The Dora-Maira Unit (Italian Cottian Alps): a reservoir of ornamental stones locally and worldwide employed since Roman age

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The Dora-Maira Unit (Italian Cottian Alps): a reservoir of ornamental stones since Roman times

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SUMMARY

The Dora-Maira is a geological unit cropping out in the inner part of the Cottian Alps and belonging to the Penninic Domain of the Western Alps (NW Italy). It consists of a Paleozoic basement and its Mesozoic carbonate cover, metamorphosed under eclogite facies conditions in the Cenozoic. Due to the complexity of the rock associations and the textural-metamorphic transformations, the Dora Maira Unit has been a source of ornamental stones over the centuries, and still it represents a reservoir of material locally employed for historical and contemporary buildings. Several varieties of ortho, quartzite and marble, derived from the Paleozoic basement and the Mesozoic cover are known by different local names (e.g. Luserna Stone, Borgone and Vaie Stone, Perosa Stone, Bargiolina Quartzite, Foresto and Chianocco marbles), and were largely employed, during 17th and 18th centuries, for some of the most famous and important monuments in Turin (capital of Piedmont region, NW Italy), as well as in the countryside, since Roman age. Some of the materials exploited in Dora-Maira Unit were also exported to foreign countries: Borgone and Vaie Stone were used for the paving of the Louvre Museum, and Perosa Stone was employed for the construction of the monument of Independence in Lagos, Nigeria. Consequently, the Dora-Maira Unit can be indicated as a Global Heritage Stone Province.

RÉSUMÉ

L'Unité Dora-Maira est une unité géologique affleurant dans la partie interne des Alpes Cottiennes; elle appartient au Domaine Penninique des Alpes occidentales (Italie du Nord-Ouest). Elle se compose d'une croûte continentale d'âge Paléozoïque supérieur et de sa couverture carbonatique Mésozoïque, métamorphosées en faciès éclogite pendant le Cénozoïque. En raison de la complexité des associations lithologiques et des transformations métamorphiques et structurelles, l'Unité Dora-Maira a été une source de pierres ornementales au cours des siècles, et encore il représente un réservoir de matériau employé localement pour des bâtiments contemporains et historiques. Plusieurs variétés de gneiss, de quartzite et de marbre, provenant du socle paléozoïque et de la couverture mésozoïque et connues sous différents noms locaux (par exemple Pierre de Luserna, Pierre de Borgone et Vaie, Pierre de Perosa, Bargiolina, marbres de Foresto et Chianocco), étaient largement utilisées pour certains monuments les plus célèbres et importants à Turin (capitale de la région Piémont), au cours des 17ème et 18ème siècles, et dans les alentours de la ville depuis l'époque romaine. Certains des matériaux exploités dans l'Unité Dora-Maira ont été également exportés aux pays étrangers: la Pierre de Borgone et Vaie a été utilisée pour le pavage du Musée du Louvre, et la Pierre de Perosa a été employé en Afrique, à Lagos, au Nigéria, pour la construction du monument de l'indépendance. Par conséquent, l'Unité Dora-Maira peut être indiquée comme une Pierre Province du patrimoine mondial.

INTRODUCTION

Stone resources have always been a major source of material in the construction industry and an important cultural element to create masterpieces of sculpture and architecture, that constitute a significant part of Cultural Heritage. Thus, knowledge of stone resources, their mineralogic–petrographic characteristics, and their use can provide a broad overview of the historical relevance of these materials, emphasizing the importance of a significant economic activity, that is fundamental to the understanding of the history and the traditions of different Mediterranean cultures (Cooper 2015; Marker 2015).

Every Italian region is represented by artistic creations and historic buildings often made of historic heritage stones. In particular, in the Piedmont region (NW Italy), stone has always been the most widely employed building material characterizing, for example, the architectural identity of the city of Turin (capital of Piedmont). Here, stones have been used in historical and contemporary buildings, monuments and urban art, showing the close link between an urban area and natural stone resources, and emphasizing the role that stone has played on the culture and economic wealth of Piedmont region (Borghi et al. 2015).

From the Roman age to the eighteenth century the easily workable materials (e.g. marbles and sedimentary rocks) were exploited and used for valuable infrastructures and sculptures. Lately, during the nineteenth century, thanks to the development of technologies for dimension stone exploitation and processing, granites and other silicate rocks have been progressively employed.

Therefore, the knowledge of stone resources (mineral-petrographic features, their use and exploitation techniques, etc.) enhances the historical and cultural significance of such materials. The great variety of ornamental and building stones used for architectural elements is certainly due to the complex geological nature of the region (Borghi et al. 2014). In Piedmont, indeed, many different geological units occur, in particular: the western portion of the metamorphic Alpine Chain, the sedimentary Tertiary Piedmont Basin, and a small sector of the Northern Apennines.

This paper illustrates the most important lithological varieties of cultural stones coming from the Dora-Maira Unit. This unit covers over 1000 km^2 in the inner part of the Western Alps (Fig. 1). A lithological and textural characterization and an overview of the main applications are provided for the selected rock type.

GEOLOGICAL SETTING

The Western Alps represent a collisional orogenic wedge where both continent- and ocean-derived tectonic units are currently exposed. It consists of three main structural domains: (1) the internal domain, belonging to the upper plate of the collisional system, which corresponds to the Southern Alps; (2) the external domain, representing the European foreland and consisting of the Helvetic-Dauphinois domain; and (3) the axial sector of the chain, included between the Penninic Front to the north, and the Insubric Line to the south (Fig. 1) (Dal Piaz et al. 2003). The axial portion represents a composite nappe pile consisting of the Austroalpine and Penninic domains separated by oceanic units of the Piemonte Zone.

The Dora-Maira Unit, together with the Monte Rosa and the Gran Paradiso Massifs, represents the basement nappe of the inner Penninic Domain (e.g. Schmid et al. 2004) and consists of various tectonic slices of pre-Triassic basement and metasedimentary successions of Permo-Mesozoic cover. This Unit underwent a strong Alpine tectono-metamorphic overprint characterized by high (HP) to ultra-high pressure (UHP) metamorphic assemblages and green-schist re-equilibration in Cenozoic time (e.g. Sandrone et al. 1993, Compagnoni et al. 2004). Due to the complexity of the rock associations and the textural-metamorphic transformations, the Dora-Maira Unit was, and still is, the object of extensive exploitation (Fig. 2; Table 1).

The pre-Triassic basement is represented by poly- and monometamorphic complexes both intruded by late-Variscan granitoids. The polymetamorphic complex (9 in legend of Figure 2), mainly consists of garnet-chloritoid micaschists, minor metabasites, impure dolomitic marbles, and orthogneisses with granodioritic composition of pre-Variscan age (457±2 Ma, Bussy and Cadoppi 1996). Pre-Alpine relics, attributed to Variscan metamorphism, are represented by garnet-muscovite-sillimanite and pseudomorphs after cordierite, spinel, andalusite and staurolite in the micaschists (e.g. Cadoppi 1990; Compagnoni et al. 1993), red biotite in the orthogneisses and diopside in the marbles (Cadoppi 1990). An important talc mineralization, presently exploited in the Germanasca Valley, is hosted in this complex. The polymetamorphic complex was metamorphosed under eclogite facies conditions at 15-20 kbar and 500-550 °C (Borghi et al. 1985, Pognante and Sandrone 1989; Cadoppi 1990; Chopin et al. 1991; Borghi et al. 1996; Gasco et al. 2011), though a diffuse re-equilibration to greenschist facies affects the Dora-Maira Unit as a whole. During the past and in the last decade, the only rock type exploited in this complex has been the dolomitic marbles cropping out in metre-sized lenses in the micaschists (quarry sites 10, 11, 12 and 14 in Figure 2).

In the southern Dora-Maira Unit, a coesite-bearing polymetamorphic complex (the so-called Brossasco-Isasca Complex—Kienast et al. 1991; 8 in legend of Figure 2) has been distinguished based on the peculiar metamorphic transformation (Chopin 1984; Chopin et al. 1991). This complex consists of orthogneisses and subordinate metapelites, silicate marbles and metabasites which underwent UHP metamorphism at 35 Ma (Gebauer et al. 1997, Compagnoni et al. 2004). In the Brossasco-Isasca Complex, the rock types exploited are Brossasco marble and a mylonitic orthogneiss called “Gilba stone” (quarry sites 16 and 17 in Figure 2).

As for the monometamorphic complexes, the “Pinerolo Graphitic Complex” is noteworthy (Vialon 1966; Borghi et al. 1984; Henry et al. 1993). It is exposed in the innermost sector of the Unit and represents the deepest structural tectonic element. It consists of metapelites that are sometimes graphite-rich, fine-grained gneisses and metaconglomerates, probably of Carboniferous age (6 in legend of Figure 2). Pressure-Temperature (PT) estimates for this complex are scarce but suggest a re-equilibration stage at 530-550 °C and 6.0-7.5 kbar in the metapelites (Avigad et al. 2003) with the development of blueschist facies assemblages (Borghi et al. 1985; Wheeler 1991). Another monometamorphic complex is present in the central-southern sector of the Unit (partly corresponding to the Dronero and Sampeyre complexes of Vialon 1966) and it is mainly represented by fine-grained micaschists and gneisses, chloritoid-rich micaschists, quartzites and rare basic rocks (4 and 5 in legend of Figure 2). Among these lithologies, a variety of quartzite in the Monte Bracco area (Barge and Sanfront municipalities) and known as *bargiolina*, is still exploited (quarry site 15 in Figure 2).

Various metaintrusive rock types with granitic to dioritic composition, mainly attributed to the late-Variscan magmatic event (Bussy and Cadoppi 1996), intruded both the polymetamorphic and monometamorphic complexes (7 in legend of Figure 2). Since these orthogneisses are the most widely exploited rock types in the past and at present (see quarry sites 2, 3, 4, 5, 6, 7, 8, 9, 13a,b,c, and 17 in Figure 2), their detailed description is presented.

On the top of the poly- and monometamorphic complexes, slices of the Permo-Mesozoic cover succession are preserved (3 in legend of Figure 2). These are characterized mainly by quartzite-siliciclastic levels in the lower part and carbonate sequences represented by dolomitic marbles and calcschists in the upper part (Cadoppi and Tallone 1992; Cadoppi et al. 2002). The dolomitic marble (Foresto and Chianocco marble) exposed in the Susa Valley (Dora-Riparia basin) is the exploited rock type (quarry site 1 in Figure 2).

Lastly, in the Mesozoic carbonate cover occurring in the southern part of the Dora-Maira Unit (quarry site 18 in Figure 2), the *Busca onix* is present. It represents a Quaternary speleothem of calcite composition (Marengo et al. 2014) which fills narrow fractures occurring in a dolomitic marble. This material was employed between sixteenth and seventeenth centuries exclusively as ornamental stone and is not described here.

STONE DESCRIPTION

The ornamental and building stones quarried in Dora-Maira Unit are grouped into two main categories: 1) silicates, which include all the orthogneisses and the quartzites; and 2) carbonates, which consist of all the marble varieties present in the region.

Silicate Stones

The most representative and most employed silicate stone in historical and current applications is the **Luserna Stone**, an orthogneiss deriving from leucogranites of Permian age. It crops out over a large area (approximately 50 km^2) in the Cottian Alps, on the border between Turin and Cuneo Provinces (13a,b,c in Figure 2). The *Luserna Stone* quarries are located in the Bagnolo Piemonte, Rorà and Luserna S. Giovanni municipalities, at altitudes that range between 900 and 1500 m a.s.l. (Fig. 3a). At present, the *Luserna Stone* is the most important dimension stone quarried from Dora-Maira Unit. Its overall production is nearly 330,000 t ($\cong$125,600 m^3) of "workable stone" and about 512,000 t ($\cong$194,000 m^3) of rip rap and armour stones (Sandrone et al. 2004). At the hand sample level, *Luserna Stone* shows a light-grey colour and a good fissility; it is easy to split along the schistosity planes defined by the iso-orientation of phyllosilicates (Fig. 3b). The phyllosilicates are mainly represented by white mica crystallized under high pressure conditions and, in smaller quantities, biotite and chlorite (Fig. 3c). Magmatic porphyroclasts, represented by K-feldspar, in addition to quartz and albite, partially recrystallized during the Alpine metamorphic event, give a micro-augen texture to the rock (Sandrone et al. 2000).

In the past the lower Susa Valley was characterised by the presence of numerous quarries, important for the exploitation of gneisses: the **Borgone** (Fig. 4a), **Vaie** and **Villar Focchiardo stones** (respectively quarry sites 3, 4, 5 in Figure 2) (Barisone et al. 1992). The discovery of prehistoric objects in the nearby of Vaie quarry site suggests that this material was employed during the Bronze Age; it was certainly used during the Roman age (Fiora and Gambelli 2003). At present only the **San Basilio Stone** quarry, located in Bussoleno (west of Chianocco and 50 km northwest of Turin), is active (quarry site 2 in Figure 2; Fig. 5a). This rock, corresponding to the historic *Villar Focchiardo Gneiss*, consists of a tourmaline-rich leucocratic orthogneiss, and is light grey in colour. It is characterized by a granitic composition and shows a foliation defined by the mica lamellae and the orientation of tourmaline blasts (Fig. 5b, c). Typical production is about 10,000 m^3/y (Sandrone et al. 2004). *Borgone* and *Vaie stones* are represented by a meta-granite marked by a porphyritic structure and a slightly foliated texture (Fig. 4b, c). K-feldspar porphyroclasts are embedded in a recrystallized matrix mainly formed by quartz and albite, in addition to white mica and minor biotite. Epidote and rare garnet, comprising the metamorphic products of magmatic plagioclase, are also present. Allanite, zircon, monazite and apatite occur as accessory minerals. The main difference between these two stone varieties is the presence of primary muscovite in the *Vaie stone* which is partially replaced by phengite (Cadoppi 1990).

Another important orthogneiss exploited in the Dora-Maira Unit is the **Cumiana Stone** (quarry site 6 in Figure 2). It consists of millimetre-sized K-feldspar porphyroclasts surrounded by foliated matrix of quartz, white mica, biotite, albite and epidote (Fig. 6a, b). This variety of rock is no longer quarried and can be observed only in historical monuments.

The so-called **Malanaggio Stone** is a quartz-diorite variety of metaintrusives, represented by an amphibolic - biotitic orthogneiss, intruded in the Pinerolo Graphitic Complex and dated to 288-290 Ma (Bussy and Cadoppi 1996). The quarrying activities began in the early nineteenth century, with the opening of five quarries located in Porte and Perosa Argentina area (Chisone Valley); after World War II, due to the low demand for stone materials and to the decrease availability of manpower, some of these quarries were closed (quarry site 9 in Figure 2). At present only the quarry of the so called **Perosa Stone** is active; it is located in the Brandoneugna village near Perosa Argentina (Chisone Valley) (quarry site 8 in Figure 2; Fig. 7a). The *Perosa Stone* is similar to the *Malanaggio Stone* and it can be distinguished mainly by the presence of white mica which defines the main schistosity (which is absent in the historic variety). The rock consists primarily of quartz, plagioclase, chlorite, biotite, hornblende, zoisite and clinozoisite; garnet, apatite and titanite occur as accessory minerals (Fig. 7b, c). The microstructure is weakly foliated; sometimes the original sites of magmatic amphibole and plagioclase (mainly oligoclase/andesine) can still be recognized.

Bargiolina quartzite is another important dimension stone quarried in the Dora-Maira Unit, and it is exploited in the western slope of the Monte Bracco (in the Barge and Sanfront municipalities east of Paesana village), in the lower Po Valley (quarry site 15 in Figure 2). Geologically it represents Permo-Triassic quartz arenites deposited during the post-Variscan marine transgression which were subjected to Alpine-aged metamorphism (Vialon 1966). It is a micaceous fine-grained quartzite which shows a tabular and homogeneous appearance (Fig. 8a). The *Bargiolina* – known and used since prehistoric times as substituting material for flint, and celebrated by Leonardo da Vinci (Fiora et al. 2002) – has been intensely exploited since the early twentieth century. There are different colour varieties of the *Bargiolina*: golden yellow, pale yellow, olive-grey, grey and white (*marmorina* variety). The quartzites, several metres thick, have been quarried by different companies as dimension stone both in Barge and Sanfront areas (Dino et al. 2001). At present, its market is much reduced by competition from Brazilian quartzite, and thus it is exploited now only in small quantities (5000 t of 'workable stone' in 2002) in a single quarry in Barge village (Province of Cuneo) (Sandrone et al. 2004). The *Bargiolina* shows a regular schistosity due to the presence of thin phengite layers, and thanks to this feature it is possible to split very thin slabs (1-2 cm) (Fig. 8b, c).

Carbonate Stones

The Alpine marbles (both white and coloured) were widely employed in Turin for indoor as well as outdoor prestigious applications, especially until the end of eighteenth century, when the carbonate stones, albeit easier to work, were gradually replaced by silicate rocks. Most of the marbles from Piedmont have been exploited in the Western Alps. They generally crop out as small lenses intercalated in schists and gneisses belonging to various geological units and characterized by different metamorphic conditions. Four historical marbles, named Foresto, Chianocco, Prali and Brossasco, can be recognized in the Dora-Maira Unit. The Prali and Brossasco marbles belong to the polymetamorphic basement, whereas the Foresto and Chianocco marbles come from the Permo-Mesozoic metasedimentary succession, only affected by Alpine metamorphism.

The most important white marbles are the Susa Valley ones (**Foresto and Chianocco marbles**), known and used since Roman times (quarry site 1 in Figure 2; Fig. 9a, b). They are dolomitic white marbles of Triassic-Early Jurassic age. The marble is finely crystalline with an oriented fabric, and appears whitish to ice-greyish in colour (Fig. 9c). It consists mostly of dolomite, even if calcite crystals occur. White phengitic mica and chlorite define the anisotropy of the rock (Fiora and Audagnotti 2001) (Fig. 9d).

The **Prali Marble** has been quarried in the Germanasca Valley (quarry sites 10, 11 and 12 in Figure 2) since the fourteenth century and was also known as Perrero or Faetto Marble (Peretti 1938). The Rocca Bianca quarry (quarry site 12 in Figure 2; Fig. 10a, b), whose exploitation began in 1584 and lasted until 1968, was the most important one in terms of quantity of exploited material. Since 1981, the marble has been occasionally extracted in Maiera quarry (western slope of the Rocca Bianca, quarry site 11 in Figure 2; Fig. 10c); its production has been several hundred cubic metres per year.

Prali Marble shows a banded structure characterised by whitish to greyish layers. Green veins formed by phyllosilicates can occur (Fig. 10d). It is a predominantly finely crystalline calcitic marble forming several transposed layers (up to a few metres thick) embedded within garnet- and chloritoid-bearing micaschist (Cadoppi et al. 2008). It is sometimes characterized by centimetre-thick tremolite-rich layers in dolomite-rich domains (Fig. 10e).

Lastly, the **Brossasco Marble,** cropping out in the middle Varaita Valley (quarry site 16 in Figure 2), was intensively exploited from about 1600 to 1700. It belongs to the Brossasco Isasca Complex, occurring in the southern portion of the Dora-Maira Unit. It is a coarse-crystalline isotropic marble mainly consisting of calcite with minor dolomite, which reflects high-grade metamorphic conditions (over 700 °C). The marble shows a massive, largely saccharoidal texture (Fig. 11a, b). Also present are garnet (reddish brown), omphacite (light-green), amphibole (dark-green), white mica and occasionally phlogopite (brown) associated with carbonate phases.

HISTORICAL EMPLOYMENTS

Due to the presence of different varieties of rocks, the Dora-Maira Unit can be considered as a reservoir of ornamental and building stones, employed locally since Roman times for military and religious buildings. Furthermore, these materials were used in Piedmont region for the construction of important historical palaces (especially in the seventeenth and eighteenth centuries).

Countryside

One of the more striking examples of Dora-Maira stone applications during the Roman age is the **Arch of Augustus at Susa**, built by King Cozio to celebrate the return of the Roman emperor from Gallia in 9 BC (Fig. 12a). It was built using *Foresto* and *Chianocco marbles*, directly exploited in the area near the Arch; indeed, looking through the Arch it is possible to see the remains of the original quarry. These materials were also employed for part of the **Roman aqueduct of Segusium** (present-day Susa).

During Medieval times, the most salient heritage building, partially constructed using Dora-Maira stones, was the **Sacra di San Michele**. It is standing on the peak of Mount Pirchiriano at 962 m a.s.l., near Sant'Ambrogio village, on the southern slope of the Susa Valley (Fig. 12b) and was one of the most important fortified monasteries in southern Europe. Construction of the *Sacra di San Michele* lasted several centuries and, at present, it stands out against the sky as a huge stone edifice. The first sanctuary probably dates before 1000 AD, and it was finally completed at the end of 1100 AD. In the eleventh century the monastery was enlarged with the construction of the large church, characterized by the *Scalone dei Morti* (Staircase of the Dead). Thanks to its strategic position it was an important presidium of the *Via Francigena*, one of the most ancient communication routes in Europe. Over the centuries, different variety of stones coming from the Dora-Maira Unit were exploited to build the *Sacra di San Michele*: *Borgone Stone*, used for the steps of the *Scalone dei Morti*; the *garnet-bearing micaschists* of the polymetamorphic basement are visible at the entrance gate of the Sacra; and the *Chianocco and Foresto marbles* are used for the construction of the Portal of the Zodiac, a striking expression of Romanesque art of the twelfth century (Fig. 12c). The *Luserna Stone* was used to build the access pathway to the monastery during the recent restoration for the XX Winter Olympic Games.

The Dora-Maira stones were also employed in the **Fenestrelle Fortress**, a group of military buildings and infrastructures, built between the eighteenth and nineteenth centuries in the Chisone Valley (80 km NE from Turin) (Fig. 12d). This fortified complex is spread out on the northern side of the middle Chisone Valley, over an area of 1.3 million m^2, between 1150 and 1750 m a.s.l. It consists of three core areas, built one beside the other in chronological order: *Forte Valli*, *Forte Tre Denti* and *Forte San Carlo*. The fortress is entirely made of stone, for the walls and for the blocks constituting the pillars, columns and portals. The *Scala Coperta* (Covered Staircase) is worthy of note: it is the longest stone staircase in Europe, consisting of 3996 steps. Linking 28 bastions, it looks like a great wall connecting the upper and lower part of the fortress; the first 1250 steps are made of *Malanaggio Stone* (Fig. 12e) (Fiora et al. 2006). This material was also employed for the plinths of the *Porta Reale,* which is the ancient entrance to the *Forte San Carlo*, reserved for the personages of the royal courts of Europe who visited the fortress. *Luserna Stone* and other gneisses extracted in the Chisone and Susa valleys, were employed for the roofs of the Governor’s Palace, the church of the *Forte San Carlo*, and the Officers’ Palace. Finally, the *garnet-bearing micaschist* of the polymetamorphic basement was employed in the highest portion of the fortress (*Forte Valli*) and in the last 1046 steps of the *Scala Coperta*.

Some of the historical stones quarried in Dora-Maira Unit were also used for the construction of the **Exilles Fortress,** located in the middle Susa Valley**,** and dating back to the early 1800s in its present form; the original one was built during the Medieval Age (Fig. 12f). This is a typical example of a building made of stone that crops out on site. The walls consist of blocks of strongly schistose, easily splittable, rock types. In particular, *Villar Focchiardo Stone* was employed for embrasures that overlook the French side, while *Borgone* and *Vaie stones* were used in the masonry and for the fountain of the main parade ground.

Historic Centre of Turin

Turin can be described as a ‘stone city,’ because most of the historical buildings, roads and squares are made of stones of local, national and international provenance. In particular, it is possible to appreciate the use of Dora-Maira stones in some interesting and historical buildings, such as the Gran Madre church, San Giovanni Cathedral, Palazzo Madama, the Royal Palace and Mole Antonelliana, along with infrastructure such as stone bridges. **San Giovanni Cathedral** (Turin cathedral) is the only Renaissance building still preserved in the city (Fig. 13a). Its façade is made of *Foresto and Chianocco marbles.* The marble blocks show a creamy white to light-grey colour and a metamorphic foliation defined by centimetre-thick layers of varying colour. These blocks, randomly placed on the façade of the Dome, produce a ‘checkerboard effect’ which was popular at the time. *Foresto and Chianocco marbles* were preferred to other contemporarily exploited materials because the blocks were easily transported from quarries to the cathedral yard by means of barges along Dora Riparia River. Stones from the Dora-Maira Unit were widely employed during the time of the Savoy kingdom. One of the most representative heritage buildings from this period is the **Royal Palace** where there is a great deal of *Malanaggio Stone* and *Prali marble* used for the inner court and gate pillars, respectively.

Chianocco and Foresto marbles have been also employed for columns of the façade of **Palazzo Madama** (1718-1721) (Fig. 13b), which hosted the Senate of the royal house during the Savoy period and where the Albertine Statute, progenitor of the Italian constitution, was approved. Here is possible also to appreciate several kinds of stones coming from Dora-Maira Unit, such as: *Prali marble,* used for capitals and bases of the columns of the façade, *Brossasco Marble,* for statues and vases that sit on the top of the façade, and *Vaie Stone* used for the basement.

Vaie Stone was also employed for construction of the columns of the eighteenth-century façade of **Santa Cristina church** (Piazza San Carlo; Fig. 13c), designed by Filippo Juvarra (one of the main architects at the Savoy court). Also used for the capitals and portal of the façade were *Perosa Stone* and *Chianocco and Foresto marbles*.

Dora-Maira stones were also employed in other two important churches in Turin: **San Filippo Neri Church** (1650-1891) and **Gran Madre Church** (early nineteenth century), both characterized by the typical neo-classical elements such as the *pronao* (colonnade entrance). In particular, in the **San Filippo Neri Church,** the largest religious building in Turin (Fig. 13d), the atrium is made of *Bargiolina quartzite* and the eight grooved columns consist of *Brossasco white marble*. *Malanaggio stone* and *Prali marble* are present in the **Gran Madre Church (**Fig. 13e), the former for the columns and the latter for the sculptures and statues at the entrance of the church.

Latterly, *Luserna Stone* was also employed in the **Mole Antonelliana** (1863-1904), particularly in the slabs covering the dome (Fig. 13f). This was the tallest masonry building in the world when it was inaugurated in 1889.

Other important civil infrastructures were made of Dora-Maira stones: e.g. the **stone bridges** over the Po River in Turin, six in number, three of which are entirely made of stone: King

Vittorio Emanuele I Bridge (1803-1813), Princess Isabella Bridge (1876-1880) and King Umberto I Bridge (1903-1907) (Fig.14). **King Vittorio Emanuele I Bridge** is the tangible sign of the acme of Napoleonic power; it stands as a prototype for the resurgence of stone building in Piedmont. For its historical role and for the high quality of its architecture, it represents the first modern stone bridge built in Italy after the Renaissance. The exclusive use of the *Cumiana Stone* for the construction of the bridge is documented at Turin State Archives: *Cumiana Stone* was preferred to the other because of its characteristics and the short distance between the quarry and bridge yard. *Cumiana Stone* was also employed in the slabs of the sidewalk (now replaced), and in the wedges of the archways. The original railings were made of *Malanaggio Stone*, but in 1876 they were removed and replaced by cast iron railings.

Princess Isabella Bridge was built between 1876 and 1880; it has 24 metres of span and five semi-elliptical arches entirely made of brick and resting on tall pillars of *Villar Focchiardo Stone*. The paving consists of slabs of *Luserna Stone* confined by curbs of *Villar Focchiardo Stone*.

The newer **King Umberto I Bridge** (1903-1907) is also made of bricks. It has three semi-elliptical arches on pillars each characterized by semi-circular rostrum. Several kinds of Dora-Maira stones, including *Malanaggio*, *Villar Focchiardo* and *Vaie* stones, were employed. The coating of the pillars is made of *Villar Focchiardo Stone*, while the part of the structure in plain sight, including the arches, is coated by the *Malanaggio Stone*, worked with various techniques (Fig. 14).

At present Dora-Maira stones are used in two important components of Turin's infrastructure: the **Automobile Museum** and the **Metro stations**. Both *Luserna Stone* and *Perosa Stone* have been used for the recently restored outer coating of the Automobile Museum.

The international application of Dora-Maira stones is noteworthy. For example, *Borgone* and *Vaie stones* have been used for the paving of the **Louvre Museum** and *Perosa Stone* was also employed in **Lagos** for the **monument of Independence**.

CONCLUSIONS

Ornamental and dimension stones extracted from the Dora-Maira Unit have been used from Roman times to contemporary period for important buildings. In the sixteenth and seventeenth centuries, with the establishment of the kingdom of Savoy, stone was widely employed in Turin, the capital. From the second half of the nineteenth century to contemporary times, these ornamental stones continued to be employed in public buildings, including the Mole Antonelliana which is the major landmark building in Turin, and other important infrastructural elements such as the stone bridges over the Po River. Some of these stones are still quarried and exported to foreign countries, such as the Luserna Stone, San Basilio Stone, Perosa Stone and the Bargiolina Quartzite.

The Dora-Maira Unit is almost unique for the number and variety of ornamental and building stones exploited over the centuries in a relatively small area. For this reason, the Unit can be considered as a Global Heritage Stone Province. Moreover, active and historical quarries which occur in this geological unit are interesting sites in terms of geo-tourism. The quarries can also be used to stage cultural events such as concerts and plays. In turn, this can introduce the general public to quarries as a vital industrial activity in contrast to the negative way in which they are often portrayed (Dino and Cavallo 2015). For example, cultural events in locales of past mining activity, such as those hosted in abandoned galleries of the talc mine in Germanasca Valley (*Scopri Miniera* and *Scopri Alpi*, www.scopriminiera.it), could be extended to other quarries in the Dora-Maira region (e.g. Luserna Stone quarries).

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CAPTIONS

Figure 1. Geological map of the Western Alps (modified after Fusetti et al. 2012). The red rectangle points out the area represented in Figure 2.

Figure 2. Geological map and quarry location of the most representative ornamental and building stones exploited in the Dora-Maira Unit. Legend of the geological map: **1**) undifferentiated Quaternary deposits; **2**) Piemonte ophiolite nappe (undifferentiated) and minor slices within the Dora-Maira Unit; DORA-MAIRA UNIT **3**) Mesozoic cover (marbles, metadolomites and calcschists); **4**) impure quartzite ("Bargiolina"); phengite-quartzite grading into quartz-micaschists and phengite-schists (Permian?); **5**) fine-grained gneisses and micaschists, including thin lenses of quartzites and rare bodies of blue-schist facies metabasites (Permian?); **6**) graphite-bearing micaschists, meta-arenites, meta-conglomerates ("Pinerolese Graphitic Complex", Carboniferous?); **7**) metaintrusives of different age and composition; **8**) orthogneisses and metagranitoids, coarse-grained garnet micaschists, pyrope-coesitequartzites, silicate marbles and metabasites with ultra-high Pressure re-equilibration (Brossasco-Isasca Complex); **9**) polymetamorphic garnet-chloritoid micaschists, impure marbles, eclogite-facies metabasites (mostly re-equilibrated into greenschists facies) with relics of pre-Alpine high temperature assemblages (pre-Carboniferous?); **10**) historical quarries; **11**) quarries still active in the last decade. The description of each quarry site is in Table 1. Geological map after Vialon (1966), Sandrone et al. (1993), Balestro et al. (1995), Bussy and Cadoppi (1996), Carraro et al. (2002) and Compagnoni et al. (2012)

Figure 3. Luserna Stone: **a**) Quarry site in the Pellice Valley, Rorà municipality (site 13a in Fig. 2); **b**) macroscopic aspect of the rock, characterized by a natural split surface defined by white mica, chlorite and biotite; **c**) microscopic aspect (crossed polarized light), marked by the presence of magmatic K-feldspar porphyroclasts, enveloped by Alpine tectonic foliation.

Figure 4. Borgone Stone: **a**) ancient quarry sites along the northern slope of the lower Susa valley (site 4 in Fig. 2); **b**) macroscopic aspect of the rock, characterized by large K-feldspar porphyroclast of magmatic origin: **c**) microscopic aspect (crossed-polarized light), marked by the occurrence of microcline porphyroclasts.

Figure 5. San Basilio Stone: **a**) active quarry located along the southern slope of the lower Susa Valley (site 2 in Fig. 2); **b**) macroscopic aspect of the rock, characterized by a mineralogical lineation defined by tourmaline. **c**) microscopic aspect (plane-polarized light), marked by the presence of pleochroic tourmaline crystal.

Figure 6. Cumiana Stone: **a**) macroscopic aspect of the rock, characterized by alteration of feldspars; **b**) microscopic aspect (plane-polarized light), marked by the occurrence of biotite flakes.

Figure 7. Perosa Stone: **a**) active quarry located along the eastern slope of the Chisone Valley (site 8 in Fig. 2); **b**) macroscopic aspect of the rock, characterized by tectonic foliation underlined by melanocratic inclusions; **c**) microscopic aspect (plane-polarized light), marked by the association of plagioclase, amphibole, epidote, chlorite and biotite.

Figure 8. Bargiolina quartzite: **a**) quarry site located on the Mount Bracco (site 15 in Fig. 2); **b**) macroscopic aspect of the rock, characterized by a natural split surface defined by thin mica layers; **c**) microscopic aspect (crossed-polarized light), marked by a strong dimensional preferential orientation of quartz crystals.

Figure 9. Foresto marble: **a**) the northern slope of the lower Susa Valley, where the historic quarry of the marble (**b**) is located (site 1 in Fig. 2); **c**) macroscopic aspect of the rock, characterized by a natural split surface defined by white mica; **d**) microscopic aspect (crossed-polarized light), marked by granoblastic texture and oriented lamellae of white mica.

Figure 10. **a**) The eastern slope of the Rocca Bianca Mount (Germanasca Valley) where the traces of the historic quarry of the Praly marble are still visible (quarry site 12 in Fig. 2); **b**)

graffiti dating back to the end of 1500 carved on a quarry face; **c**) Maiera Quarry, located along the western slope of the Rocca Bianca Mount (quarry site 11 in fig. 2), where the marble was exploited up to 2005; **d**) macroscopic aspect of the marble, characterized by regular intercalation of carbonate (light) and phyllosilicate levels; **e**) microscopic aspect (crossed-polarized light), marked by oriented crystals of tremolite and white mica, which define the anisotropy of the rock. Photo credits a) and b): Alessandro Ghelli and Cadoppi et al. 2008.

Figure 11. Brossasco marble: **a**) macroscopic aspect of the rock in a architectonical element of the San Filippo Neri Church; **b**) microscopic aspect (crossed-polarized light), characterized by the coarse and heterogeneous grain-size of the carbonate and the occurrence of phlogopite lamellae.

Figure 12. Main examples of employment of Dora-Maira dimension stones in historic buildings: **a**) Arc of Augustus at Susa (Roman Age, 9 BC); **b**) Sacra di San Michele Abbey located at the mouth of the Susa Valley; **c**) "Portale dello Zodiaco", one of the great expressions of Romanesque art of the twelfth century; **d**) external features of the Scala Coperta of the Fenestrelle Fortress along the northern slope of the Chisone Valley; **e**) steps and internal appearance of the Scala Coperta; **f**) Exilles Fortress located along the Susa Valley.

Figure 13. Representative examples of historic buildings in Turin, mainly made of Dora-Maira dimension stones: **a**) façade of San Giovanni Battista Church, made of Chianocco and Foresto marbles; **b**) façade of Palazzo Madama, seat of the Savoy Senate, made with Chianocco and Foresto marble and the Vaie Stone; **c**) façade of Santa Cristina Church, with the columns made of Vaie Stone; **d**) San Filippo Neri Church, with the colonnade built of Brossasco Marble; **e**) colonnade of the Gran Madre Church made of Malanaggio Stone; **f**) Mole Antonelliana, symbol of the city of Turin, built in the late nineteenth century with material from the Alpine valleys. The dome is covered by the Luserna Stone slabs.

Figure 14. Satellite map of Turin (from Google Earth®, 22/03/2015) with location of the Po River bridges built with Dora-Maira stones.

Table 1. Location and description of the main lithologies exploited in the Dora-Maira Unit.

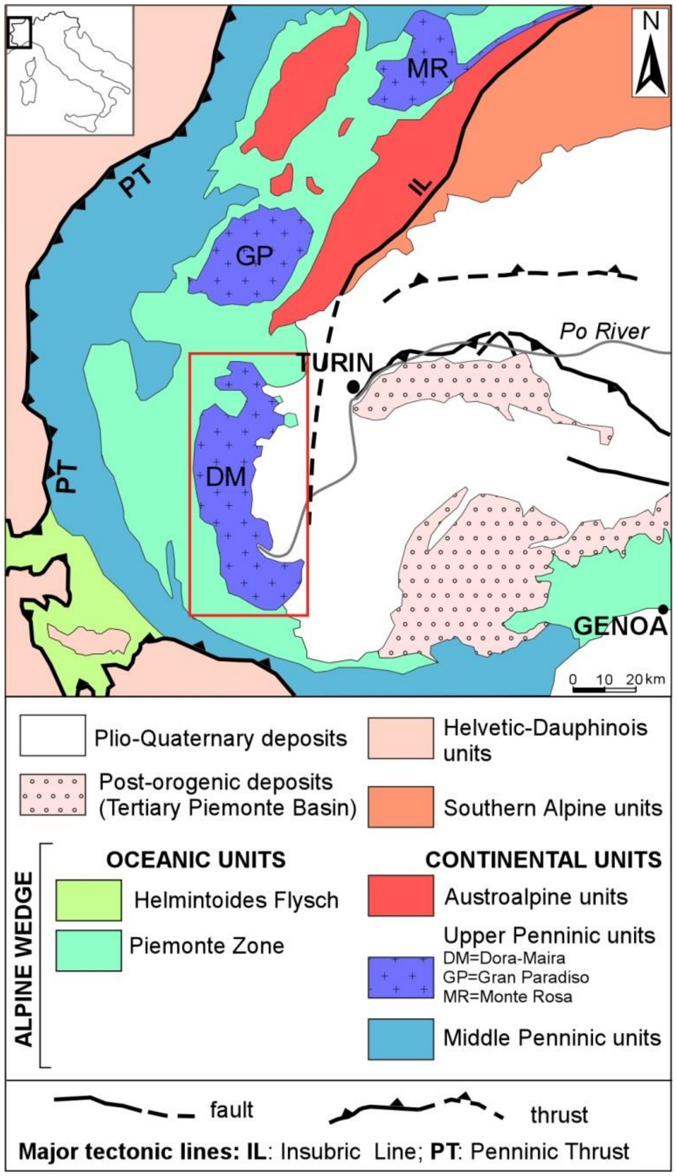
N
MR
PT
IL
GP
Po River
TURIN
DM
PT
GENOA
0 10 20 km
Plio-Quaternary deposits
Helvetic-Dauphinois units
Post-orogenic deposits (Tertiary Piemonte Basin)
Southern Alpine units
ALPINE WEDGE
OCEANIC UNITS
CONTINENTAL UNITS
Helmintoides Flysch
Austroalpine units
Piemonte Zone
Upper Penninic units
DM=Dora-Maira
GP=Gran Paradiso
MR=Monte Rosa
Middle Penninic units
fault
thrust
Major tectonic lines: IL: Insubric Line; PT: Penninic Thrust

Fig. 1

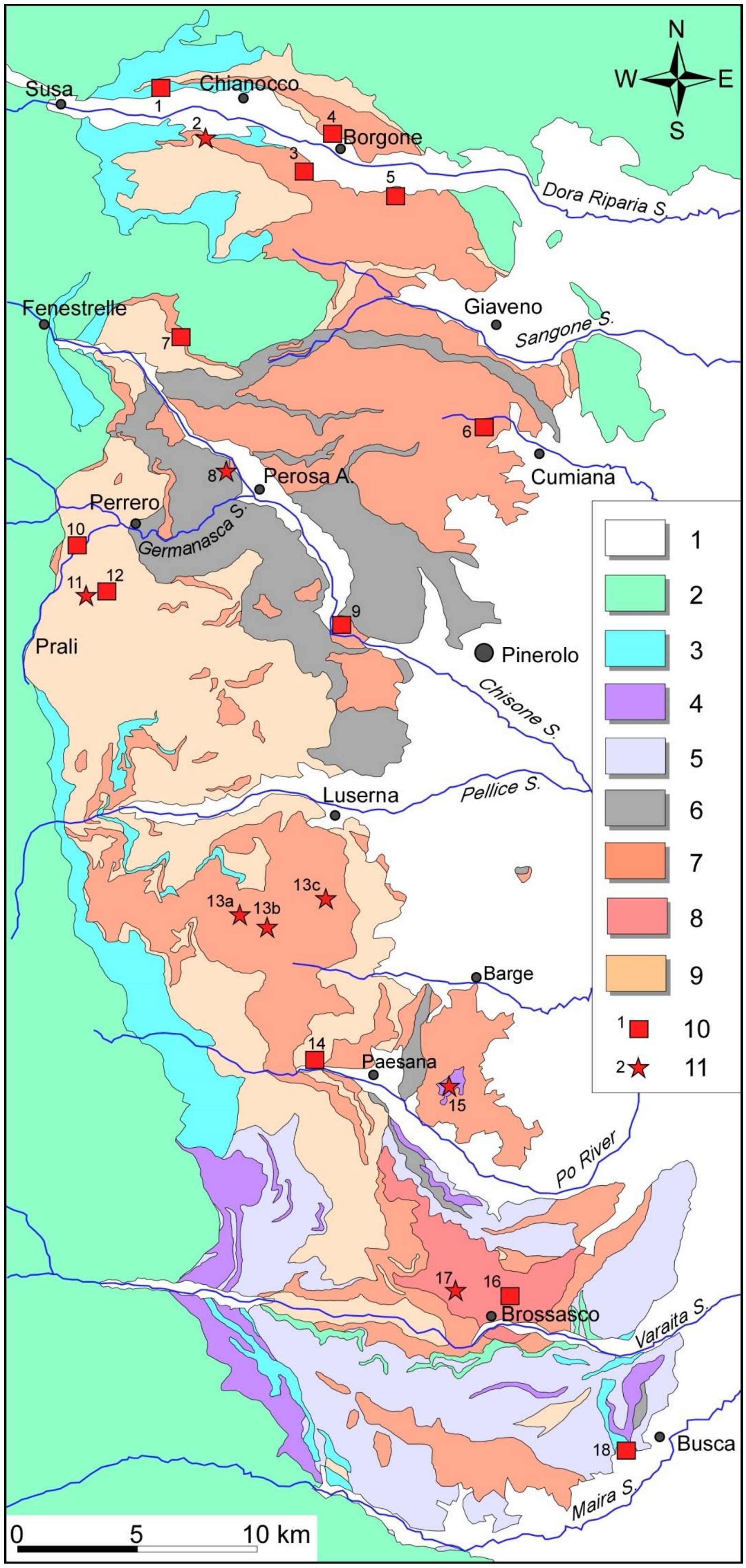
N
W
E
S
Susa
Chianocco
Borgone
Dora Riparia S.
Giaveno
Sangone S.
Fenestrelle
Cumiana
Perosa A.
Perrero
Germanasca S.
Prali
Pinerolo
Chisone S.
Luserna
Pellice S.
13a
13b
13c
Barge
Paesana
Po River
Brossasco
Varaita S.
Busca
Maira S.
1
2
3
4
5
6
7
8
9
10
11
12
14
15
16
17
18
0
5
10 km

Fig. 2

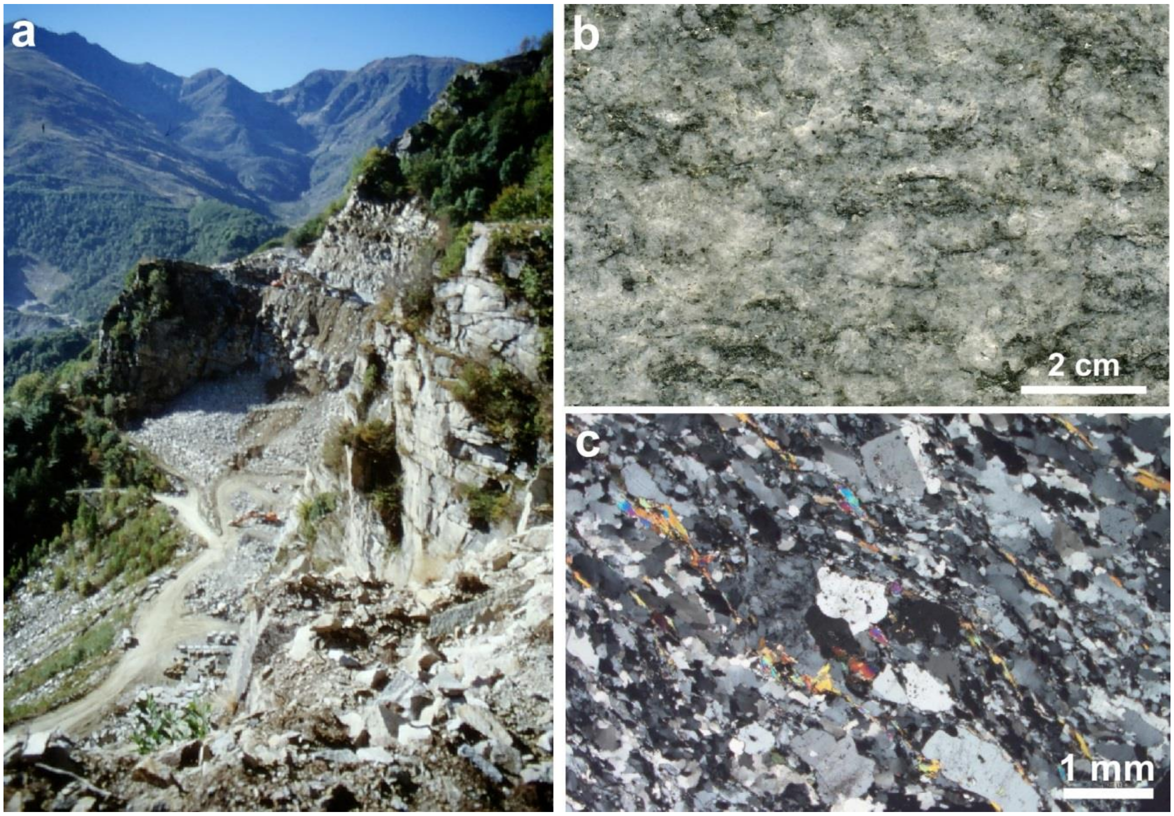

Fig.3

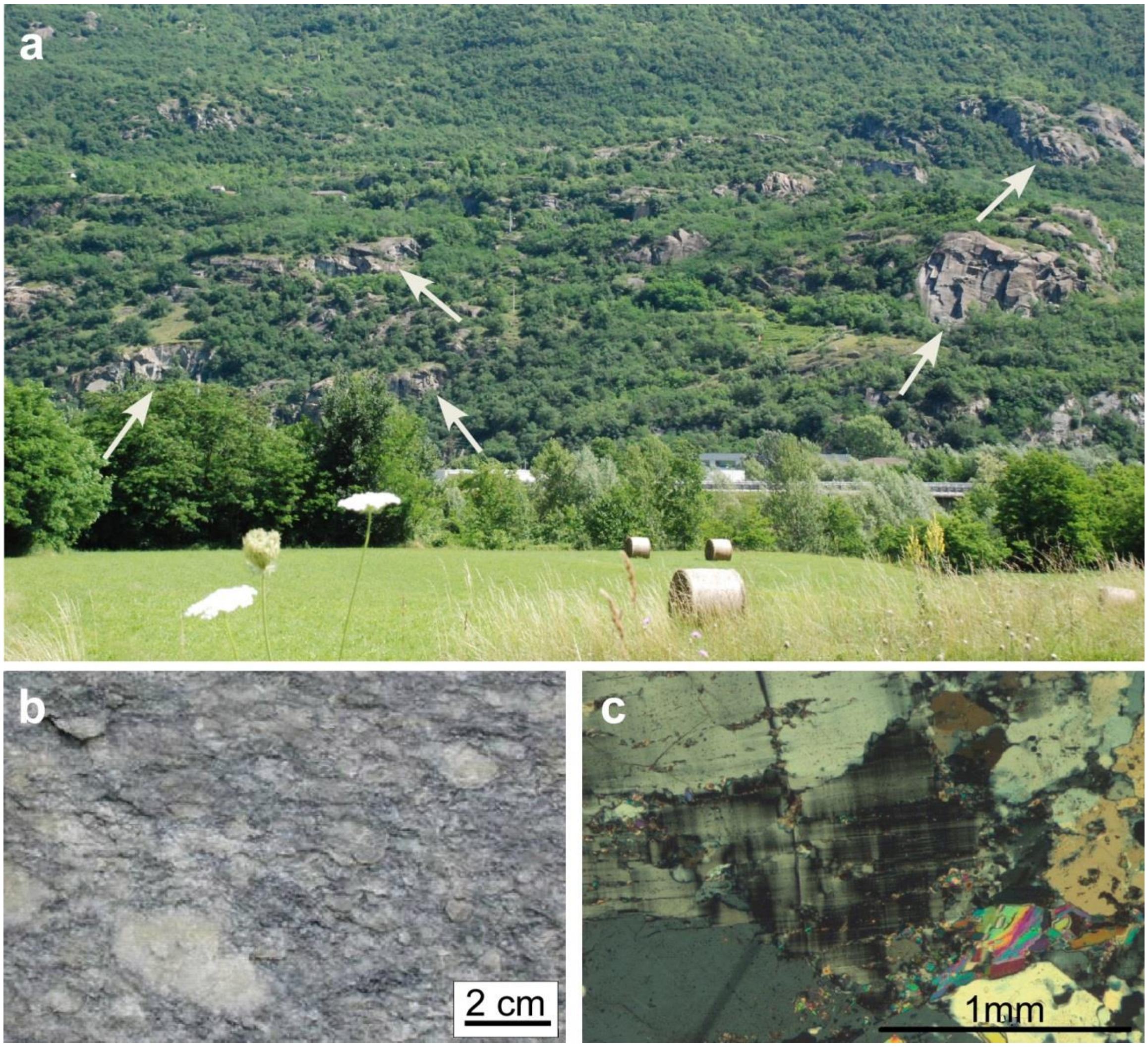

Fig. 4

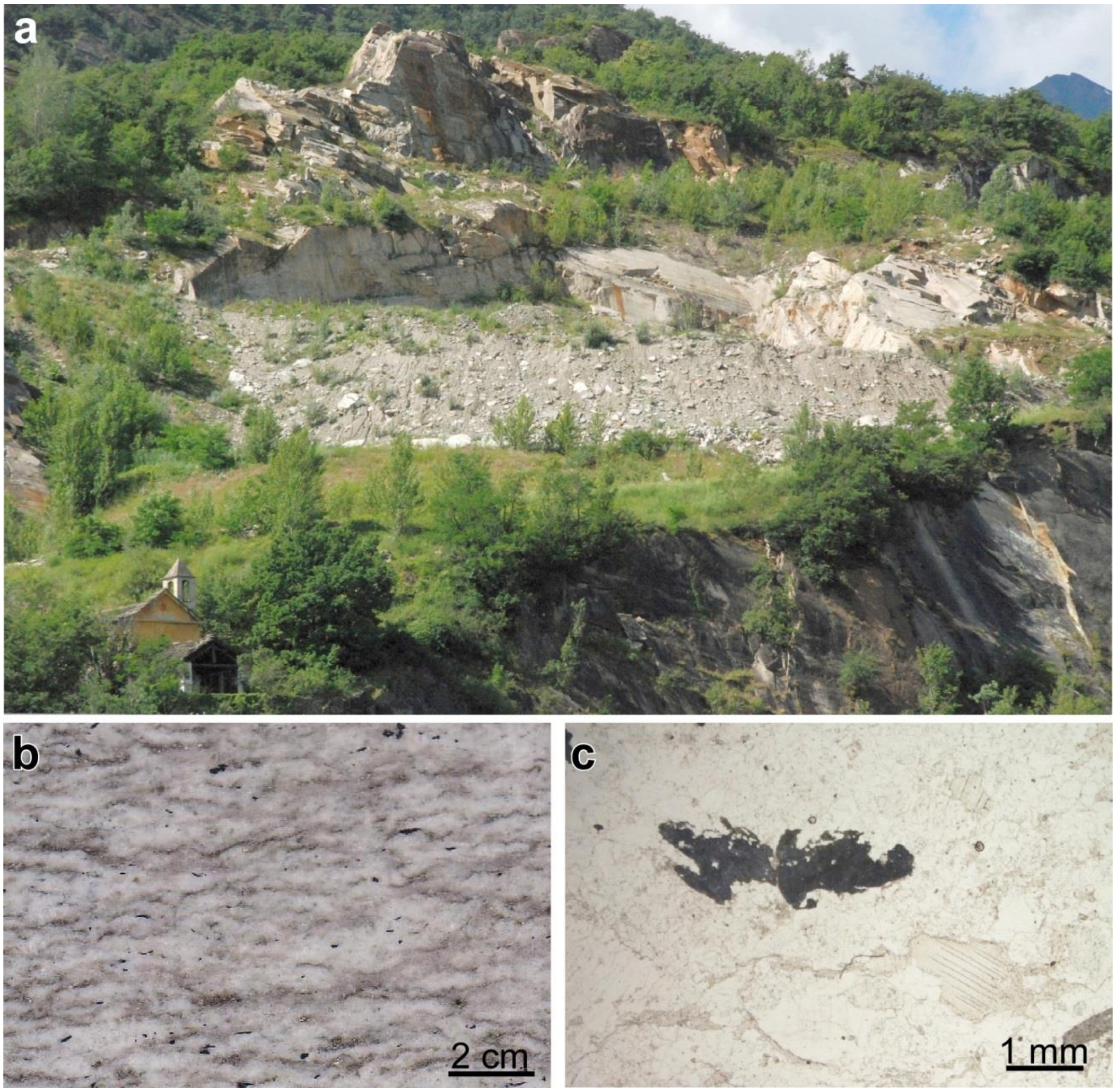

Fig. 5

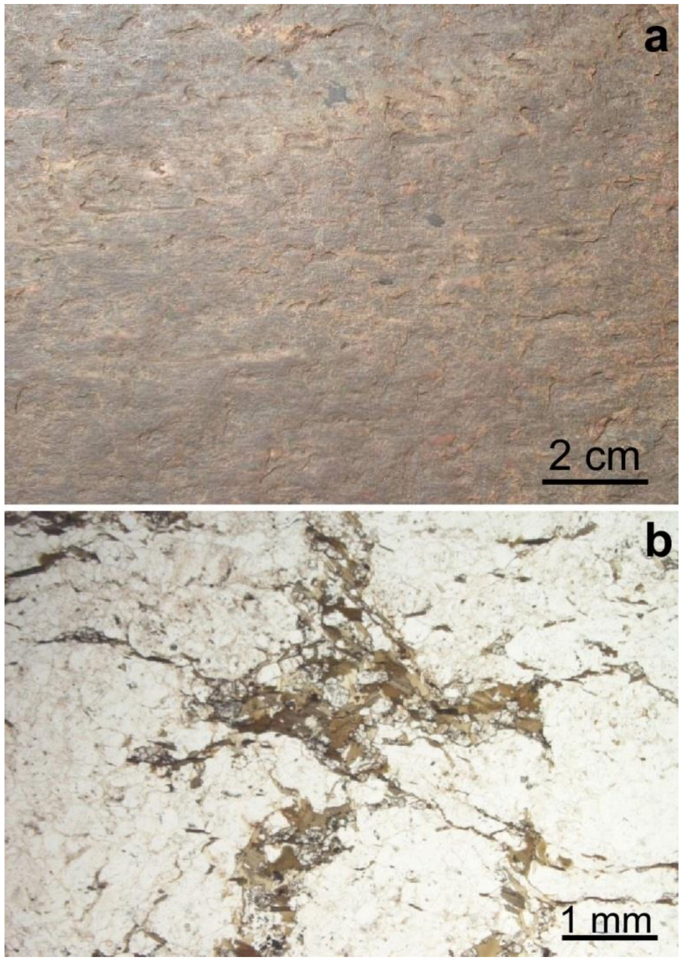

Fig. 6

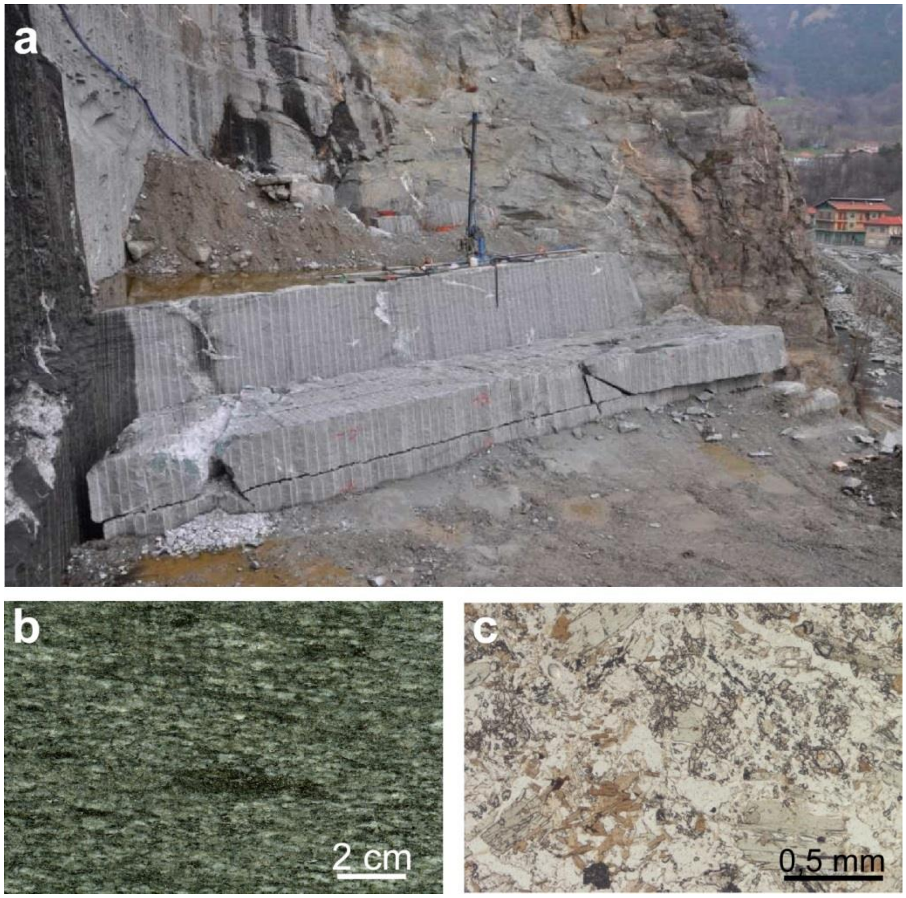

Fig. 7

Fig. 8

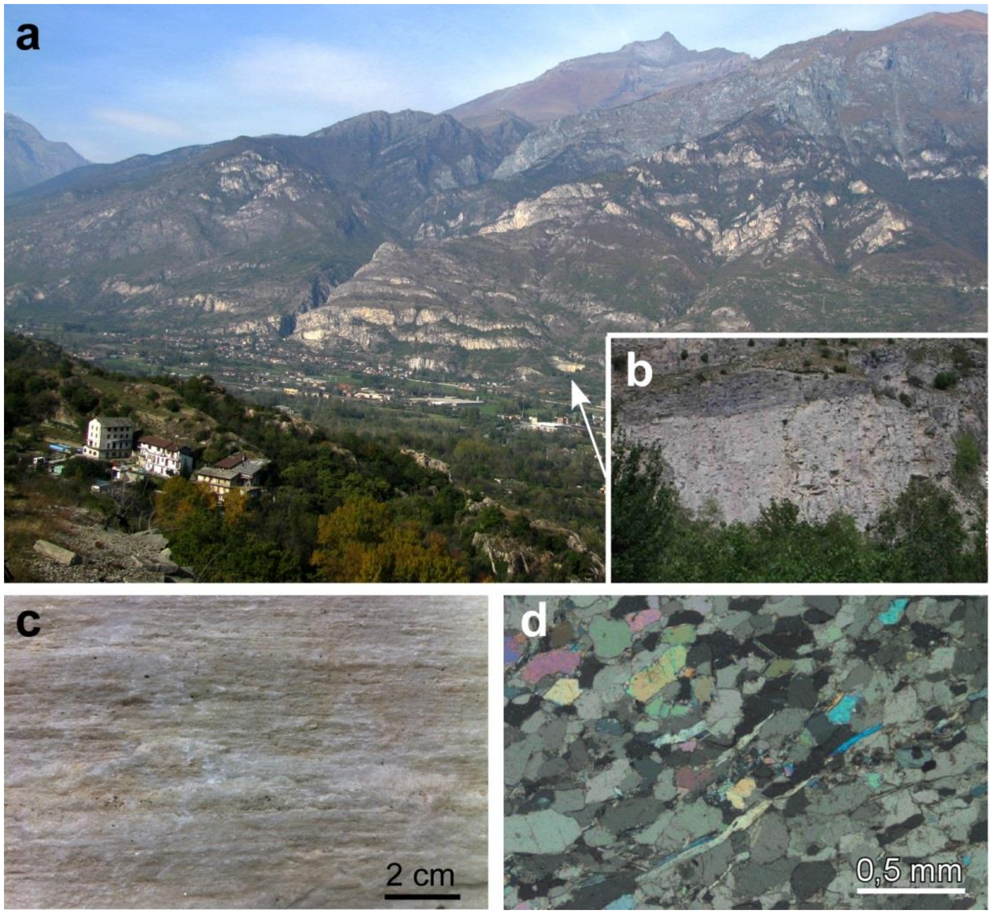

Fig. 9

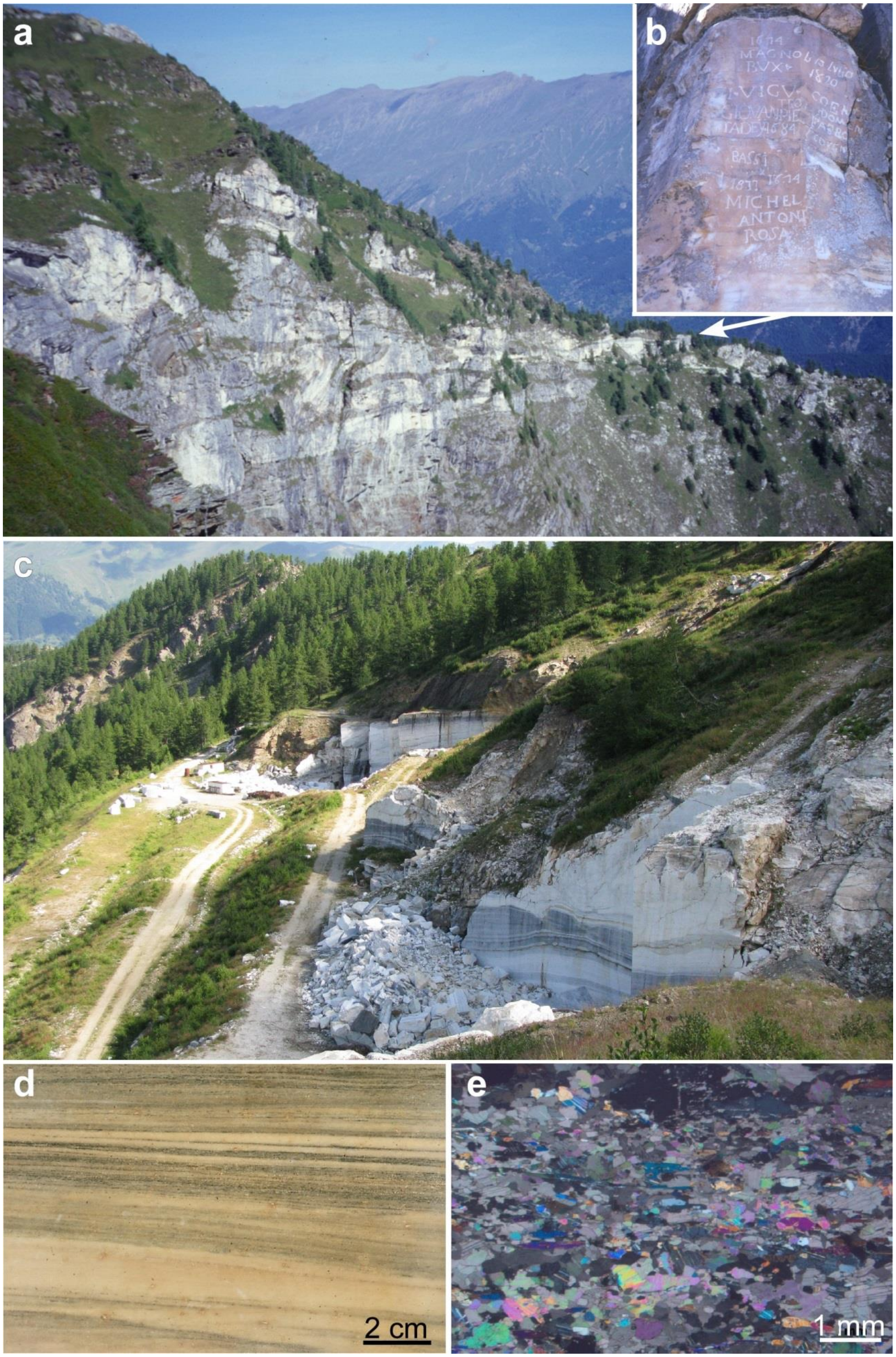

Fig. 10

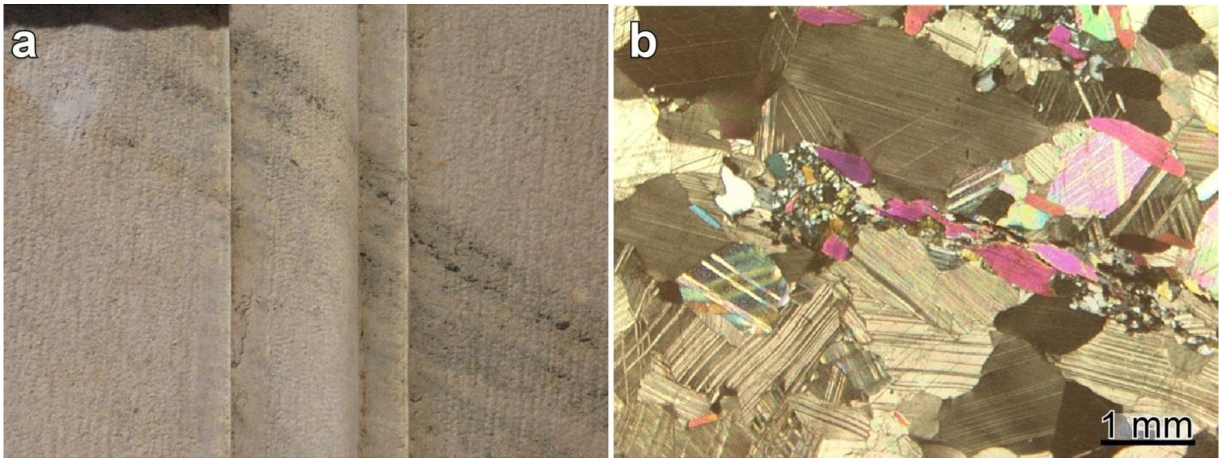

Fig. 11

Fig. 12

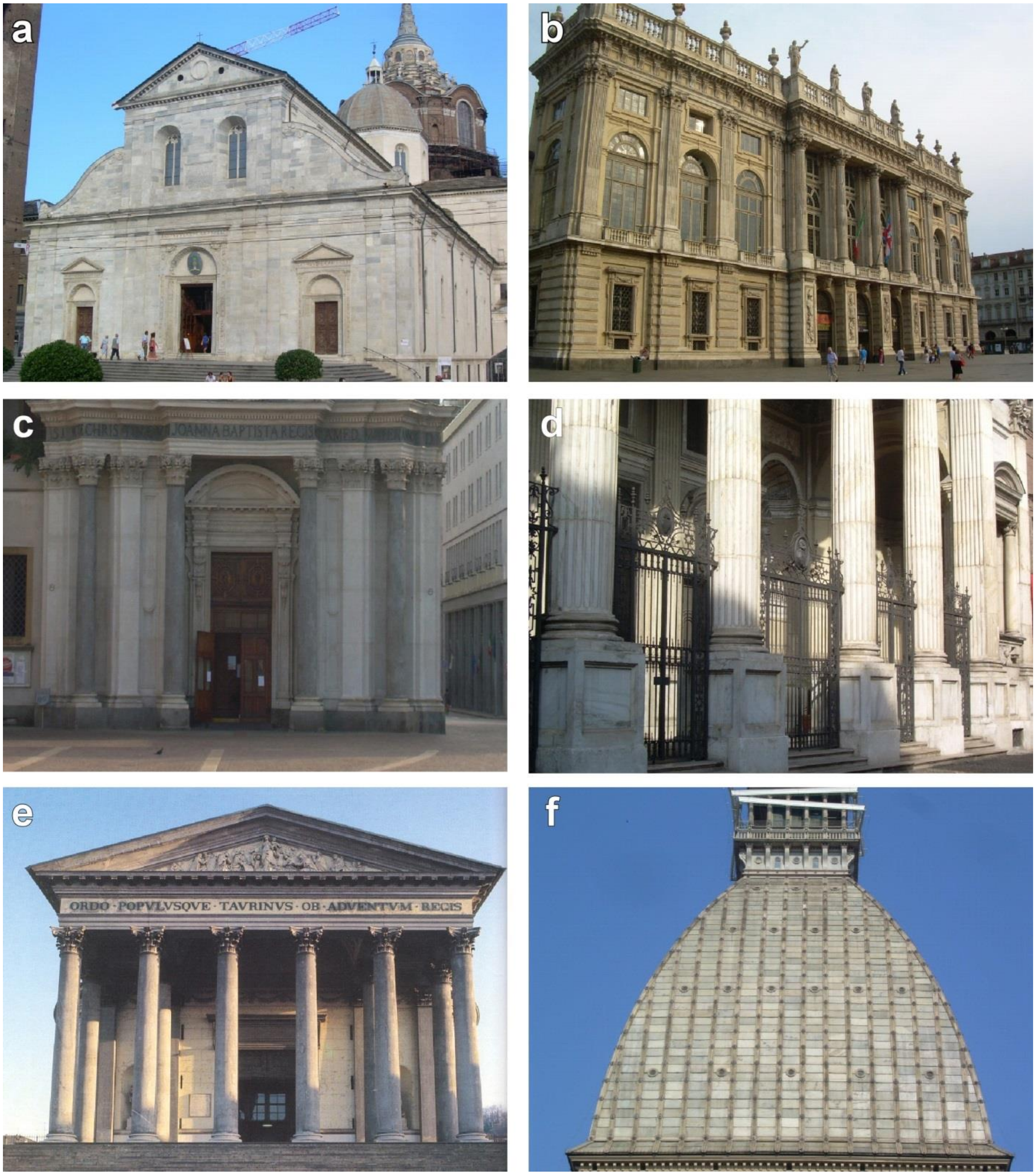
a
b
c
JOANNA BAPTISTA REGIS
d
e
ORDO · POPVLVSQVE · TAVRINVS · OB · ADVENTVM · REGIS
f

Fig. 13

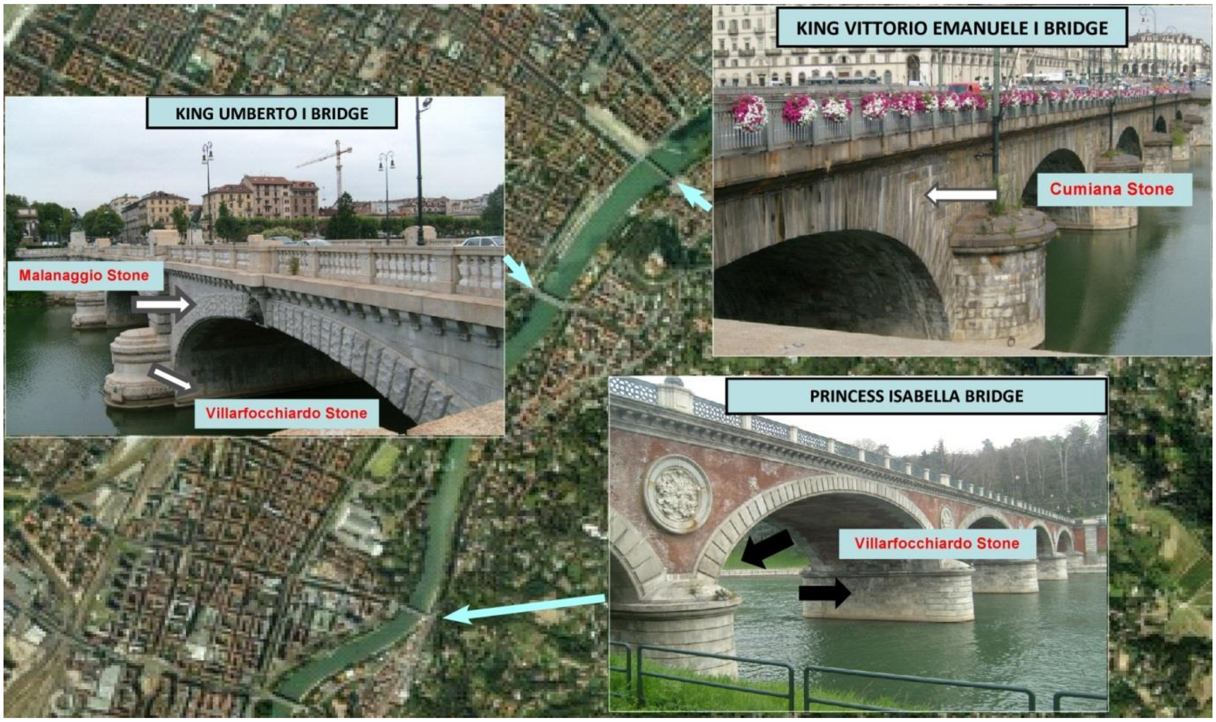
KING VITTORIO EMANUELE I BRIDGE
KING UMBERTO I BRIDGE
Cumiana Stone
Malanaggio Stone
Villarfocchiardo Stone
PRINCESS ISABELLA BRIDGE
Villarfocchiardo Stone

Fig. 14

Quarry site in fig. 2	*Name*	*Lithology*	*Paragenesis*	*Fabric*	*Age*
1	Foresto and Chianocco marble	Dolomitic marble	Dol - Cal - Wmca	Foliated	Triassic
2	S. Basilio Stone	Leucocratic orthogneiss	Qtz – Ab – Kfs – Wmca – Tur	Gneissic layering	Late Variscan
3	Villar Focchiardo Stone				
4	Borgone Stone	Metagranite-augengneiss	Qtz – Ab – Kfs – Wmca – Bt	Gneissic layering to poorly foliated	Late Variscan
5	Vaie Stone				
6	Cumiana Stone	Orthogneiss	Qtz – Ab – Kfs – Wmca – Bt – Ep	Gneissic layering	Late Variscan
7	Luserna type Stone	Orthogneiss	Qtz – Ab – Kfs – Wmca ± Bt ± Chl	Tabular foliation	Late Variscan
8	Perosa Stone	Dioritic- to granodioritic gneiss	Pl – Am – Ep – Chl – Bt – Wmca ± Qtz ± Kfs	Gneissic layering	Late Variscan
9	Malanaggio Stone				
10	Salza di Pinerolo marble	Impure to layered marble	Dol – Cal – Tr ± Chl ± Ep ± Wmca	Foliated	Paleozoic
11	Prali marble				
12	Prali marble				
13a	Luserna Stone Basin (Luserna S. Giovanni, Rorà and Bagnolo municipalities)	Orthogneiss	Qtz – Ab – Kfs – Wmca ± Bt ± Chl	Tabular foliation	Late Variscan
13b					
13c					
14	Paesana marble	Impure to layered marble	Dol – Cal – Wmca – Tr	Poorly foliated	Paleozoic
15	Bargiolina	Quarzite	Qtz – Wmca – Ab	Tabular foliation	Permo Triassic
16	Brossasco marble	Silicate marble	Cal ± Dol ± Cpx ± Ph ± Ep ± Grt ± Phl	Isotropic to poorly foliated	Paleozoic
17	Gilba Stone	Orthogneiss	Pl + Qtz + Kfs + Ph ± Bt	Strongly foliated	Late Variscan(?)
18	Busca Alabaster	speleothem	Cal	Columnar and fibrous	Quaternary

Ab=albite Am=amphibole Bt=biotite Cal=calcite Chl=chlorite Cpx=clinopyroxene Dol=dolomite Ep=epidote Grt=garnet Kfs=K-feldspar Ph=phengite Phl=phlogopite Pl=plagioclase Qtz=quartz Tur=tourmaline Tr=tremolite Wmca=white mica