Contemporary natural stones from the Italian western Alps (Piedmont and Aosta Valley Regions)

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ABSTRACT. — At present about 60 different kinds of stones are quarried in the Italian Western Alps, most of which are metamorphic rocks (gneiss, ophicalcite, marble and quartzite) and, to a lesser extent, magmatic (granite, syenite and diorite), with an overall production of 380'000 m³ in the year 2002. This work synthetically illustrates their geologic and petrographic characteristics, gives essential historical information and examines the technical, environmental and economic aspects of their extraction and production.

RIASSUNTO. — Nelle Alpi Occidentali italiane sono attualmente coltivate circa 60 varietà di rocce, in prevalenza metamorfiche (gneiss, ophicalcite, marmo e quarzite) e subordinatamente magmatiche (granito, sienite e diorite), con una produzione complessiva nel 2002 dell’ordine di 380'000 m³. Il lavoro ne illustra sinteticamente i caratteri geo-petrografici, ne fornisce notizie storiche essenziali ed esamina aspetti tecnici, ambientali ed economici della loro estrazione e trasformazione.

KEY WORDS: natural stones, Western Alps, geology, petrography, production

INTRODUCTION

In the Italian Western Alps a great deal of different varieties of stones were quarried in the past and can be considered historical stones because of their diffusion or use in monumental works (see, for example, Barelli, 1835; Jervis, 1889; Salmoiraghi, 1892; Blangino, 1895; Sacco, 1907; Peretti, 1938). There are now about 60 varieties on the market which can be grouped together in a few lithotypes (granite, syenite, diorite, gneiss, quartzite, ophicalcite and marble). Their overall production in the year 2002 was more than 380’000 m³ of «workable stone», which means material that is suitable for processing, and 97% of this was in Piedmont. Among the various lithotypes that are quarried, gneiss is the most prevalent: it is marketed in about twenty varieties and it represents more than 90% of the entire production in Piedmont. It is extracted and worked above all in the Verbano-Cusio-Ossola province and in the Luserna Stone (Pietra di Luserna) district, on the border between the Turin and Cuneo provinces (Fig. 1). Ophicalcite, whose production is limited to the...
Fig. 1 – Structural sketch map of the Western Alps with location of the stones that are referred to in the text.

**Delphinois-Helvetic domain** 1: undifferentiated basement and cover. **Penninic Domain** 2: Prealps; 3: Subbriançonnais Zone (Sion-Courmayeur Zone or North-Penninic Valais Zone in the northern part of the map); 4: Briançonnais Zone (Grand St. Bernard multinnappe system in the northern part of the map) and Moncucco-Orselina-Isorno Zone (MO); 5: Simplon-Tessin Nappes (A = Antigorio; ML = Monte Leone); 6: Internal crystalline massifs (MR = Monte Rosa; GP = Gran Paradiso; DM = Dora Maira); 7: Piemonte Zone; North-Penninic Calcischists; Triassic-Neocomian succession of Versoyn, Montenotte and Sestri-Voltaggio Units; 8: Alpine Helminthoid Flysch of Ubaye-Embrunais and Liguria. **Austroalpine Domain** 9: Sesia-Lanzo Zone (SL) and Dent Blanche Nappe (DBL); **Southern Alps** 10: Ivrea-Verbano Zone; 11: Serie dei Laghi and Canavese Zone (W of Ivrea); 12: mainly Permian-Mesozoic volcanic and sedimentary cover. **Post-collisional Alpine intrusives** 13: Traversella stock and Valle del Cervo pluton. **Apennines and Torino Hill** 14: Cretaceous and Tertiary sediments. **Po Plain and Ligurian-Piedmontese Basin** 15: Tertiary and Quaternary sediments. 16: Main tectonic lines (CL = Canavese Line; SVL = Sestri-Voltaggio Line). 17: Stones that are referred to in the text (A: granites; B1: Candoglia-Ornavasso marbles; B2: Crevoladossola marble; B3: Val Germanasca marble; B4 and B5: marbles from the Cuneo province; C1: Beola; C2: Serizzo; C3: Luserna Stone; C4: Perosa and Malanaggio Stones; C5: San Basilio Stone; C6: Verde Argento, Verde Selene and Verde Aosta; C7: Courtile Stone; C8: Cogne and Traversella Diorite; D: Bargiolina Quartzite; E: «Green Marble» from the Aosta Valley; F: Cervo Valley Syenite; G: Vico and Traversella Diorite; H: Morgex Stone). 18: Italian state border. 19: Regional borders.
Aosta Valley where it represents about 60% of the entire regional production, is known on the market as «Green Marble» and a dozen or so varieties are extracted.

THE VERBANO-CUSIO-OSSOLA (VCO) DISTRICT

The 81 ornamental stone quarries, that were authorized to operate in the year 2003 according to legislation in force, exploit granite (5 quarries), marble (4 quarries) and two types of orthogneiss which are locally and commercially known as Beola (17 quarries) and Serizzo (55 quarries); in the year 2002 the production of workable stone was 193,000 m³.

Granite (A in Fig. 1) is extracted in two varieties known as Rosa di Baveno (2 quarries) and Bianco di Montorfano; a third variety (Verde di Mergozzo) stopped being quarried in recent years. At present, the largest quarry dumps, located in historical extraction sites that have not yet been re-naturalised, are again subject to quarrying operations for the recuperation of industrial minerals, such as quartz, mica and, above all, feldspar (Bozzola et al., 1995).

From a geo-petrographic point of view, the granites (Boriani et al., 1988a; 1988b; 1992; Pinarelli et al., 1988; 1993), which are characterised by medium or medium to fine grain sizes, pertain to a composite complex of plutonic bodies of the Lower Permian age, that intruded at a shallow depth the Southern Alps basement (Fig. 1) of the Serie dei Laghi (see the review in Boriani, 2000).

Apart from the intermediate early facies (Appinitic suite), their composition varies from granodiorites to granites (Fig. 2 and Table 1), with a dominant calcalkaline character.

The Mergozzo Green Granite is an «episyenite» that formed in the peripheral part of the intrusion due to hydrothermal metasomatism, with the dissolution of quartz, the replacement of feldspars with albite, and the chloritization of biotite.

The Ossola Valley marbles are now exploited in two particular areas: Candoglia-Ornavasso and Crevaldossola (B1 and B2 in Fig. 1). In the former area, they are represented...
by calcitic marbles while in the other by dolomitic ones.

The Candoglia and Ornavasso marbles occur as quite small lenses (up to 30 m of thickness) that are interlayered within the pre-alpine high-grade paragneisses of the Kinzigitic Complex of the Ivrea-Verbano Zone (Southern Alps). Their grain size is medium to coarse and the main colour is pink with frequent dark-green layers containing diopside and tremolite; other subordinate minerals are quartz, epidote, sulphides, Ba-feldspar, barite and occasionally phlogopite. The chromatic, textural and compositional features are responsible for the different variety of marbles (pink, white, grey, and venato marble). The Candoglia marble is not sold on the market because the two working quarries belong to the «Veneranda Fabbrica del Duomo» of Milan and the produced stone (about 1'000 t/y) is only used for the restoration of the Cathedral (Ferrari da Passano, 2000). On the contrary, two varieties of the less valuable coarse-grained Ornavasso marble are sold on the market: Grigio Boden and Rosa Valtoce. The latter has an inhomogeneous colour due to the presence of dark veins. The production is rather limited (overall less than 400 m$^3$/y) because of the heterogeneity of the design and colour and, above all, due to the intense jointing of the material. The excavations are in part performed in a large sized underground space, with the necessity of consolidation works and static controls (Oreste and Peila, 1998; Fornaro and Bosticco, 1999). Both the open pit and underground exploitation mainly uses diamond wire technology.

The Crevoladossola marble belongs to a thin layer of the Mesozoic metasedimentary cover embedded within the lower Penninic Units (Monte Leone and Antigorio nappes); its attitude is quite steep as the regional one is. It has a fine grain size and different colours (yellowish or light blue) due to the

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### Table 1

*Modal composition range for Granito Rosa di Baveno (1), Granito Bianco di Montorfano (2), Granito Verde di Mergozzo (3), Beola (4), Serizzo (5), Lasernina Stone (6), Bargiolina Quartzite (7), Valle del Cervo Syenitic Complex (from old active quarries) (8) and Cogne-Valsavarenche metatonalite (9).* Mineral symbols according to Kretz (1983); Qtz = quartz, Kfs = K-feldspar, Pl = plagioclase, An = anorthite, Btl = hornblende, Bt = biotite, Chl = chlorite, Ms = muscovite (phengite in 6 and 7). Data from Gandolfi and Paganelli (1974) for 1, 2 and 3; Pagliani (1944), Reinhard (1966) and Bigioggero et al. (1982-83) for 4; Hunziker (1966), Joos (1969) and Bigioggero et al. (1977) for 5; Vialon (1966) and Barisone et al. (1979) for 6; unpublished data by Fiora for 7; unpublished data by Colombo and Tunesi for 8; Fenoglio and Rigault (1959) and unpublished data by Grasso for 9.

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R. SANDRONE, A. COLOMBO, L. FIORA, M. FORNARO, E. LOVERA, A. TUNESI and A. CAVALLO
concentration of phlogopite, sulphides or tremolite that are associated to the main mineral, dolomite; the varieties on the market are Palissandro Bluette, Palissandro Blu Nuvolato, Palissandro Classico and Palissandro Oniciato. The Crevaldossola marble has physical and mechanical properties more anisotropic than the Candoglia and Ornavasso ones. It is a stone of historical importance that has been used in some famous monuments in Lombardy, such as the Arco della Pace in Milan and the Cathedral in Pavia (Vago and Zezza, 2000), but today it is used for internal linings, furnishings and objects of value, especially the Palissandro Classico and Oniciato varieties. The maximum production is 10,000 m$^3$/y, which includes blocks for frames and workable under-sized blocks.

Beola and Serizzo ($C_1$ and $C_2$ in Fig. 1) are the most important stones from the Ossola district, due to the abundance of quarries and extracted materials. Based on the chromatic and/or structural features or on the geographical area of provenance, the main varieties of beola and serizzo are (Regione Piemonte, 2000): Beola Bianca, Grigia, Ghiandonata, Favalle; Serizzo Antigorio, Formazza, Sempione, Monte Rosa.

Most of these stones are orthogneisses that are derived from Permian granites (270-280 Ma), which are similar to the Graniti dei Laghi but which have been overprinted by alpine structural and metamorphic events.

Beola (Fig. 2 and Table 1) is characterised by a sparkly grey or a silver white colour and a fine-to-medium grain size; it shows marked foliation, which is usually associated to a strong lineation, due to the alignment of the tourmaline crystals or to the stretching of the K-feldspar porphyroclasts. Beola Bianca Vogogna and Beola Verde Vogogna (or Quarzite Bianca and Quarzite Verde) have a very fine grain size and a mylonitic foliation, that were formed during the late-Alpine back-thrusting phase of the Austroalpine nappes over the Ivrea-Verbano Zone. Beola Bianca Vogogna is possibly an orthogneiss, whereas Beola Verde Vogogna is a metabasite that is mainly composed of chlorite, epidote and albite. The attitude of Beola is sub-vertical; it geologically pertains (Fig. 1) to the Austroalpine domain (Beola Bianca and Verde Vogogna), to the Upper Penninic Units (Beola Bianca and Ghiandonata from the Monte Rosa Zone; Beola Grigia from the Moncucco-Orselina-Isorno Zone, Bigioggero et al., 1982-83), and to the Lower Penninic Unit of the Monte Leone Nappe (Beola Favalle, Argentea and Isorno, Bigioggero and Zezza, 1997). Detailed geological, petrographical, geochemical, physical and mechanical features of Beola are reported in Cavallo et al. (a, this volume).

The transformation from block to slabs can be done by sawing (34% of the excavated rock) or manual wedging (29% of the excavated rock).

Serizzo is a granitic/granodioritic orthogneiss (Fig. 2 and Table 1) with a darker colour and larger grain size than those of the beola varieties; it is characterised by a foliated texture which is rarely associated with a lineation; it geologically mainly pertains to the lower Penninic Unit (Fig. 1) of the Antigorio Nappe (Serizzo Antigorio, Formazza and Sempione) and, in one case, to the Upper Penninic Unit of the Monte Rosa Zone (Serizzo Monterosa). The attitude of the Antigorio nappe is sub-horizontal and the thickness is about 1000 m; this explains the great exploitation of the Serizzo varieties.

The transformation from blocks to slabs can be done by sawing (40% of the excavated rock) or by manual wedging (4% of the excavated rock).

The VCO quarries, that are located at altitudes which vary between 300 and 1300 m above-sea-level, mainly pertain to the Baveno (granite), Mergozzo (granite + marble), Ornavasso (marble), Beura Cardezza and Trontano (beola), Premia, Formazza, Trasquera, Varzo and Crodo (serizzo), and to the Crevaldossola (serizzo + beola + marble) municipalities.

Further details on the dimension stones of this particular district can be found in
Bigioggero and Zezza (1997) and Cavallo et al. (b, this volume).

### THE LUSERNA STONE BASIN (LSB) AND THE OTHER STONES FROM THE DORA-MAIRA MASSIF

Luserna Stone (Sandrone et al., 2000; 2001; Sandrone, 2001) is a leucogranitic orthogneiss (Fig. 3 and Table 1) probably of the Lower Permian age, that is characterized by a micro-«Augen» texture and grey-greenish or locally pale blue colour. Luserna Stone has a sub-horizontal attitude, with a marked foliation that is mostly associated to a visible lineation: it geologically pertains to the Dora-Maira Massif (see the review in Sandrone et al., 1993) and it outcrops in a quite large area (approximately 50 km²) in the Cottian Alps, on the border between the Turin and Cuneo provinces (C₃ in Fig. 1).

The transformation from blocks to slabs can be done by sawing (13% of the excavated rock) or manual wedging (32% of the excavated rock).

The 96 quarries that were authorized in autumn 2003 lie in the Bagnolo Piemonte (68 quarries), Rorà (20 quarries) and Luserna San Giovanni (8 quarries) municipalities at altitudes that range from 900 m to 1500 m.

In the year 2002, there was an overall production of 331,604 t (≈ 125,600 m³) of «workable stone» and 512,156 t (≈ 194,000 m³) of blocks for river bank defence and retaining walls.

Different bodies of a granodioritic-tonalitic composition (Fig. 3) crop out in the lower Chisone Valley (C₄ in Fig.1) and intrude the monometamorphic graphite-bearing sequence. It is from one of these bodies that the well known and by now historical Malanaggio Stone (also known as Malanaggio Diorite)

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**Fig. 3 – Cumulative R₁R₂ diagram (De La Roche et al., 1980) for Luserna, Perosa and Malanaggio Stones, Susa Valley leucogneiss, Sesia Zone albitic gneiss, Syenitic Complex of the Cervo Valley, Vico and Traversella Diorite and Cogne-Valsavarenche metatonalite. Abbreviations: mo di = monzodiorite; mo = monzonite; gb di = gabbrodiorite; di = diorite; sye di = syenodiorite; to = tonalite; grd = granodiorite; qz mo = quartz monzonite; sye = syenite; gr = granite; qz sye = quartz syenite; alk gr = alkali granite. Data from Pagliani (1954), Vialon (1966) and Sandrone et al. (1982) for Luserna Stone, Vialon (1966) and unpublished data by Sandrone for Perosa and Malanaggio Stones, Cadoppi (1990) for Susa Valley leucogneiss, Lattard (1974) for Sesia Zone albitic gneiss, Bigioggero et al. (1994) for the Syenitic Complex of the Cervo Valley, Van Marcke de Lumen and Vander Auweria (1990) and unpublished data by Colombo and Tunesi for Vico and Traversella Diorite, Novarese (1894) and Fenoglio and Rigault (1959) for Cogne-Valsavarenche metatonalite.**
originates, while from another body is still quarried *Perosa Stone*. This is composed of quartz, albite, chlorite, biotite, actinolitic hornblende, zoisite and clinozoisite/epidote; garnet, apatite, sphene, calcite and ores are also present as accessory minerals. The only functioning quarry is situated in the Municipality of Pomaretto in the province of Turin and it has a declared production of more than 2,000 m³/y of «workable stone», which is obtained exclusively through the use of explosives.

In the past there were numerous gneiss quarries in the lower Susa Valley (Barisone *et al*., 1992; Fiora and Gambelli, 2003), but at present only one is worked and this quarry was recently re-activated in the Municipality of Bussoleno in the Turin province. This gneiss, called *San Basilio Stone* (C3 in Fig. 1), is also known on the market as *Adrian White*. This is a tourmaline-rich leucocratic orthogneiss with granitic composition (Fig. 3) of a colour that ranges from white to greyish-white, with foliation defined by the orientation of the mica lamellae and the tourmaline blasts. The fundamental mineralogical components are, in descending order of quantity, quartz, microcline, albite, tourmaline and phengite.

The foreseen mean production of «workable stone» is around 10,000 m³/y at a full production regime. *Barge quartzite*, known on the market as *Bargiolina* (Sandrone *et al*., 1999; Fiora *et al*., 2000d; 2002), is a perfectly splittable phengite-rich quartzite with different colours (yellow, greyish-green, grey and more rarely white) that crops out over an area of 1.5 km² on the western slope of Mount Bracco, in the lower Po valley (D in Fig. 1).

From a geological point of view, it belongs to the Mesozoic cover of the Dora-Maira Massif and it represents the product of the alpine metamorphic and structural transformations of an arenaceous sediment, which was deposited on the Hercynian basement during the eo-Triassic stages of marine ingresson (Vialon, 1966).

It is an easy-to-work stone with natural splitting due to its plain-schistose texture and it has an elevated strength and hardness due to its mineralogy (Table 2). It has been used for centuries in the building trade for tile roofing and for internal and external paving. It is now greatly penalised by competition from a Brazilian quartzite and is only extracted in limited quantities (5102 t of «workable stone» in the year 2002) from one single quarry in the Municipality of Barge in the Cuneo province.

In the high Germanasca valley (B3 in Fig. 1), a series of marble layers occurs. They belong to the polymetamorphic basement of the Dora-Maira Massif (Borghi *et al*., 1984), have been quarried since 1600 and are known as *Perrero Marble* or *Faetto Marble* (Peretti, 1938; Gola and Pelizza, 1971). At present only a few hundred cubic metres are extracted each year from one single quarry in the Municipality of Prali in the province of Turin.

**THE GNEISSES FROM THE SESIA-LANZO ZONE**


Verde Argento Granite and Verde Selene Granite are both jadeite-bearing metagranites, and this mineral is responsible for the green colour of the rock. Apart from jadeite their mineral composition is given by quartz, albite, phengite, epidote, microcline, garnet, sphene, apatite, zircon and sometimes fluorite (Fiora *et al*., 2000b). *Verde Argento* is quarried in only one quarry in the Settimo Vittone Municipality in the Turin province with a production of about 1500 m³/y of «workable stone» and *Verde Selene* is quarried in two quarries in the Tavagnasco Municipality in the province of
Turin with an overall production of about 20'000 m³/y (C₆ in Fig.1).

**Verde Oropa Granite** is a heterogeneous gneiss in which leucocratic domains alternate with melanocratic ones: the latter are green in colour and partially preserve eclogitic paragenesis. Its mineralogy is given by quartz, phengite, omphacite, garnet and epidote while sphene, apatite and zircon are also present in accessory quantities and white mica, green biotite, actinolite, aegirine and albite are present as retrogression products. It is quarried just above the Oropa sanctuary in the province of Biella.

**Verde Aosta or Verde Montey Granite** (C₆ in Fig. 1) is also an orthogneiss whose fundamental mineralogical components are quartz, phengite, albite, epidote, garnet, green biotite and green amphibole; the common accessories are apatite, zircon, calcite and sphe. Rare relics of Na-pyroxene and allanite are also present. At the moment this rock, which was extracted in the Donnaz Municipality in the Aosta province and whose production was of about 2'000 m³/y of sawing blocks, is not quarried.

**Courtil Stone** (C₇ in Fig. 1) is a gneiss that is made up of quartz, albite, epidote, chlorite, green biotite, greenish-blue amphibole, calcite, garnet and abundant sulphides. The grain size is generally rather fine and varies from point to point according to the mineralogy. It is quarried in the Pont Bozet Municipality in the Aosta province and the yearly production of «workable stone» is about 1’000 m³ compared to 1’800 m³ of quarried material; it is processed both by natural splitting and sawing.

**THE «GREEN MARBLE» FROM THE AOSTA VALLEY**

From the geological point of view, the **Green Marble** (E in Fig.1) is a metaophicalcite that mostly belongs to the Combin nappe and to a lesser extent to the Zermatt-Saas nappe of the Piemonte Zone (Dal Piaz et al., 2001, with references).

Quarried in the Aosta Valley since the twenties and sold on the market with the generic name of **Verde Alpi** (Fiora and Ferrarese, 1998; Ferrarese et al., 1999), it shows a remarkable textural and chromatic heterogeneity, as it includes both tectonic breccias and, to a much lesser extent, sedimentary breccias. The first are made up of angular fragments of serpentinite immersed in a clear or greenish matrix of carbonates and silicates, while in the second case the green serpentinite clasts are together with white marble clasts. The design created by the carbonatic veins and the colour that ranges from green to greenish-black of the serpentinite portions are of particular importance from the merchandise point of view. A great heterogeneity of these rocks can sometimes be found in individual quarries, and sometimes these individual quarries produce several varieties.

There are about twenty authorized quarries and a little more that half of these are still in production. These quarries can be found in the three extraction basins of Issogne, Gressoney and Media Valle (the Middle of the Valley). The overall production increased between 1999 and 2002 from 5’000 to 6’000 m³/y of profitable material, with a quarry yield that varies between 30 and 40%.

The basins, the quarries of origin and the mineralogical composition (in decreasing order of abundance) are reported in Table 2 for the main varieties on the market: the latter should be considered as an estimate, taking into consideration the great variability of the rock from point to point.

Although not belonging to green marble from a market point of view, **Verde Cheran** is here mentioned as it also comes from the Piemonte Zone. It is a «prasinite» (greenschist) that is quarried in the Municipality of Verrayes and its present production is about 1’200 m³/y of workable stone with a yield of about 30%.

**OTHER STONES**

Other stones are exploited in Piedmont for ornamental use: the rocks of the Valle del Cervo pluton (Cervo Valley or Biella pluton) and Traversella stock, which are referred to the
same alpine magmatic event, and the Mesozoic marbles from the Cuneo province. The first ones pertain to the largest Oligocene pluton of the Western Italian Alps intruded in the eclogitic micaschists of the Sesia-Lanzo Zone. According to Bigioggero et al. (1994), the pluton consists of monzo-granitic rocks (Granitic Complex) in the core surrounded by a discontinuous rim of syenitic rocks (Syenitic Complex) and, finally, by a wide rim of monzonitic rocks (Monzonitic Complex). A subdivision in Complexes rather

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<td>Gressoney</td>
<td>Ciuen Dover</td>
<td>Atg, Cal, Tr, Di, Mag, Mg-Chl</td>
</tr>
<tr>
<td>Verde Moderno (or Golette)</td>
<td>Media Valle</td>
<td>Golette (Verrayes)</td>
<td>Cal, Atg, Tr, Di, Mag</td>
</tr>
<tr>
<td>Verde Rameggiato</td>
<td>Media Valle</td>
<td>Croce di San Martino (Verrayes)</td>
<td>Atg, Cal, Mag, sulphides</td>
</tr>
<tr>
<td>Verde Aver</td>
<td>Media Valle</td>
<td>Aver</td>
<td>Atg, Cal, Tr, Mag, sulphides</td>
</tr>
<tr>
<td>Verde Maisonetta</td>
<td>Media Valle</td>
<td>Maisonetta</td>
<td>Atg, Cal, Di, Mag, sulphides</td>
</tr>
<tr>
<td>Verde Assoluto</td>
<td>Media Valle</td>
<td>Vencore Prelez (Verrayes)</td>
<td>Atg, Cal, Mag</td>
</tr>
<tr>
<td>Verde Damascato</td>
<td>Media Valle</td>
<td>Plan de Verrayes</td>
<td>Cal, Dol, Atg, Tr, chromian Mg-Chl, Mg-Chl, Brc, Mag</td>
</tr>
<tr>
<td>Verde Chiesa</td>
<td>Media Valle</td>
<td>Morge Raffort</td>
<td>Atg, Tr, Cal, Mag, Mg-Chl</td>
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<tr>
<td>Verde St. Denis</td>
<td>Media Valle</td>
<td>Blavesse (St. Denis)</td>
<td>Atg, Cal, Mag</td>
</tr>
<tr>
<td>Verde St. Nicolaus</td>
<td>Media Valle</td>
<td>Champlong (St. Denis)</td>
<td>Atg, Cal, Tr, Mg-Chl, Grt, Di, Spl</td>
</tr>
<tr>
<td>Verde Issorie</td>
<td>Media Valle</td>
<td>Issorie (Châtillon)</td>
<td>Atg, Cal, Dol, Tr, Di, Mg-Chl</td>
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</table>
than in lithological units is preferred because of the heterogeneity of rock types: for example, locally, the syenites gradually change their composition into monzonites.

*Sienite della Balma* (Fiora et al., 1999; 2000b) is the most famous quarried stone of the Valle del Cervo pluton (F in Fig. 1); its exploitation was abandoned but has now begun again. The rock has a typical grey-violet colour, medium grain size and a well developed magmatic flow foliation. Its mineralogical composition (Table 1) is: K-feldspar (orthoclase), plagioclase (andesine), Mg-hornblende, biotite, diopside and scarce quartz. Sphene is the distinctive accessory mineral; the others are apatite, zircon and ores. K-feldspar typically occurs as megacrysts with Carlsbad twinning and perthitic exsolutions; its colour mainly influences the colour of the rock. The quarrying activity at present involves two quarries: the Cava Vej della Balma (reactivated in the year 2003) and the Cava Colombari, both of which are located in the San Paolo Cervo Municipality in the Biella province. The estimated mean yearly production for the two quarries is about 2,000 m$^3$ of «workable stone».

Monzo-granite was also used in the past as ornamental stone. It has a reddish colour, medium-to-coarse grain size and pseudoporphyrític texture. Its mineralogical composition differs from that of syenite because of the smaller amount of Mg-hornblende and the lack of pyroxene (diopside). Traversella stock (Van Marcke de Lummen and Vander Auwera, 1990; unpublished data by Colombo and Tunesi) crops out on the left side of Val Chiusella (near Ivrea) and it intrudes the eclogitic micaschists of the Sesia-Lanzo Zone, as the Biella pluton does. The prevailing rock type is quite homogeneous in composition because only the external parts of the intrusive body are visible; it varies from quartz-monzonites to quartz-diorites because of the variable content of K-feldspar. The grain size is medium-to-fine, the colour is dark green to light grey and the rock often presents igneous and metasedimentary xenoliths that negatively influence the general aspect. The mineralogical composition is: plagioclase, biotite, hornblende, clinopyroxene (augite) and variable amounts of K-feldspar and quartz. The biotite also locally shows coarse pectilitic lamellae (up to 4 mm in length). The fine grained samples have orthopyroxene (hypersthene) associated with clinopyroxene. The accessory minerals are apatite, zircon, sphene and ores.

The quarried stone is sold on the market in two varieties that basically differ according to their colour: a darker grey for *Vico Diorite* and lighter grey for *Traversella Diorite*. The physic-mechanical characteristics are basically the same and are always excellent (Fiora et al., 2000c). There are 4 quarries at present working and these are located in the Vico Canaveses and Traversella Municipalities in the province of Turin (G in Fig. 1). The overall production is of about 8,500 m$^3$/y of «workable stone».

In the Cuneo province, in the area around Mondovi (B4 in Fig. 1), which was once the main Piedmontese marble yielding basin (Badino et al., 2001) there are still some historical quarries which are partially working, though with a limited overall production (1,000-2,000 m$^3$/y of quarried material, with 30-40% «workable stone»). These quarries exploit lithotypes belonging to the calcareous-dolomitic Mesozoic Briançonnais succession of the Dolomie di S. Pietro dei Monti (Vanossi, 1974a; 1974b). The materials are known as *Bigio di Moncervetto Marble*, *Verzino* and *Bigio di Frabosa*. The latter, which is not at present in production, is of interest for the future for the restoration works of the Chapel of the Shroud in the Turin Cathedral. *Ormea Black Marble* (B5 in Fig. 1) is found at the top of this sequence. The quarrying of this marble has recently been re-organised and the quarry has modern mechanisation and sophisticated working techniques for slabs, kerbstones, handmade articles and even for «aged» bricks and tiles, which are particularly appreciated in urban furnishings in many Ligurian Riviera resorts. A total of 3-4,000 m$^3$/y of sawn blocks...
are obtained from the quarried material with a yield of 30%. The use of small-sized blocks for Belgian blocks leads to an overall yield of more than 40%.

In the Aosta Valley, apart from the «Green Marbles» and the Courtil Stone, some other stones are at present quarried for local external use, for road paving and building coverage. This is the case, for example, of Cogne Stone which takes its name from the municipality it comes from, and of Senagy Stone which is quarried in the Municipality of Aymavilles (C₃ in Fig. 1). The quarried quantities are 800 m³/y (a yield of 600 m³/y) and 35’000 m³/y (a yield of 3’000 m³/y), respectively. From the geological point of view both stones belong to a tonalitic-granodioritic Permian pluton, included in the Paleozoic Briançonnais schists, that crop out in the Cogne valley and Valsavarenche, whose most common lithotype is a biotite-amphibole-bearing metatonalite (Fig. 3 and Table 1) with a medium-fine grain size. Finally, Morgex Stone (H in Fig. 1), which is a calcschist that geologically belongs to the Sion-Courmayeur Zone, was once used to a great extent for roof tiles (Clerici and Pelizza, 1986; Frisa Morandini, 1986) but is today rarely quarried both because of site protection reasons (Tête d’Arpy, a lookout point in front of Mont Blanc) and because of the competition from other Piedmont and Lombardy stones and from abroad (Fiora et al., 2001).

**REMARKS ON THE EXPLOITATION AND PROCESSING**

The considered rocks are mostly exploited by a hill side development. A descending development method is used from the higher quotes, using slices - sub-horizontal or sometimes very upward sloping - mostly where systematic discontinuity points exist which assist the splitting of the regular ornamental stone blocks. The splitting of the quarry benches is obtained through the use of explosives (using detonating cord as a «cutoff agent» and sometimes blasting powder as a «thrust agent»). The blast holes are parallel and arranged in row with small intervals. Simultaneous blasting is carried out in an area that is sufficiently large to let the blocks move. The necessary creation of a «free surface» for the block exploitation, which in the past was performed by explosives, is nowadays more often performed using a diamond wire machine (Cardu et al., 2000; Lovera et al. 2001; Fornaro, 2001).

The green marble quarrying techniques, given the intrinsic heterogeneity of the deposits and the fragile nature of the materials that have to be extracted, require quarrying from the top (but also for site safety reasons) and systems for the detachment of the stone from above without the use of explosives. Open pit quarrying, mostly on the hill side and rarely from the top (given the greater visual impact on the countryside) is carried out in steps, at various levels with the use of diamond wire and chain saws. High benches are cut and then overturned onto the quarry yard.

Some quarries are exploited underground, carrying out a selective excavation and quarrying the best and soundest material. This option can be taken for both environmental and economic reasons, avoiding the removal of thick unexploitable overburdens. Quarrying is performed in voids and is carried out using tunnel chain cutters, which are indispensable for blind advancement. The subsequent production lowerings take place using mixed techniques: diamond wire-saws and chain cutters are used together to cut low benches. «Pillars» (junctions between tunnels) or «rib pillars» (placed between parallel tunnels close together) are usually left in place.

In a VCO quarry block handling is traditionally performed by a derrick, instead in an LSB quarry it is carried out by large front-end loaders, characterised by an eclectic application which requires service ramps for each exploited level. The use of diamond wire machines (with sintered tools) is at present very popular also in siliceous rock quarries and, most of the time, the producers design «made
to measure» diamond wires that are adapted for the different rock types, thus optimising the services and diminishing the costs.

«Small» quarry wastes are considered essential elements for quarry management: they are used, at the beginning of the quarry development, for the temporary ramps and, at the end of the exploitation, for the quarry rehabilitation.

A typical quarry management in the VCO basin involves 4 people (one of them is usually the owner); the exploitation is organized with a derrick, an excavator, 1-2 tractor loaders and 6-7 hard rock drillers. Wire saws are also used in most of the quarries. The total installed power in the whole basin is about 46’000 kW (85% diesel), with a fuel and electricity consumption of about 3·10^6 l/y and 4.5·10^6 kWh/y, respectively.

A typical quarry management in the LSB involves 2 people (one of them is usually the owner); the exploitation is organized with an excavator, a tractor loader and 2-3 hard rock drillers. The total installed power in the whole basin is about 23’000 kW (100% diesel), with a fuel consumption of about 10^6 l/y (Lovera et al., 2001; Radicci and Sandrone, 2001a).

In the VCO district there are also 155 manufacturing plants that essentially process the local rocks. A typical manufacturing plant includes an open air block storage with one or more gantry cranes, a shed where all the machines (e.g. gang saws, block and bridge saws, flaming machines, polishing lines) are located and a building for the offices.

The workers employed in the manufacturing plants can vary from 2 to 40: up to 8 employees for nearly 33% of the manufacturing plants and 15 or more for about another 33%. In the small manufacturing plants, the storage and the buildings cover less than 1000 m^2 and the energy consumption is nearly 100’000 kWh/y. In the large manufacturing plants, the storage areas cover more than 10’000 m^2 and 3’000 m^2 respectively, and the energy consumption is more than 400’000 kWh/y; there are also at least 4 overhead travelling cranes and a gang saw (Radicci and Sandrone, 2001b).

The total sludge production in the LSB amounts to 16’000 t/y (Dino et al., 2003).

The products that reach the stone market are mostly slabs (70%), kerbstones (20%), squared blocks and Belgian blocks. The regional market absorbs 56% of the production, 29% of the production is instead bound for the national market and 15% for the international market.

CONCLUSIONS

Quarrying activity for natural stones in Piedmont and the Aosta Valley, though concentrated in specific basins, also includes small local productions and it represents an important part both of the whole regional quarrying sector, and of the general economy of the mountain valleys, considering the connected processing and the generated activities.

Moreover, the artistic and architectural heritage, which has over the years used these
rocks, requires the conservation not only of the already existing monuments, but above all, of the culture of the stone, which is today made easier thanks to the modern technology that is available and to the experience of the workers which would otherwise be difficult to pass on.

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