical and contemporary stone cladde roofs, showing examples of ancient roofing and demonstrating that, traditionally, only natural and durable stone were used in comparison with the requirement of visual appearance in the contemporary architecture.

Roofs, made with stone slabs, are one of the specific characteristics of the Aosta Valley architecture. The slabs for roofing have an irregular shape and larger dimensions and thickness than in the roofs of other mountain sites. The choice of a stone should be based on its strength, its easy splitting and its durability in aspect and properties [2]. Several studies have been carried out on this

43 typical Aosta stone roofing by different authors [3;4;5;6] dealing with traditional use of local stone in
44 roofing (named traditionally “lose”).

45 In some locations of the Aosta Valley, such as Ayas, a Prasinite (type of metabasite) has been
46 employed since ancient times (1700’s) for roofing. However, in more recent time Prasinite has been
47 substituted by other stones due mainly to its scarcity. A very fine-grained stone with the trade name
48 “Porfiroide”, coming from Lombardy and belonging to the petrographic family of phyllites, was
49 therefore used for the roofing in the valley.

50 The regional law n. 10 of 1990 concerning roof cladding [7], has been in force in the Aosta Valley
51 with the aim of enhancing the use of stones for roofing, funding part of the cost if the chosen stone
52 met specific requirements. The law n. 13 of 2007 [8], replacing the one of 1990, updated the test
53 methodologies, previously established according to the Italian test method UNI, to the harmonised
54 European standard UNI EN (specified in the Annex 1 of the law). In the Table 1 a comparison
55 between the threshold limits of 1990 and 2007 law, for different technical determinations, required
56 by legislation, is shown.

57 **Table 1.** Comparison between the threshold limits for physical and mechanical requirements of
58 Aosta Valley Region law n. 10 of 1990 and law n. 13 of 2007*. Significant absence of pyrite is defined
59 when, to a macroscopic evaluation, no surface inclusion of pyrite is visible in the covering elements.

Technical determinati	Threshold limits of Aosta Valley Region law n. 10 of 1990	Threshold limits of Aosta Valley Region law n. 13 of 2007	*EN reference standard, according to Law n.13 of 2007 - Annex 1
Water absorption	0.30% for gneiss 0.25% for all the other stones	<0.5%	EN 13755
Flexural strength	≥15 MPa	>15 MPa	EN 12372
Variation in flexural strength after freeze thaw cycles	≤ 20%	<20%	EN 12371
Resistance to HSO ₄ (1%)	Thickness of the weathered layer ≤ 0.05mm	/	
Resistance to decay caused by atmospheric agents	/	To be performed only when calcium carbonate content >5%	EN 12407
Presence of pyrite	Absent	Absent	
Material uniformity	Homogeneity	Homogeneity (no stain or veins)	

60 The goal of this research is to verify if the tests required by Aosta Valley laws (table 1) are
61 sufficiently representative to define the durability of roofing stone slabs analysed. This has been
62 made comparing the results obtained in the laboratory with the in situ observation.

63 2. Materials and Methods

64 2.1. Stones

65 This research is based on the analysis of 146 technical reports on different samples tested
66 according to the 2 laws of the Aosta Valley Region. All the tests performed for this study were
67 carried out in Marble Laboratory of Politecnico di Torino between the years 1998 and 2014. Before
68 carrying out the tests, each stone was studied from a mineralogical point of view. In Table 2 the
69 stones tested, as well as information on their origin the number of quarries and the number of tests
70 performed were given.

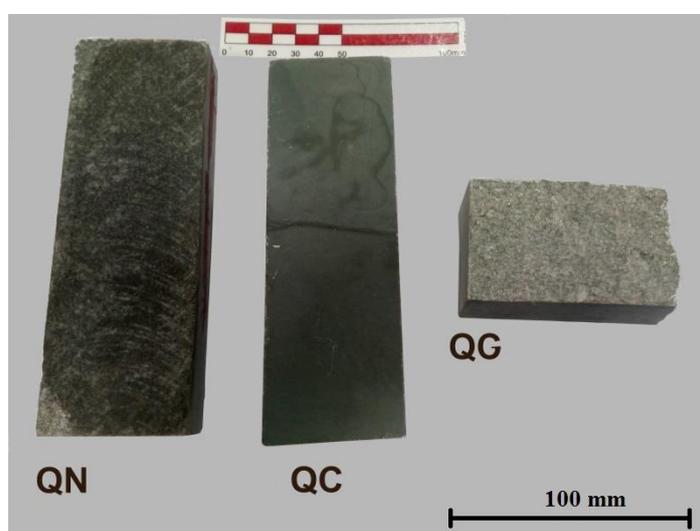
71 Gneiss PL from Piedmont, and BS from Switzerland, Calcschist from Aosta Valley, Serpentine
72 and Phyllite named Porfiroide from Lombardy, Quartzites from Greece, Norway and China are the
73 stones considered.

74 The oldest roofs of the valley are covered with Calcschist slabs found, during the in situ survey,
75 in the villages of Ayas (Challant Saint Anselme, Lignod, Antagnod and Magneaz). This stone is
76 known as "Morgex stone" and is quarried in Morgex near Aosta [9]. Porfiroide, used since the 1950,
77 is characterised by a high resistance and it is easy to split, but, in site, its alteration is connected with
78 oxidation or detachment. The other varieties of stones were installed in the roofs from about 30-40
79 years ago.

80 **Table 2.** Different kinds of roofing stone employed in the Aosta Valley.

Petrographic name	Acronym	Country of origin	Number of quarries	Samples tested *
Gneiss	PL	Piedmont (Italy)	22	85
	BS	Switzerland	1	3
Morgex Calcschist	CM	Aosta Valley (Italy)	3	6
Serpentine	SE	Lombardy (Italy)	5	11
Phyllite "Porfiroide"	PO	Lombardy (Italy))	2	11
Quartzite	QC	China	2	7
Quartzite	QG	Greece	2	17
Quartzite	QN	Norway	2	8

81 *Each sample is constituted from 7 to 10 specimens.

82 Different Quartzite samples, coming from Norway (QN), Greece (QG), China (QC) are shown
83 in Fig. 1.

84

85 **Figure 1.** Different kinds of quartzite tested for Aosta Valley roofing. QN from Norway, QG from
86 Greece, QC from China.87 *2.2. Laboratory tests*88 Physical and mechanical test executed for stone roofing qualification follow the requirements
89 indicated by Law n. 13 of 2007 according to EN standard. In the Law n. 10 of 1990 the same tests
90 were referred to UNI standard according to Annex A of the same law. As specified from the laws
91 (Table 1), the main physical tests to be executed for the qualification of roofing stone are: water
92 absorption according to EN 13755 [10], flexural strength under concentrated load according to EN
93 12372 [11], freeze and thaw resistance after 48 cycles according to EN 12371 [12], resistance to decay
94 caused by atmospheric agents according to EN 13919 [13], evaluation of the presence of pyrite.95 The determinations required from Aosta Valley regulation of 1990 were described in Annex A
96 of the same law and referred to the UNI standards in force at that time and there were only few
97 differences between the two group of tests are mainly in the specimen dimensions and not in the test
98 method. The resistance to decay was the only parameter whose methodology changed: when the
99 resistance to H₂SO₄ attack was required, the methodology of EN 13919 (a standard now deleted) was
100 provided, but only for the stones with a calcium carbonate content > 5 %.101 The presence of pyrite and of calcium carbonate is determined through petrographic analysis
102 on the hand sample and microscopically on thin sections. Concerning calcium carbonate content, an
103 attack with HCl (33% dilution in water) in three different parts of the specimens was performed to

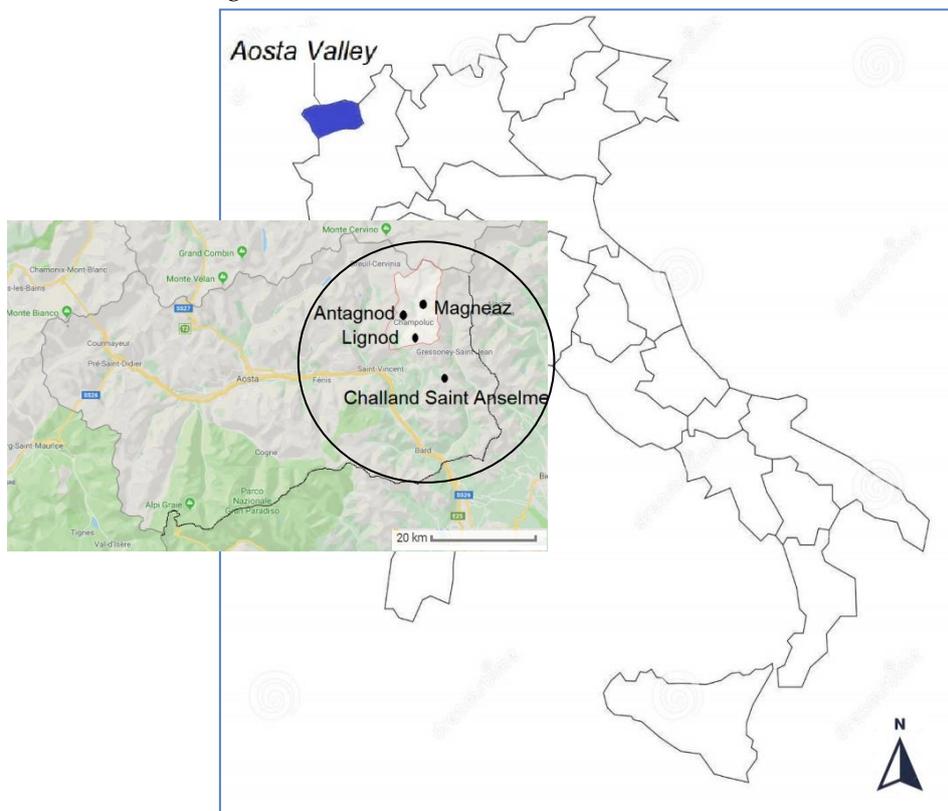
104 confirm the petrographic observation: if no effervescence was noted, the calcium carbonate content
 105 was considered minor than 5%.

106 Water absorption and flexural strength before and after 48 freeze and thaw cycles were
 107 measured on 14 specimens (7 in natural conditions and 7 subjected to weathering cycles) with
 108 dimensions of 20*30*120 mm according to the regulation of 1990 and on 20 specimens (10+10)
 109 25*50*150 mm for each sample according to 2007 law. The effect of thickness on flexural strength
 110 value is negligible considering the measurements uncertainty: in other terms varying the thickness
 111 specimens there is no considerable variation in the flexural strength measured.[14].

112 For water absorption both methodologies require the ratio between the surface area and
 113 volume between 0.08 mm^{-1} and 0.20 mm^{-1} . On the base of these considerations, the results obtained
 114 on specimens of different dimensions have been comparatively evaluated.

115 2.3. Stone roofing (*in situ* monitoring)

116 The site investigated in order to identify the state of conservation of the different stones used is
 117 in Val d'Ayas (Aosta Valley). In particular, the sites where monitoring campaigns have been carried
 118 out are shown in Fig. 2.



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120 **Figure 2.** Aosta Valley in Italy and the site of the stone roofing monitoring (Source: Google maps).

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131 In figure 3 the photos of the details of the historical centres of the 4 investigated municipalities are
 132 shown, with their altitude.
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137 Figure 3. From above: Antagnod, Challant Saint Anselme, Lignod and Magneaz old town maps, with altitude.

138 Source: Google Earth.

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140 As can be seen from figure 3, in Valle D'Aosta, all the buildings present in the historic center
 141 have stone roofs. This is what is defined by the Regional law 1 June 2007, n. 13 [8].

142 In Aosta Valley, the climate is warm and temperate. There is significant rainfall throughout the
 143 year, even during the driest month. The average temperature is 9.7 ° C. The average annual rainfall
 144 is 805 mm. The driest month is January with 51 mm. The month of August is the one with the
 145 greatest rainfall, having an average of 82 mm.

146 Roofing of Antagnod, Magneaz and Lignod (Ayas hamlets) were monitored together with the
 147 nearby Challant Saint Anselme comparing the in situ slabs with stone specimens kept after the tests
 148 for Aosta Valley. During this surveys only 4 of 8 stones of table 2 (Porfiroide, Morgex Calcschist,
 149 gneiss PL and Norwegian quartzite) have been identified.

150 3. Results

151 3.1. Stones description

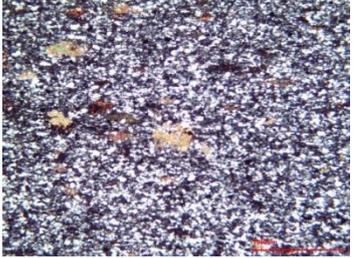
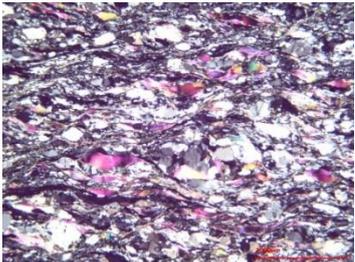
152 In Tables 3 and 4, a microphoto of a representative thin section for each stone tested is shown
 153 together with a brief description. The petrographic analysis has been made in addition to test report
 154 elaboration in order to better understand the behaviour of different kind of stone. The compositions
 155 as a percentage, were the mean values obtained from the different samples tested of the same stone,
 156 sometimes coming from different quarries as in the case of PL (Table 2.)

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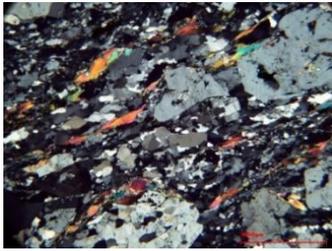
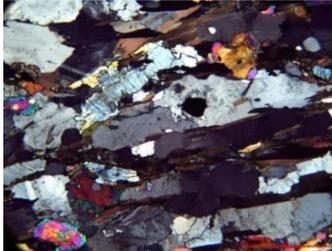
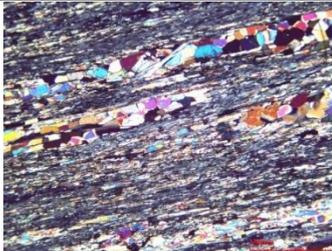
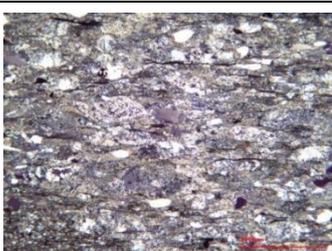
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161**Table 3.** Stones from China, Greece and Norway used for Aosta Valley roofing. Reference size: 100 μm .

Thin section	Stone and main mineralogical composition
 <p style="text-align: center;">100 μm</p>	<p>QUARTZITE (China) QC: Greenish, very fine-grained with schistose texture. Main minerals:</p> <ul style="list-style-type: none"> - 50% quartz; - 40% white mica; - 10% biotite, opaque and chlorite.
 <p style="text-align: center;">100 μm</p>	<p>QUARTZITE (Greece) QG: Grey-green, fine grained and schistose texture. Main minerals:</p> <ul style="list-style-type: none"> - 45% quartz; - 20% chlorite; - 25% feldspars; - 10% epidote; zircon and rutile.
 <p style="text-align: center;">100 μm</p>	<p>QUARTZITE (Norway) QN: Dark grey, medium-fine grained and schistose texture. Main minerals:</p> <ul style="list-style-type: none"> - 70% quartz; - 20% feldspar; - 10% white mica; carbonates, opaque and pyroxene.

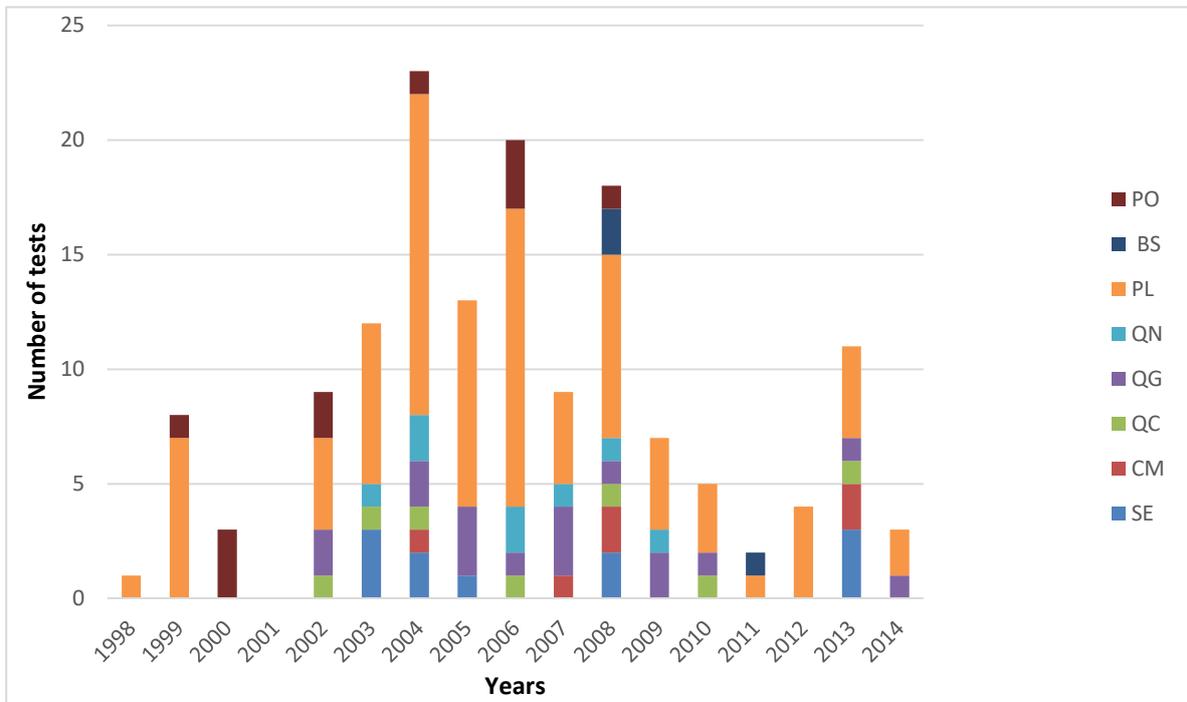
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Table 4. Stone from neighbouring quarries used for Aosta Valley roofing Reference size: 100 μm .

Thin section	Stone and main mineralogical composition
 <p style="text-align: center;">100 μm</p>	<p>GNEISS PL: Grey rock with a fine grained and schistose texture. Main minerals:</p> <ul style="list-style-type: none"> - 40% quartz; - 30% plagioclase; - 15% K-feldspar; - 10% white mica; - 5% epidote biotite and chlorite, apatite, zircon and rutile.
 <p style="text-align: center;">100 μm</p>	<p>GNEISS BS: Grey in colour with white lentiform levels alternating with wavy black, medium-fine grained and schistose texture. Main minerals:</p> <ul style="list-style-type: none"> - 35% quartz; - 35% feldspars; - 20% biotite; - 10% pyroxene.
 <p style="text-align: center;">100 μm</p>	<p>CALCSCHIST CM: Light grey rock with small white eyes, medium grained and schistose texture. Main minerals:</p> <ul style="list-style-type: none"> - 65% carbonate; - 25% quartz; - 10% white mica and opaques.
 <p style="text-align: center;">100 μm</p>	<p>SERPENTINITE SE: Dark green, fine-grained rock with a schistose texture. Main minerals:</p> <ul style="list-style-type: none"> - 60% serpentine antigorite; - 30% olivine; - 10% pyroxenes, chlorite and opaque.
 <p style="text-align: center;">100 μm</p>	<p>PORFIROIDE (PHYLLITE) PO: Dark grey, very fine grained and schistose texture. Main minerals:</p> <ul style="list-style-type: none"> - 35% chlorite; - 30% white mica; - 20% quartz; - 10% opaque minerals: pyrite and other opaque ; - 5% feldspar.

166 roofing slate decreased, due to a new regional law (l.r. 17/2012 [15] art. 38) the tests became
 167 compulsory only for the stones employed in the historical centre buildings.

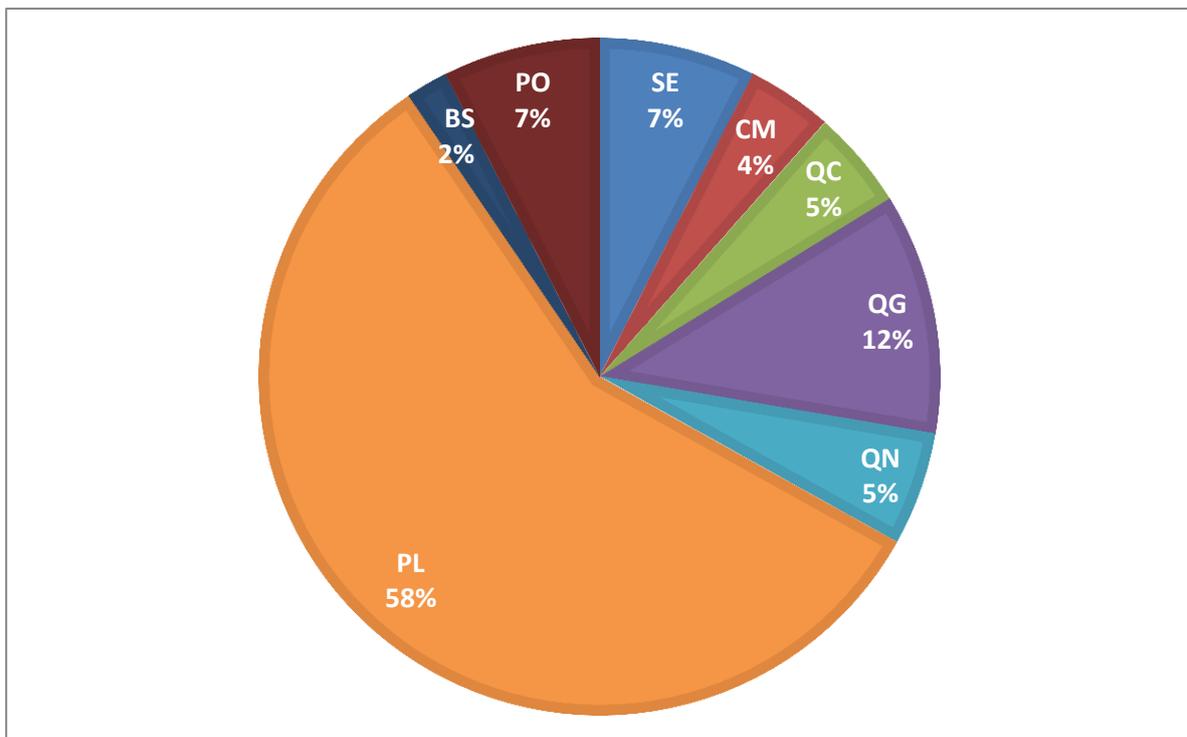
168 In Fig. 5, where there are reported the percentages of different stones tested in 2004, the year
 169 with the higher number of tests for Aosta Valley, (Fig. 4), it is evident that more than 20% of roofing
 170 stones come from outside Italy (Chinese, Norwegian and Greek Quartzites).



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Figure 4. Number of tests for different stones tested in the years for roofing.



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Figure 5. Tests performed in 2004 on different roofing stones.

175 3.2. Laboratory tests

176 In Table 5, the results of flexural tests carried out according to the Aosta Valley region laws are
 177 reported for the 8 types of stone analysed. In addition, in table 6, the main petrographic as mean
 178 grain size, carbonate content and water absorption data are shown. The mean grain size is the
 179 weighted average of the dimension of the crystals of the different minerals constituents the stones.

180 All the specimens tested are characterised by a very low or any presence of pyrite content and
 181 only CM has a carbonate content more than 5%. PO and CM are those with the higher variation in
 182 flexural strength after the freeze and thaw cycles.

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Table 5. Mechanical properties of stones tested.

Stone tested	Flexural strength (MPa)				Variation in FS (%)
	FS in natural condition		FS after freeze-thaw cycles		
	Mean value	Stand. Dev.	Mean value	Stand. Dev.	
PL	24.7	3.0	24.3	2.8	-1.9
BS	22.6	1.4	22.1	3.3	-2.2
PO	45.0	6.7	40.7	8.7	-9.6
SE	83.0	15.8	83.8	17.1	0.9
CM	24.5	3.2	22.3	3.2	-9.2
QC	33.9	5.6	33.1	6.4	-2.4
QG	34.3	4.7	33.3	4.9	-2.9
QN	47.4	6.4	46.6	4.4	-1.6

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Table 6. Physical and petrographic characteristics of stones tested.

Stone tested	Water absorption (%)		Carbonate content (%)	Mean grain size (mm)
	Mean value	Stand. Dev		
	PL	0.3		
BS	0.3	0.0	<5	1.5
PO	0.2	0.0	<5	0.2
SE	0.1	0.0	<5	0.3
CM	0.2	0.0	>5	0.3
QC	0.3	0.1	<5	0.5
QG	0.3	0.1	<5	0.4
QN	0.1	0.0	<5	1.2

185 3.3. Conservation of Stone roofing (in situ observation)

186 The in situ survey was carried out comparing specimens of the tested samples with roofs slabs
 187 easily accessible.

188 In Challant Saint Anselme, from a roof slab with lichens (Fig. 6 on the right) installed in 2002
 189 (communication of the owner) the sample 1 of Fig.10 was taken. From a quick comparison with the
 190 sample brought from the laboratory it was assumed that the stone used was the Norway Quartzite
 191 QN . The preservation state of quartzite slabs of this roof can be compared with the older one slabs
 192 probably by Calcschist CM covering a nearby house (Fig.6 on the left)



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Figure 6. An ancient roofing in Challant Saint Anselme on the left and Norway quartzite roofing on the right.

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In Ayas municipality, Lignod hamlet, the slabs of the roof in Fig. 7 have been recognized as Calcschist according to the comparison with the specimens brought by the laboratory. These slabs were similar but less weathered than those of Fig 6 on the left: the whole house was restructured in the early 2000s.



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Figure 7. Calcschist CM roofing in Lignod after renovation.

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In Antagnod, it was possible to detect other varieties of ornamental stones: Prasinite in the cemetery, Quartzite and Porfiroide. In Fig. 8, the roofing in Porfiroide near new kinds of stones is shown. The Porfiroide slabs were broken therefore a sample of Porfiroide was taken (sample 2 of Fig. 10).

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In Magneaz, a sample from an old roofing dated to 1980 (Fig. 9) where detachment and oxidation traces were present was taken (sample 3 of Fig.10).



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Figure 8. Porfiroide roofing near the new roofs of gneiss on the left and Quartzite on the right in Antagnod.



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Figure 9. Old stone roofing in Porfiroide in Magneaz hamlet.

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In laboratory, the macroscopic comparison of the samples taken in situ with specimens tested, confirmed that sample 1 is a Norway quartzite QN, and samples 2 and 3 are Porfiroide PO (Fig. 10).

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The climatic condition of the municipalities considered is the same, as they are not very distant from each other, as can be seen from figure 2. The weather conditions therefore do not influence the diversity of deterioration in the stone types analyzed, unlike stone properties that is the main aspect affecting different stone decay .

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Figure 10. Comparison of sample from in situ and the laboratory specimens tested. On the left the sample 1 compared with Norway quartzite specimen; on the right samples 2 and 3 compared to Porfiroide specimen.

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233 4. Discussion and conclusions

234 All the stones tested respect the threshold limits of physical and mechanical properties
 235 requested by the Aosta Valley Region (Table 1) apart from the carbonate content of CM. However,
 236 from table 5 and 6, Porfiroide (PO) and Calcschist (CM) show high decreasing in flexural strength
 237 after freeze and thaw cycles (respectively -9,6% and 9,2%) despite the mechanical resistance after
 238 artificial decay still maintain good performances (PO > 40 MPa, CM > 22 MPa). These behaviours, for
 239 Morgex Calcschist CM, can be due surely to the high carbonate content (>5%) and mica (10%) and
 240 for Porfiroide PO to the very high mica content (30%). From the in situ monitoring, the low
 241 durability of PO and CM is enhanced. These are the stone roofing slabs with highest percentage of
 242 detachment and weathering (Fig. 7, 8 and 9). The relation between mica content and resistance to
 243 decay is well known [16,17]. Consequently, the mica content could be a further petrographic feature
 244 to take into account in the evaluation of stone roofing durability: the increasing in mica content
 245 (more than 10%) is strictly connected to the increasing in the decay under the action of climatic
 246 agents as thermal shock and presence of water that causes the mica swelling and therefore stone
 247 deterioration and detachments.

248 The in situ survey suggest that the uniformity of stone slab samples is an important factor to be
 249 taken into account together with physical and mechanical characteristics. The difference between the
 250 technical performance and the behaviour in situ can be related also to the high variability of some
 251 rocks when supplied in high quantity. The samples sent to laboratory for technical characterisation
 252 do not always reflect this variability, specimens probably were chosen among the first-class choice
 253 while for big supplying all the produced slabs have to be used.

254 Concerning the "new" stones as the Norway quartzite, further research in addition to those
 255 developed on other quartzite in the past [18,19,20] could be a future research, in order to study the
 256 growing of the lichens on the stone slabs and the methods to prevent this kind of biological attack in
 257 site also after a few years in new constructions.

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 259 investigation, Bellopede and Marini; data curation, Bellopede and Zichella.; writing—original draft
 260 preparation, Bellopede and Zichella.; writing—review and editing, Bellopede and Marini.;
 261 supervision, Marini .

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263 References

- 264 1. Dobszay, G. Building Constructions of stone cladde roofs in Contemporary Architecture.
 265 *Factauniversitatis-series: Architecture and Civil Engineering* **2011**, 9(1), 35-56.
- 266 2. Cardenes, V., V. Cnudde, and J. P. Cnudde. "Petrography of roofing slate for quality assessment." *World* 1
 267 (2015): 12-6.
- 268 3. Fusinaz H. Valutazione dello stato di conservazione delle lose da copertura in pietra in Valle d'Aosta,
 269 *Master Degree thesis*.2008 Politecnico di Torino 75p.
- 270 4. Fiora L. Navillond E , The "rascard" of the Rhêmes Valley" *L'informatore del marmista*2001 40:469 pp 12-25
- 271 5. Fiora, L., Alciati, L., Ghigo, G., Navillod, E., Rolfo, R., Sandrone, R. Historical and contemporary roofing:
 272 in Valle d'Aosta and Piedmont, various stone materials no longer available have been replaced with other
 273 materials*L'informatore del marmista* **2001**4 0:474 pp 46-52.
- 274 6. Sandrone R., Colombo A., Fiora L., Fornaro M., Lovera E.1, Tunesi A. and Cavallo A. (2004)
 275 Contemporary natural stones from the Italian western Alps (Piedmont and Aosta Valley Regions) *Per.*
 276 *Mineral. SPECIAL ISSUE 3: A showcase of the Italian research in applied petrology.* **2004**, 73, 211-226.
- 277 7. Norme Tecniche di cui all'Allegato A (Capo I, B) della Legge Regionale n. 10 del 28.02.90 della Regione
 278 Autonoma Valle d'Aosta.
- 279 8. Legge regionale 1° giugno 2007, n. 13. Nuove disposizioni in materia di obbligo di costruzione del manto
 280 di copertura in lose di pietra. Modificazionellaleggerregionale 27 maggio 1994, n. 18.Valle d'Aosta
- 281 9. Clerici C, Pelizza S. I calcescisti i di Morgex una risorsa mineraria, Quarry and Construncion, Atti del
 282 Convegno "Attività estrattiva e difesa del suolo, 1986 Saint Vincent 5p.

- 283 10. EN 13755 Natural stone test methods - Determination of water absorption at atmospheric pressure CEN
284 Brussels **2008** 12p.
- 285 11. EN 12372 Natural stone test methods - Determination of flexural strength under concentrated load CEN
286 Brussels 2008 18p.
- 287 12. EN 12371 Natural stone test methods - Determination of frost resistance CEN Brussels **2010** 18p.
- 288 13. EN 13919 Test methods for natural stones - Determination of resistance to aging due to SO₂ in the
289 presence of humidity. CEN Brussels 2004.
- 290 14. Marini P., Bellopede R., Loudes N. M. Influence of thickness on flexural strength under concentrated load
291 of natural stone in relation to EN 12372. *Quarterly Journal of Engineering Geology and Hydrogeology*
292 50(4):qjegh2016-147. 2017. DOI: 10.1144/qjegh2016-147.
- 293 15. Legge regionale 12° giugno 2012, n. 17 Modificazioni alla legge regionale 6 aprile 1998, n. 11 (Normativa
294 urbanistica e di pianificazione territoriale della Valle d'Aosta), e ad altre disposizioni in materia di
295 governo del territorio. Valle d'Aosta
- 296 16. Gambino, F., Borghi, A., d'Atri, A., Gallo, L. M., Ghiraldi, L., Giardino, M., ... & Macadam, J.
297 TOURinSTONES: a free mobile application for promoting geological heritage in the city of Torino (NW
298 Italy). *Geoheritage*, **2019** 11(1), 3-17.
- 299 17. McKinley, J. M., & Warke, P. A. Controls on permeability: implications for stone weathering. *Geological*
300 *Society, London, Special Publications*, **2007** 271(1), 225-236.
- 301 18. Vazquez, P., & Alonso, F. J. Colour and roughness measurements as NDT to evaluate ornamental granite
302 decay. *Procedia Earth and Planetary Science* **2015**, 15, 213-218.
- 303 19. Chen, J., Blume, H. P., & Beyer, L. Weathering of rocks induced by lichen colonization—a review. *Catena*,
304 **2000**,39(2), 121-146.
- 305 20. Bechtel, R., Rivard, B., & Sánchez-Azofeifa, A. Spectral properties of foliose and crustose lichens based on
306 laboratory experiments. *Remote Sensing of Environment*, **2002**. 82(2-3), 389-396.