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The Verbano Cusio Ossola province: a land of quarries in northern Italy (Piedmont)

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ABSTRACT. — The Verbano Cusio Ossola province (Piedmont, north-western Italy) is one of the most important quarrying areas due to the peculiarity of its exploited rock types; actually this is one of the few areas in Italy with ornamental stones represented mainly by orthogneisses such as Serizzo and Beola and subordinately by granites, marbles and finally ultramafites and carbonatic rocks. The exploitation dates back to the Roman period and is nowadays strongly improved also because of the development of technology. This work describes the historical use, the petrography, the physical and chemical properties (for orthogneisses) and the exploitation technology of the different rock types, evidencing, for the metamorphic rocks occurring in the Ossola Valley, the strong connection between textural features and geological setting which produces several varieties within each rock type.

RIASSUNTO. — La provincia del Verbano Cusio Ossola (Piemonte) è una delle più importanti aree di estrazione di rocce ornamentali in Italia, grazie alla peculiarità dei tipi litologici affioranti: ortogneiss, subordinatamente graniti, marmi e da ultimo serpentiniti e rocce carbonatiche. Nelle rocce metamorfiche affioranti in Val d'Ossola la stretta connessione tra tessitura e assetto geologico-strutturale produce più varietà commerciali nell'ambito di ciascuna litologia.

Le prime coltivazioni sono fatte risalire al tempo dei Romani. Il forte aumento della produzione attuale è comunque legato allo sviluppo tecnologico e alle crescenti richieste del mercato. In questo lavoro vengono presentate, per le singole litologie, le caratteristiche petrografiche, le proprietà fisico-meccaniche, le tecniche di escavazione nonché l'uso storico delle principali litologie coltivate attualmente ed in passato.

KEY WORDS: *ornamental stones, VCO province, Ossola Valley, quarries, historical use.*

INTRODUCTION

Exploiting activity in the Verbano Cusio Ossola province (VCO) is developed from the area between the Cusio and Verbano lakes to the northern Ossola valleys close to the borders with Switzerland. The stone for the inhabitants of alpine valleys always represents a natural resource but in the Ossola valleys it was and is a wealth that allowed to a local community a significant economic growth. The VCO, and the Ossola in particular, is a land of quarries

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(Bigioggero and Zezza, 1997). Post-quarry processing is a more recent activity because most of the quarried rocks can be splitted and used as building stones without any other processing. Since the Roman period split stones were used to build up roads and split slabs of gneisses were utilized for external walls and roofs of the ancient houses in the Ossola (for the historical uses, see Regione Piemonte Ed., 2000; Dematteis, 1985; Casalis, 1979; Gruppo Archeologico Mergozzo AA. VV., 1978; Rodolico, 1953).

The VCO represents one of the most important quarrying districts in Italy mainly because of the great varieties of rock types occurring in a relatively small area, but also because the same rock type offers different textures and colours. This peculiarity is due to the geological setting of the area. Crossing the region from south to north it could be observed one of the best structural sections of the entire Alpine chain: from the sedimentary cover of the Southern Alps to the lowest Sub-Penninic Unit represented by the «Verampio granite».

GEOLOGY

A structural sketch map of the VCO province is shown in Fig. 1. In the area, two main structural domains are exposed: the Southern Alps (Africa verging) and the Alpine nappe system (Europe verging), separated by the Canavese Line. For detailed studies on this area, see Boriani and Giobbi (2004), Engi *et al.* (2001), Boriani (2000), Steck and Hunziker (1994), Pfiffner (1993), Polino *et al.* (1990) and their references.

The Southern Alps (Fig. 1) are constituted by a sedimentary cover and a pre-alpine crystalline basement represented by the «Serie dei Laghi» to the south-east and the Ivrea-Verbano Zone to the north-west, divided by the subvertical Cossato-Mergozzo-Brissago Line (CMB Line). The «Serie dei Laghi» comprises the metapelitic Scisti dei Laghi in the southern part and the metapsammitic Strona-Ceneri in the northern part: the contact is represented by banded amphibolites, lenses of ultramafites and metagabbros (Strona Ceneri Border Zone-SCBZ). Large lens-shape bodies of Ordovician metagranitoids are mainly located near SCBZ. The main metamorphic imprint is Variscan and occurred under amphibolite facies condition. Late Variscan granites (Graniti dei Laghi) and dikes or stocks (Appinite suite) intrude this basement. The late Variscan plutons, such as the granites of Baveno (pink), Montorfano (white), Alzo, Roccapietra and Quarna, were extensively quarried in the past. At the present the exploitation is restricted at two main quarries of Baveno and Montorfano granites. The Ivrea-Verbano Zone is made up of two main units: the Kinzigite Formation and the Mafic Complex which suffered upper-amphibolite to granulite facies condition. The age of metamorphism is still debated: Ordovician, Carboniferous or Permian; for details see Boriani and Giobbi (2004), Boriani (2000), Colombo and Tunesi (1999), all with references. The Kinzigite Formation is a volcano-sedimentary sequence with lenses of ultramafites mainly occurring near the Canavese Line; it is constituted of prevailing metapelites, metapsammites, marbles and quartzites with interlayered metabasites of MORB affinity. During the Early-Permian this sequence was intruded by the Mafic Complex, a layered sequence (peridotites, pyroxenites, gabbro-norites and anorthosites) and a huge body of quite homogeneous amphibole-bearing gabbro (Main Gabbro). High temperature assemblages are widespread and locally rocks of the Kinzigite Formation underwent partial melting with melt segregation. In the Ossola Valley (Fig. 2) rocks of the Ivrea-Verbano Zone are quarried to extract marbles from the Kinzigite Formation (Candoglia and Ornavasso, Sambughetto in Strona Valley) and a granulitic amphibole-bearing gabbro (Gabbro di Anzola or Nero di Anzola) which is now used as crushed stone for roads and railroads ballast.

The Alpine nappe system occurs from the middle Ossola Valley up to the Switzerland throughout the national borders (Fig. 1). From

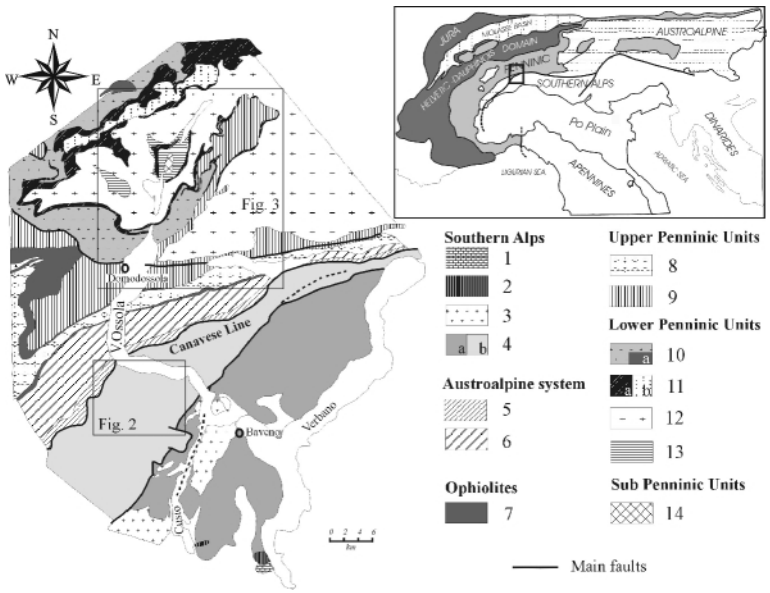

Fig. 1 – Structural sketch-map of the Ossola Valley. 1) Triassic units; 2) Permian volcanic complex; 3) Permian granitoids; 4) Pre-alpine metamorphic basement, a = Serie dei Laghi, b = Ivrea-Verbano Zone. 5) Fobello-Rimella mylonitic schists; 6) Sesia-Lanzo Zone, polymetamorphic basement; 7) Zermatt-Saas Zone and Antrona Zone amphibolites and serpentinites; 8) Monte Rosa Zone; 9) Orselina-Moncucco-Isorno Zone; 10) Monte Leone nappe, mainly orthogneisses, a = Cervandone ultramafic Complex; 11) Permo-mesozoic cover units, a = mainly calc-silicate marbles, b = Lebendun serie; 12) Antigorio and Pioda di Crana orthogneissic nappes; 13) Baceno schists; 14) «Verampio Granite».

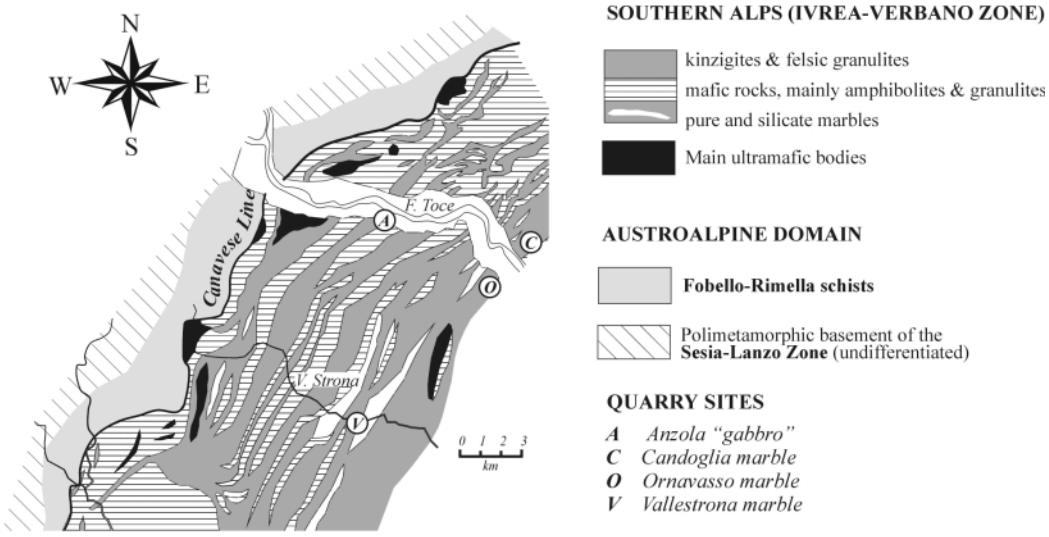

Fig. 2 – Geological sketch-map of the lower part of the Ossola Valley.

south to north it comprises the uppermost Austroalpine domain (Sesia-Lanzo Zone), the ophiolitic sequence (Piemontese Zone), the Upper Penninic nappes (Monte Rosa Zone and Orselina-Monucco-Isorno Zone, separated by another ophiolitic slab, i.e. the Antrona Zone), the Lower Penninic nappes (Monte Leone, Lebendun, Antigorio, Pioda di Crana) and finally the Sub-Penninic «Verampio granite» (Fig. 3). The nappes consist of Permo-Mesozoic cover rocks and pre-alpine crystalline basements, intruded by late-Variscan gabbro and granite to granodiorite plutons, with strong Alpine metamorphic overprinting under amphibolite facies conditions; relicts of the pre-alpine history are scarce and mainly reported for the Austroalpine units and the Upper Penninic nappes (Monte Rosa). The granitoids occur both in the Austroalpine and Penninic basement; on the

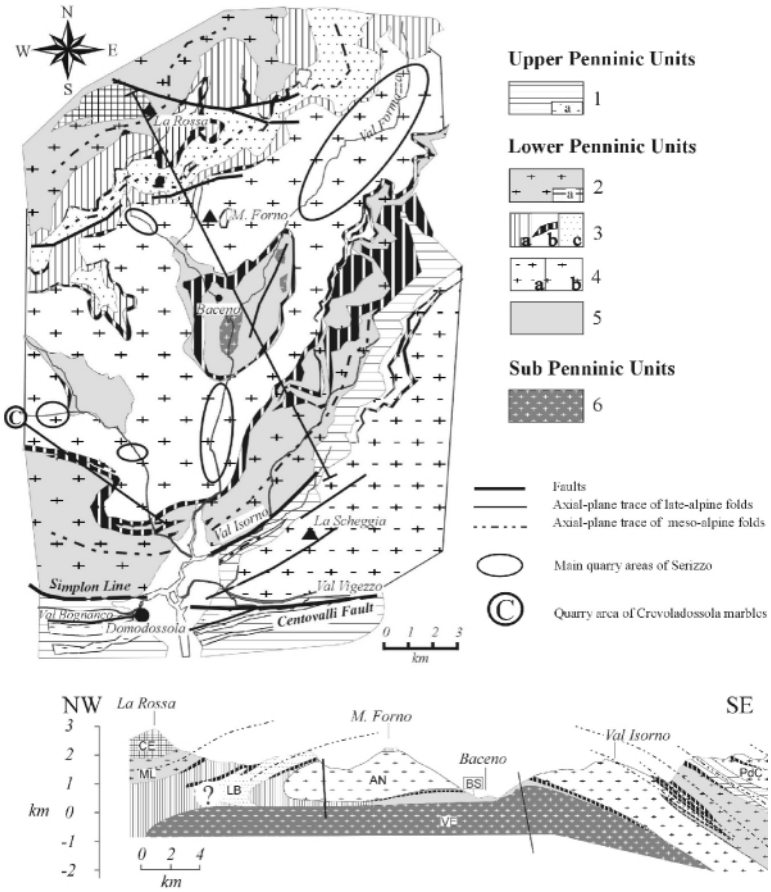

Fig. 3 – Geological sketch-map of the upper part of the Ossola Valley. 1) «Verampio Granite» (VE); 2) Baceno Schists (BS); 3a) Pioda di Crana (PdC) orthogneissic nappe; 3b) Antigorio (AN) orthogneissic nappe; 4) Permo-Mesozoic cover units; a = calcschists and impure marbles with intercalations of basic rocks, mainly Jurassic; b = marbles, mainly Triassic in age; c = Lebendun Series (LB), corse to fine grained metaclastic schists and calc-silicate rocks; 5) Monte Leone nappe (ML), mainly orthogneisses with minor paragneissic intercalations, a = Cervandone ultramafic Complex (CE); 6) Orselina-Moncucco-Isorno Zone, paragneisses with amphibolite intercalations, a = main orthogneissic bodies.

contrary, the gabbro intrusions completely lack in the basement of the Penninic units. In the Austroalpine domain and in the Upper Penninic units (Orselina-Moncucco- Isorno Zone) the basement consists of pre-Mesozoic metasedimentary rocks with interbedded lenses of marbles and metabasites. The Lower Penninc units are mainly composed of late-Variscan granitoids separated by a very heterogeneous (Carboniferous?) Permo-Mesozoic sedimentary cover (with prevailing carbonatic rocks – e.g. Crevoladossola marbles).

The structural evolution of the «Alpine nappes» is extremely complicated and it is continuously object of discussion within the scientific community. For the aims of this paper, which wants to describe the rock types quarried in the VCO, a classical structural approach is awkward, but some considerations must be emphasized. Surely several phases of deformations occurred during the alpine event (e.g. Grujic and Mancktelow, 1996) and the most significant can be summarized as follow. The first alpine phase (D_1) is due to the «nappe piling» that could be seen as a succession of imbricate thrusts. During this phase discrete shear zones (Fig. 4a) mainly developed in the Lower Penninic orthogneisses (Antigorio) which therefore show mylonitic fabric associated with augen texture. In the oceanic sequences, in the Upper Penninic Units and in Austroalpine domain, the D_1 phase of deformation is associated with subduction processes and subsequent obduction of these complexes in the alpine accretionary prism. In the central Ossola Valley, the D_1 phase of deformation is rarely preserved at the mesoscale; the most common structural relict consists of transposed D_1 fold hinges. The second phase of deformation (D_2, meso-alpine) is the main phase connected to thermal relaxation. It is recognizable at a regional scale and is responsible for the most pervasive S_2 foliation (axial-plane foliation). It derives from a complex series of isoclinal folds that involved both the basements and the cover rocks (Fig. 4b); the contacts among the units are folded and so clearly D_2 phase postdates the «nappe piling». D_3 phase of deformation is late-alpine and is due to the upwelling of the alpine nappe system and back-thrust on the Southern Alps (Fig. 4c). To this phase are associated large scale folds (e. g. Vanzone antiform) to the south and at a regional scale a «dome structure» centred in the area of Baceno (see fig. 3 – geological section) to the north. As indicated by the general variation of the S_2 foliation, in the southern margin of this «dome» tight folds developed. S_2 foliation is verticalized in the area of Domodossola and is steeply dipping to the north along the southern margin («*root zone*» auct.).

For the complexity of the geological setting of the area, the commercial varieties of orthogneisses quarried as dimension stones in the Ossola Valley show different textures and colours as a consequence of the three main phases of alpine deformation, although their protoliths can be traced back to similar magmatic rocks of Permian age.

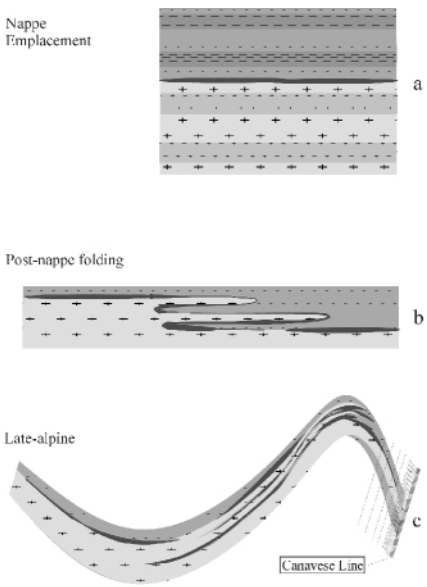

Fig. 4 – Cartoon illustrating the main phases of alpine deformation (see text).

MAJOR STONES

The Serizzo

The most important and extensively exploited ornamental stone from the VCO province is surely the *Serizzo* (or *Sarizzo*). It is commercialized as *Serizzo Antigorio*, *Serizzo Formazza*, *Serizzo Sempione*, *Serizzo Monte Rosa*; the *Antigorio* variety is the most abundant. The former three types pertain to the Antigorio nappe, whereas the last one to the Monte Rosa Zone. Fifty-five active quarries are located in the Divedro, Antigorio-Formazza and Devero valleys and produce about 70% of all the dimension stones from the Ossola area. The quarries are mostly concentrated in the Antigorio and Formazza valleys, where the Antigorio nappe presents sub-horizontal attitude and reaches its largest thickness (1000 m). The protholith of the *Serizzo* is a Permian granite metamorphosed during the alpine events. The mineralogical composition is: Qtz, Kfs, Pl (An 25-30%), Bt, Ms (variable content) and allanite as typical accessory mineral. The rock type from the Antigorio nappe is a granitic to granodioritic orthogneiss (Bigioggero *et al.*, 1977) with medium grain size, generally marked planar foliation and augen texture; the less deformed varieties occur in the inner and higher part of the body. The partially recrystallized K-feldspars have quite homogeneous dimension up to 2 cm in length. Locally the rock presents mineralogical lineation and iso-orientation of the feldspar aggregates parallel to the direction of the main foliation. The *Serizzo Antigorio* shows darker colour due to higher content of biotite and finer grain-size than the *Serizzo Formazza*. On the contrary, the *Serizzo Sempione*, occurring in the southern verticalized part of the body, shows more gneissic texture and a fine grain size as a result of a major degree of the alpine deformation. The *Serizzo Monte Rosa* is quarried in Anzasca Valley (Ceppo Morelli); it is an augen gneiss with coarse K-feldspar porphyroclasts (3-4 cm) surrounded by discontinuous layers of biotite and so the foliation planes are irregularly distributed. It is the coarsest and lightest coloured variety of *Serizzo*. The chemistry of the orthogneisses from the Antigorio nappe evidences a quite homogeneous composition, peraluminous character and calcalkaline affinity, similar to those of the other Penninic orthogneisses. On the contrary, the REE pattern (Fig. 5a) show fractionation ratios (La_N/Yb_N between 15.96-19.69) and Eu/Eu* values (0.71-0.79) higher than those of the other orthogneisses (5.34-17.68 and 0.26-0.67 respectively); they are surely more similar with the values and REE patterns of the augen orthogneisses of Pioda di Crana Zone, to which the Antigorio nappe was always structurally connected. Also in the

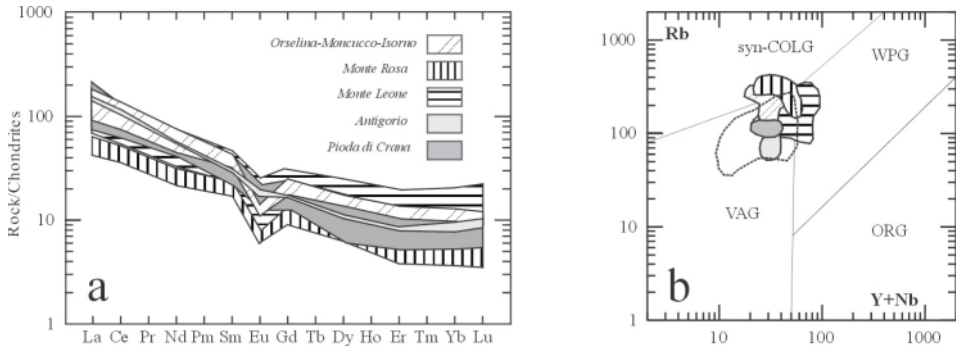

Fig. 5 – a) REE normalized patterns (normalizing values from Nakamura, 1974) and b) discrimination diagram (after Pearce *et al.*, 1984) of the Penninic orthogneisses. Dashed line: banded Pioda di Crana orthogneisses.

tectonic discriminations diagrams (e.g. Rb/Y+Nb, fig. 5b; Pearce *et al.*, 1984), the Antigorio and Pioda di Crana orthogneisses plot in the same field, typical of granites from volcanic arc, suggesting an origin from similar tectonic setting although differences in the age of emplacement are reported (Permian for the Antigorio; pre-Permian for the Pioda di Crana orthogneisses, unpublished data). The *Serizzo* was largely used for columns since the end of XV century (e.g. the old Ospedale Maggiore in Milano now Università degli Studi di Milano) and later on it was replaced with granites. It was also used in the building structure of the Duomo di Milano, for the plinth and the piers. Nowadays it is mainly used in polished slabs for paving due to its good wear resistance (Table 1) and low cost; only the most foliated types (*Serizzo Antigorio*) is used in splitted slabs, but very subordinately.

The Beola

The other important ornamental stone of the VCO province is the *Beola*, a series of heterogeneous materials with marked foliation and strong mineralogical lineation occurring in the mediun Ossola Valley between Vogogna and Montecrestese. Its production is subordinated with respect to that of *Serizzo* (15% of the whole stones of the Ossola Valley). For details on geology, historical use and features of the *Beola*, see Cavallo *et al.* (this volume).

The Granites

The granites follow *Serizzo* and *Beola* in order of commercial importance. They occur to the south of the province in the Verbano area, close to the entrance of the Ossola Valley, between Lakes Cusio and Verbano. The active quarries are located in the Baveno-Gravellona-Mergozzo area, but in the past they were also sited near Alzo (western shore of Lake Cusio) where a very appreciated white variety of granite was quarried. The geology and petrography of the granites can be found in Boriani *et al.* (1988). The granites typically are pink, white and green in colour. The well-known pink granite pertains to the Baveno pluton and occurs only in the uppermost part of the body; the area of exploitation is restricted also because of the frequent fractures and the inhomogeneity in texture, composition and colour of the rocks. The quarrying technique uses diamond wire for vertical cuts and adjacent drilling with parallel holes in separating secondary medium to coarse blocks. Now the production of pink granite is not very significant, because the quarry fronts need re-profiling. The *Granito Rosa Baveno* was quarried and processed since 16th century and its use, as building stone, was also exported in Milano: examples are the columns of the Lazzaretto, those of churches (Santa Maria alla Porta or San Alessandro) or those of the courtyards of famous buildings (Brera, Senato, Seminario, Ospedale Maggiore now Università degli Studi di Milano). Also in the façade of the Duomo there are two gigantic columns of this material. In the 18th century the granite was used for plinths or structural elements of façade associated with plaster base (Teatro alla Scala and Palazzo Litta in Milano). In 19th century it was also utilized in Torino for the beautiful arcade streets in the centre of the city and in 20th century again in Milano for the facing of the Arengario and Palazzo dell'Arte, the portal of the Università Cattolica and the paving of Corso Vittorio Emanuele, one of the most fashionable streets in the historical centre of the city. Also in Roma there are examples of buildings with some elements in *Granito Rosa Baveno* (e.g. Basilica Lateranense). The Baveno granite was extensively exported in France, Germany, Switzerland, Argentine, Brazil, United States of America, Cuba.

The white varieties mainly are from quarries located in the southern foothills of the little pluton of Montorfano (Gravellona Toce). The exploitation in terraced quarries uses the diamond wire for the primary cuts along peculiar surfaces of splitting. The present quarried stones are much more abundant than in the first half of the 20th century due to the

TABLE 1

Physical and mechanical properties of the VCO ornamental stones.

	Serizzo Antigorio	Serizzo Monte Rosa	Serizzo Formazza	Serizzo Sempione	Beola Bianca	Beola Favalle	Beola Ghiandonata	Beola Grigia	Granito Montorfano	Granito Baveno	Granito Verde Mergozzo	Palissandro Classico Crevola	Rosa Val Toce	Grigio Boden
Compression breaking load (MPa)	141 168-169 *112*	148-150 *92*	150 164-167 *86*	161 164-167 *90*	192 99-102 *104*	181-182 *185*	164 *127*	178 181-183 *185*	229 *147*	177 *162*	112-115 *116* **143**	112 142-147 *134*	80-85 *81*	*68*
Compression breaking load after freezing (MPa)	128		138	150	190		160	172	220	172		111		
Water absorption by weight (%)	0.36 0.34-0.39 *0.33*	0.36-0.40 *0.42*	0.31 0.32-0.35 *0.41*	0.28 0.32-0.35 *0.37*	0.29 0.37-0.42 *0.41* **0.31**	0.33 0.35-0.40 *0.40* **0.33**	0.28 *0.39* **0.42**	0.29 0.35-0.40 *0.40* **0.30**	0.28 *0.31*	0.33 *0.58*	0.29-0.33 *0.32* **0.56**	0.18 0.40-0.50 *0.20*	0.08-0.11 *0.11*	*0.18*
Flexural strenght (MPa)	16 14.1-15.1 *16.8*	11.3-11.7 *12.1*	15 13.7-14.7 *17.1*	14 13.7-14.7 *20.7*	21 18.1-20.1 *19.0* **21.2**	*19.9* **18.1**	19 *19.3* **16.1**	14 *19.9* **15.1**	14 *14.5*	11 *11.7*	*19.3* **20.6**	8 27.4-28.4 *12.0*	*24.2*	*19.4*
Impact test: minimum fall height (cm)	82		98	82	100		85	97	70	69		70		
Thermal linear expansion coefficient (mm/m °C)	0.0127		0.0113	0.0105				0.0135	0.0063	0.0075		0.0057 0.0045		
Wear resistance (mm)	5.33 4.94	4.44	5.26	5.26 5.06	4.94 **7.14**	5.48 **5.50**	4.30 **5.41**	5.71 **8.36**	4.35	3.60	**4.17**	14.81 10.00-10.56		
Weight per unit of volume (kg/m^3)	2730 2580-2640 *2680*	*2640*	2690 2550-2600 *2630*	2640 2550-2600 *2690*	2550 2610-2630 *2630*	2650-2670 *2670*	2570 *2650*	2630 2650-2670 *2670*	2570 *2630*	2510 *2590*	2660-2680 *2680* **2727**	2810 2550-2570 *2850*	2680-2730 *2710*	*2720*
Knoop micro-hardness (MPa)	4576 *7109*	*4047*	4729 *5552*	4094 *6619*	4156 *3789*	*3445*	3892 *5044*	5181 *3445*	*5445*	*5683*	*5223*	2122 *2023*	*1337*	*2285*

Regular: data from www.assocave.it
underlined: data from Redaprint (1996)
italic: data from Regione Piemonte (2000)
bold: data from the authors

technological development that allowed to have more regular blocks. The *Granito Bianco Montorfano* contains a lot of mafic microgranular enclaves that influence negatively the quality of the stone. Nowadays, the white granite is largely utilized in buildings and urban décor, while in the past it was mostly used as building stone although in a lesser extent than the *Granito Rosa Baveno*. Its use started in the 16th century and continued up to now: in Milano we find some columns in the Lazzaretto, Cappella Trivulzio, cloister of San Pietro in Gessate (16th century), Sant' Angelo, cloister in the convent of San Vittore, courtyard of Ospedale Maggiore (17th century). In the 19th century it reached Novara (Piedmont) and Roma (San Paolo Fuori le Mura).

The green granite occurs on the north-western slope of the Montorfano, in a small area near the Toce river in the Mergozzo municipality. The exploitation was surely active since 1700 as evidenced by buildings in Milano (e.g. Palazzo Mellerio) and was abandoned at the end of the 20th century; now only the waste blocks on the quarry working site are processed and so it is less used than in the past. The main products are represented by slabs for facing and paving and subordinately by blocks for décor. The mineralogical composition of the *Granito Verde Mergozzo* (Ab, Chl which is responsible of the green colour, Qtz and sericite) is due to post-emplacement hydrothermal metasomathism (Boriani, 2000) which modified the original white colour. The major problem for the exploitation of this rock type is the presence of Fe-carbonates that are easily weathered to give yellow spots and the scarce resistance to the polishing; on the other hand, the mechanical features show good properties, in agreement with those of other granites (Table 1).

The Marbles

Another valuable group of ornamental stones in the VCO area is represented by marbles, less important in volume with respect to the above mentioned rock types, but extensively quarried since the Renaissance and used as building stones (together with the Musso marble, western shore of Lake Como) in famous monuments in Lombardy. There are two distinct types of marble occurring in the Ossola Valley, different for geological and structural setting, features, physical and mechanical properties, uses and exploitation techniques. A lens of marble is also present in the Strona Valley (Omegna, Lake Cusio), but the quarrying is abandoned since seventeenths.

The Ossola marbles are now exploited in two peculiar areas: Candoglia-Ornavasso and Crevoladossola. The *Candoglia* and *Ornavasso marbles* are calcite-rich; they are lenses interlayered within the kinzigites of the Ivrea-Verbano Zone, Southern Alps. They respectively occur in the eastern and western steep slope of the lower Ossola Valley with a sub-vertical attitude and small thickness (8-30 m). In the *Candoglia marble*, structural studies evidenced isoclinal folds, with subvertical axial plane parallel to the main foliation, which connect the different small lenses (Fig. 6). The lenses crosscut the valley within a restricted band of few hundred of metres with a discontinuous appearance. The geological and morphological framework requires peculiar ability in the choice of front sites and splitting technique and precludes the extraction of large blocks. The quarries of Candoglia were firstly located near the village, but later on their position moved up to higher levels. Now there are five recognizable extraction fronts (Fig. 6) and two active quarries: the Cava Madre (500 m; underground quarry) and Cava Cornovo Est (860 m; open pit quarry). The first one gives very homogeneous material and the second one veined marble. Since 1387 the *Candoglia marble* quarries pertain to the «Veneranda Fabbrica del Duomo» of Milano and the produced stone (about 1.000 t/year) is only used for the restoration of the Cathedral (Ferrari da Passano, 2000). It was used as facing stone in few other monuments such as Certosa in Pavia, Cappella Colleoni in Bergamo, San Petronio Cathedral in Bologna; formerly the Romans used it for altars and columns (e.g. two columns

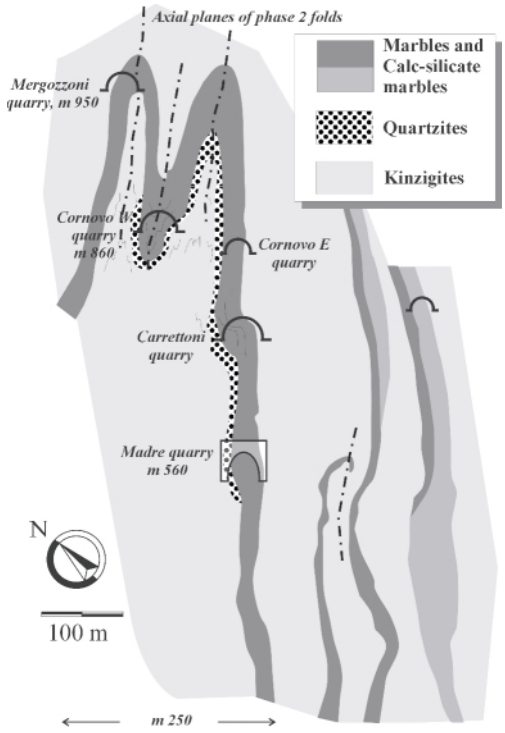

Fig. 6 – Geological sketch-map of the quarry area of Candoglia.

in the Chiostro Arcivescovile in Novara, Piedmont). The present cutting technique mainly uses diamond wire which allows to cut more quickly (11 m^2/h) than the old technology with helicoidal wire (0,23-0,88 m^2/h). The marble has medium to coarse grain size and mainly pink colour with frequent dark-green layers due to the presence of Di and Tr; others subordinate minerals are Qtz, Ep, sulphides, Ba-feldspar, barite and rare Phl. The chromatic, textural and compositional features are responsible for the varieties of marbles (pink, white, grey, veined marble). The white variety is the finest grained and more homogeneous with respect to the pink material; it also has less content of quartz and pyrite.

The Ornavasso marble is less valuable than the Candoglia, due to the coarse grain size, dark colour (*Grigio Boden* variety) or more abundant dark veins (*Rosa Valtoce* variety). The exploitation was interrupted many times during the centuries: in 1996 it is resumed in underground quarry using diamond wire, in the historical area of Casino Visconti (Ornavasso). Two are the active quarries, but the production is limited, due to the inhomogeneity in colour.

The other calcite-rich marble was extracted from the Massiola and Sambughetto quarries (Strona Valley; fig. 2); it is also interlayered within the kinzigites (Ivrea-Verbano Zone), in analogy with the Candoglia and Ornavasso marbles. It is largely exploited since 1881 until 1973, using formerly the explosives and then the helicoidal wire. This marble was used in facing of several buildings in Italy, such as Palazzo di Giustizia in Milano, Ministero delle Corporazioni in Roma, Nuovo Palazzo delle Poste in Napoli, but it was also exported in USA (New York). The marble contains veins of barite and has medium to coarse grain size. The colour varies from white to pink and grey, therefore the traded varieties were *Bianco Avorio di Vallestrona*, *Grigio di Vallestrona*, *Bianco Rosato*.

On the contrary, the Crevoladossola marble is dolomite-rich; it pertains to the Mesozoic metasedimentary cover that tectonically separates the Monte Leone and Antigorio nappes (lower Penninic Units; fig. 3); its structural setting, similar to the regional one, is quite steep. The location of the quarry (Lorgino di Crevoladossola) is the same of the historic Pavia quarry of the «Fabbriceria del Duomo di Pavia», at the beginning of the 16th century. Nowadays there is only one active quarry which produces the commercialised varieties: *Palissandro Bluette*, *Palissandro Blu Nuvolato*, *Palissandro Classico* and *Palissandro Oniciato*. The quarry front is terraced and the extraction technology only uses diamond wire technology. The large extracted blocks are then selected based on their dimension, textural and chromatic features. The Crevoladossola marble has fine grain size and variable colour due to the different amount of phlogopite which defines the foliation plane, disseminated sulphides

mostly in the blue types, or tremolite; the most well known types are whitish, with no or scarce phlogopite, or yellowish with evident layers of mica (*Palissandro Classico* and *Oniciato*). With respect to the Candoglia and Ornavasso marbles, the Crevoladossola marble has markedly anisotropic physical and mechanical properties (Table 1). In the Archaeological Museum of Milano possibly there is the first evidence of the use of this type of marble, represented by a sculpture of a Roman person (T. Labieno). Since 13th and 14th centuries this material was widely utilized in the local architecture of Domodossola, Baceno and Montecrestese, whereas its use was scarce in Lombardy: the main representative buildings are Arco della Pace in Milano with eight monolithic marble columns (10 m height) and the Duomo in Pavia (since 14th century). The marble is now used for internal facing, furnishings and valuable objects: in 1995 a block of *Palissandro Classico* was worked to produce the significant sculpture «Uovo della Pace» for UNICEF.

The Table 1 represents a summary of the existing physical and mechanical properties of the traded stones. Formerly it is to emphasize the difference among the values from different laboratories within each rock type and test; moreover the data from literature do not specify the load direction (perpendicular or parallel to the foliation and/or lineation) for compression and flexural tests on metamorphic rocks, so it is difficult to compare the materials. In any case, the Table 1 shows that all the VCO materials have very good physical and mechanical properties; the *Beola* is better than the *Serizzo* for almost all the tests, possibly due to its finer grain size and minor content in phyllosilicates; granites and marbles have properties similar to those of other comparable rock types.

MINOR STONES

In the VCO province, other rock types were quarried and worked as dimension stones: serpentinized ultramafites (*Pietra Laugera* or *Pietra Ollare*), granulitic gabbros (*Gabbro di Anzola* or *Nero di Anzola*) and dolomitic limestones (*Pietra di Angera* or *Pietra di Arona*).

The Ultramafites

The ultramafites are mostly serpentinites and talc-chlorite schists occurring in the Ossola Valley; they had a great historical, artistic and archaeological importance. Used since the Bronze Age, the *Pietra Laugera* shows many applications: the typical «laveggi» (pots for cooking), stoves and fireplaces (still in use, due to the excellent temperature resistance), millstones for cereals. Artistic and ornamental uses are documented by many churches and buildings in the Ossola Valley: for example, the Sacro Monte del Calvario chapels (now UNESCO heritage) and the Collegiale Church in Domodossola show many details in *Pietra Laugera* (columns, capitals and bas-reliefs). Because of its easy workability, in the past the *Pietra Laugera* was extracted and processed entirely by hand, as testified by many outcrops and erratic boulders that show the typical cavities of the «laveggi». The use of hydraulic lathes was introduced only at the beginning of the 19th century, for the production of pipes and pots in every shape. In the past the *Pietra Laugera* was quarried in many valleys: Brevettola, Antrona, Bognanco and Loana. The Cisore quarry in Bognanco Valley is well-known and its activity is documented at least since the 17th century. Nowadays the extraction of the *Pietra Laugera* occurs only in the Loana Valley (south to Vigezzo Valley), with a very limited production. Serpentinites and talc-chlorite schists derive both from the classic ophiolitic complexes (Antrona Zone and Zermatt-Saas Zone) and from the peridotitic complexes within the Orselina-Moncucco-Isorno Zone, Monte Leone nappe, Sesia-Lanzo Zone. For this reason, many varieties of *Pietra Laugera* can be recognized, with different petrographic features. The serpentinites from the Antrona Zone come from Bognanco Valley (near Bognanco Terme and S. Lorenzo),

Antronapiana area and Vigezzo Valley. They present deep green colour, very fine to fine (rarely medium) grain size, marked foliation and non-pseudomorphic texture in the types from Bognanco and Antrona area, whereas pseudomorphic texture for those from Vigezzo Valley. The Srp is associated with Mag, cataclastic Ol, Tr, Ttn, ± Ep in Bognanco Valley; Tlc is also present in the Vigezzo Valley rocks and Mag, Ep and carbonates in the Antronapiana area types. The varieties from the Orselina-Moncucco-Isorno Zone come from Brevettola and Anzuno valleys; they have grey-green or dark green-brown colour, weak or no foliation and fine grain size. The prevailing minerals are Tlc and Tr (mm to cm crystals) associated to Chl, with small amounts of Ol and Srp in the rocks from the Brevettola Valley; variable amounts of carbonates (Mgs and Dol) occur in the Anzuno Valley types. The serpentinized peridotites from the Monte Leone nappe occur near Montecrestese; they have grey-greenish colour, breccia-like texture and medium to coarse grain size. Ol and Tlc prevail in the mineralogical composition, associated with Chl that shows decussate texture, Srp and Mag. Finally, the variety from the Loana Valley is a serpentinized peridotite of the Sesia-Lanzo Zone; it is a medium grained, massive rock with spotted green colour, pseudomorphic texture and mineralogical composition: Srp, Ol (porphyroclasts with Srp along fractures), Tr. Tlc, Chl and Dol can also be found.

The Gabbro

The *Gabbro di Anzola* (or *Nero di Anzola*) is quite similar to the Main Gabbro of the Ivrea-Verbano Zone. The rock shows medium grain size, subsolidus re-equilibration with granoblastic texture and slightly mineral orientation. The colour is black with white veins due to plagioclase concentration that locally gives an heterogeneous appearance to the rock. The assemblage is: brown Hbl, Cpx, Opx, Pl, opaques. Most of the gabbro presents low temperature retrogression, mainly concentrated in discrete areas: the plagioclase is saussuritized and the brown amphibole and pyroxenes are transformed into colourless amphibole. It was extracted near Anzola (medium Ossola Valley), close to the Toce river (Fig. 2). News of its exploitation date back to 1906; it was used as décor of buildings (in Torino and Napoli), monuments, tombs (Mausoleo Cadorna in Pallanza) and was also exported (mainly in Amsterdam). Nowadays the Anzola quarry produces only crushed stones.

The carbonatic rocks

The *Pietra di Angera or Travertino di Angera* is a massive dolomitic limestone pertaining to the «Dolomia Principale» Formation (Upper Triassic); it has yellow-pinkish colour, very fine grain size and high porosity due to the presence of several vugs. This stone was quarried since Roman times and mainly used in Lombard architecture up to the middle of the 20th century. The quarries are located near Angera, on the eastern shore of the Lake Maggiore (Verbano), while a similar dimension stone was quarried on the western shore near Arona (*Pietra di Arona*). In the 17th century the exploitation was abandoned, because it damaged the stability of the above sited Rocca dei Borromeo in Angera. It was used for paving, internal and external facing, décor and architectural elements due to its easy workability. Local examples are columns (16th century) and other details in the portico and Chapels of Santa Caterina del Sasso Ballaro (south of Laveno, eastern shore of the Lake Verbano) and the Castellana Tower, entirely built with this stone, in the Rocca di Angera complex. In Milano, examples are the courtyard of the Ospedale Maggiore (15th-16th centuries, now Università degli Studi di Milano), the Certosa (16th century), the façades of the San Fedele and San Raffaele churches (both built during the 17th century) and the bases of the columns in the entrance building of the Cimitero Monumentale (19th century). The *Pietra di Angera* was also used in Pavia,

for masonry and ornaments of churches (e.g. San Pietro in Ciel d'Oro) and private buildings (Collegio Borromeo), in Parma (façade of S. Giovanni Evangelista) and in Varese for the Palazzo di Giustizia.

CONCLUSIVE REMARKS

In Piedmont, 61% of the production of ornamental stones comes from the VCO province; this zone is a primary area for number of quarries and exploitation of several rock types which are mostly metamorphic (orthogneisses) and subordinately magmatic and sedimentary rocks. The quarries are mainly located in the Ossola Valley which therefore assumes a dominant role within the VCO area. *Serizzo* and *Beola* (mainly Variscan metagranitoids) have very good physical and mechanical properties and versatility of working, so that they were and are largely used for internal and external paving or facing in Italy and abroad. Also the granites have similar features and then the same importance as building stones, although they represent 1/10 of the extracted volume of the Serizzo-Beola group. In Italy, Milano offers the best exposition of the VCO stones, because the quarry areas were easily connected to the Lombard city through the Lake Verbano and some navigable rivers and channel (Toce and Ticino rivers, Naviglio channel). The VCO is a traditional area of exploitation since medieval time. The diffusion of their stones developed during the Renaissance due to the strong requirement of valuable ornamental stones for building and churches and during Napoleon period till to the 19th and 20th centuries: the VCO materials have remarkable uses not only in valuable but also in ordinary buildings for paving, terraces, balconies or stairs.

In the VCO province, the quarrying and processing of ornamental stones have a fundamental role to develop the craft and industrial sectors: the last ones would be improved (also with financial support) in order to favour the major diffusion of the exploited materials which have excellent technical properties and agreeable aesthetic features. The use of traditional local stones, such as those from VCO, would have a considerable importance both as building or décor stone, and in conservation and restoration of the architectural heritage in the provenance areas and in the national territory. In order to reach this goal it is necessary a major sensibility towards the historical and cultural significance of the stones used in the past in a certain area and a major knowledge of the geological, petrographical, physical and mechanical data of the different materials.

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