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Fragments of the Western Alpine chain as historic ornamental stones in Turin (Italy): enhancement of urban geological heritage through Geotourism

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Abstract

In Piemonte, stone has always been the most widely used raw material for buildings, characterizing the architectural identity of the city of Turin. All kinds of rocks, metamorphic, igneous and sedimentary, are represented, including gneisses, marbles, granitoids and less commonly limestones. The great variety of ornamental stones is clearly due to the highly composite geological nature of the Piemonte region and related to the presence of the orogenic Alpine chain and the sedimentary Tertiary Piemonte Basin.

This paper provides a representative list of the most historic ornamental stones of Piemonte, which have been used over the centuries in buildings and architecture. The main stones occurring in Turin have been identified and described from a petrographic and mineralogical point of view in order to find out the corresponding geological units and quarry sites, from which they were exploited. This allows the associated cultural and scientific interest of stones to be emphasized in the architecture of a town which lies between a mountain chain and a hilly region.

Keywords: historic natural stones, cultural heritage, urban geology, Geotourism, Western Alps, Piemonte (NW Italy).

Introduction

Stone resources have always been a major source of material in the construction industry and, in particular, an important cultural element because they are employed as raw materials to create the masterpieces of sculpture and architecture that are now part of the cultural heritage of humanity. Therefore, knowledge of stone resources, their mineralogic-petrographic characteristics, their use and cultivation techniques from ancient times to the present, can provide a broad overview of the historical and cultural relevance of these materials, emphasizing the importance of a significant economic activity for the history and traditions of the different cultures that have developed over the centuries in the Mediterranean area (Fiora et al. 2002a).

In particular, in every Italian region a significant historic stone heritage occurs, which can be found in the artistic creations of value and in the historical buildings. It is represented by a wide variety of rocks, often of local extraction, representing a historical and cultural wealth worthy of scientific study and dissemination not only among experts, but also aimed at a wider audience. In this regard, the multidisciplinary research project "PROGEO- Piemonte" (Giardino 2012), has set up to achieve a new conceptual and operational discipline in the management of the geological heritage of the Piemonte Region (NW Italy) by means of the development of scientific techniques for recognizing and managing its rich geodiversity at the local and regional scale. In this framework the knowledge and enhancement of historic ornamental stones from Turin, ancient capital of the Kingdom of Savoy and current chief town of Piemonte, can perform a new geotouristic approach for the development of urban geological heritage.

Stones in Piemonte have always been widely used as construction materials: walls, floorings, cladding, roof tiles and roofing elements, as well as various architectural and statuary elements are often made using rocks outcropping in the different geological units of the Western Alpine Chain. The façades and other architectural elements of historical buildings in Turin, therefore, represent a petrographic collection in the open air where an attentive visitor can enjoy a feeling of both scientific and cultural character. However, although the petrographic description of Turin ornamental stones has been the subject of several papers (e.g. Sacco 1907; Peretti 1937; Rodolico 1953; Chiari et al. 1992; Fiora et al. 2001; Fiora et al. 2007) un updated treatment of the most significant stone buildings of the city is missing.

In the City of Turin, there are over 150 varieties of stones, used both as a structural element, or, more recently, for ornamental effect. It is an extraordinary richness probably unsurpassed at a national scale. From Roman times to the 18th century marbles and other carbonate rocks were mainly used in the construction of value. Starting from 19th century, silicate rocks are increasingly taking over through the development of technologies to process them and to new means of transport with the arrival of the railway.

Currently, in the city metamorphic rocks are the most widespread, used both as street furniture (gneisses and other stones) and for more precious employments (marbles). By order of abundance they are followed by magmatic rocks (granites and other granitoids) and finally by sedimentary rocks (limestones, sandstones and travertines).

This article, along with a brief description of the regional geology, exemplifies the main ornamental stones of Piemonte and highlights their importance in the historical landscape and architecture. Moreover it is aimed to highlight how significant parts of the geological evolution of a region may be inferred from a guided observation of the rocks “exposed” on monuments of a town adjacent to a complex orogenic system.

Geological setting

The great variety of ornamental and building stones found in Turin is certainly due to the highly composite geological nature of our region. In Piemonte, in fact, variable geological features such as the western portion of the Alpine Chain and the Tertiary Piemonte Basin occur.

The Alps are a small segment of the huge orogenic systems stretching from Morocco to the Himalayas deriving from a complex geodynamic process which began more than 100 million years ago and is still underway today. The Alps, like all mountain ranges, are formed of large volumes of rocks of different appearance, chemical composition and genetic significance. Metamorphic rocks are the most represented. Those of igneous (both plutonic and volcanic) and sedimentary nature are volumetrically subordinate, although of great interest from an extractive point of view..

Historically, geologists have grouped the wide variety of rocks outcropping in the Alpine chain in four main domains separated by major tectonic surfaces and characterized by a homogeneous paleogeographic origin and geological history (Dal Piaz 1992). These domains, from the inner to the outer part of the chain, have been termed Southalpine, Austroalpine, Pennidic and Helvetic-Dauphinois (Fig. 1a).

The Alps represent the product of complex geodynamic processes that through a first subduction phase of oceanic lithosphere and a second phase of continental collision between the paleoeuropean and apulian margins led to the formation of an orogenetic chain (e.g. Beltrando et al. 2010). The tectono-stratigraphic setting of the Alps is therefore rather complex, being constituted by different units tectonically juxtaposed at different times and thermo-barometric conditions. Particularly, the Alps include poly-metamorphic units of continental crust tectonically interposed with oceanic units. Also the internal structure of the chain is rather complex (Fig. 1b). The Alps show, indeed, a structural setting marked by a double vergence, NW directed in the external sector and SE directed in the inner sector. The contact between the two opposite verging sectors is of tectonic type and is known as the Periadriatic Line (LP in Figs. 1a and 1b), which consists of a system of subvertical faults showing a prevailing dextral transcurrent character.

Given the extension and the particular position of the Piemonte region, more or less extensive portions of all four domains mentioned above crop out (Fig. 2). The Piemonte region is therefore significantly representative of the geology of the entire Alps. It is probably for this reason that in

Piemonte natural stones have been, and in part still are, abundantly extracted (Barelli 1835, Jervis 1889; Sacco 1907; Peretti 1938).

The Southalpine domain outcrops exclusively in the easternmost sector of Piemonte and is bounded to the north by the major tectonic alignment named the Periadriatic Line, whereas to the south it is covered by the Quaternary sediments of the Po Plain. It consists of geological units of deep and intermediate crust respectively named the Ivrea-Verbano Zone and the Serie dei Laghi (Zingg et al. 1990; Boriani et al. 1990). They are composed of very ancient metamorphic rocks subjected to both the Caledonian (about 500 million years ago) and the Variscan (about 340 million years ago) orogenic events (Boriani and Villa 1997). The Ivrea-Verbano Zone represents a section of deep continental crust brought to shallow levels during the crustal extensional phase of Early-Mesozoic age. It consists of paragneisses with minor metabasites and marbles showing a metamorphic gradient ranging between amphibolite to granulite facies conditions (Kinzigite Formation) intruded by a basic-ultrabasic magmatic complex (Mafic Complex) of Permian age (Quick et al. 1994). At the western margin of the Ivrea Verbano Zone, between the Insubric Line and the Mafic Complex, bodies of spinel peridotites, interpreted as subcontinental mantle slices, crop out (Zingg et al. 1990), The Serie dei Laghi, on the other hand, is largely made up of rocks of sedimentary origin metamorphosed under amphibolite facies conditions and thus transformed into micaschists and gneiss. It includes significant masses of granitic rocks of Permian age, known as "Graniti dei Laghi"; they are rather important in Piemonte quarrying activity (Boriani et al. 1992). A tectonic unit, known as the Canavese Zone, is juxtaposed between Southalpine and Austroalpine domains from which is separated respectively by the Internal (ICL) and external (ECL) Canavese Lines, which represent the western segments of the Periatriatic Line (Fig. 2). It consists of a low-grade metamorphic pre-Mesozoic basement and of a volcanic and sedimentary cover of Mesozoic age.

The Austroalpine and Penninic domains are the portions most affected by Alpine orogenesis: in this sector of the chain, the rocks are extremely deformed and affected by high pressure metamorphism, typical of subduction zones. They make up the greatest part of the Alpine chain in Piemonte, extending without break from the Ossola valleys to the Ligurian Alps. The Austroalpine domain, particularly extensive in the Eastern Alps, in the western sector is limited to the Sesia Lanzo Zone, which partially outcrops in Piemonte, and the Dent Blanche system, together with more or less extensive Klippen which only outcrop in Valle Aosta Valley (Ballevre et al. 1986). The rocks of this unit, well-known to geologists because they show parageneses characteristic of deep subduction zones (e.g. Dal Piaz et al. 1972; Compagnoni et al. 1977), are not particularly significant from a quarrying point of view. The Sesia Lanzo Zone is intruded in the Oligocene by two small plutons in the Cervo valley, slightly to the North of Biella, and Traversella, which provide numerous varieties of Piemonte ornamental stones.

The Penninic domain is classically divided into tectonic units of both oceanic and continental crust. The various units made up of oceanic crust and relative Mesozoic sedimentary cover are generally grouped into the so-called Piemonte Zone and outcrop extensively in the valleys of the Cozie and Graie Alps (Dal Piaz 1999). In tectonic terms, the Piemonte Zone lies between the Austroalpine Domain above and the Penninic continental units below. The oceanic Piemonte Zone can be divided into lower (Zermatt Saas unit) and upper (Combin unit) complexes. The lower complex is essentially made up of metamorphic rocks re-equilibrated under conditions of high pressure and low temperature (eclogitic facies) derived from tectonic slices of oceanic crust (metabasites) or, to a lesser extent, upper mantle (serpentinites). The upper complex is largely made up of metamorphic rocks originating from deep-sea turbidite sediments now represented by calcschists, which are easily visible in many Alpine valleys. Even if these rocks were not exploited by an intensive quarrying, the calcschists have been used since ancient times for roofing of rural housings. In southern Piemonte there are also minor outcrops of the Ligurian unit named "*Helminthoides* Flysch", more extensively present in Liguria and in the French Alps. This unit is made up of turbidite successions deposited in the Ligure-Piemontese ocean during Late Cretaceous-Paleocene and presently thrust over the more external units.

The continental Penninic units are generally divided into upper, intermediate and lower Penninic units. The upper Pennidic units correspond to the so-called "Internal Crystalline Massifs" represented by the Monte Rosa, Gran Paradiso and Dora-Maira units (Borghi et al. 1996). These units are essentially made up of late-Hercynian granitoids metamorphosed during the Alpine orogenic cycle (orthogneiss) and poly- and mono-metamorphic schists. The ortho-derivates of the Dora-Maira Massif are particularly significant from a quarrying point of view. Marbles and quartzites are also quarried in the Internal Crystalline Massifs. The intermediate part of the Penninic Domain generally correspond to the Briançonnais Unit. This composite tectonic unit is made up of a poly-metamorphic crystalline basement (schists and gneiss) and a mono-metamorphic cover, originally consisting of Meso-Cenozoic carbonate successions now transformed into marbles (Sartori et al. 2006). In the southernmost sector of the Briançonnais Unit (Ligurian Briançonnais) sedimentary successions, not or very slightly affected by metamorphism, are present. The Briançonnais Unit crops out rather extensively in the southern sector of Piemonte and, in part, in Susa valley (Ambin Massif).

Lastly, the lower Penninic units include the tectonic units outcropping NE of the Sempione tectonic Line corresponding to the northernmost part of the Ossola valleys. They are essentially made up of orthogneiss with interlayered schists, representing the deepest structural levels of the Alpine chain. These units (Antigorio, Lebendum and Monte Leone nappes) are characterized by significant metamorphic overprinting under amphibolite facies conditions (Steck 2008).

The Helvetic-Dauphinois domain represents the more external Alpine domain; it consists of basement units of continental crust (External Crystalline Massifs) and of the overlying Mesozoic sedimentary cover. In Piemonte it includes the Argentera Massif and relative sedimentary successions outcropping in the valleys near Cuneo.

The Tertiary Piemonte Basin (TPB) developed in the internal part of Western Alps from Eocene to Miocene and it is filled with essentially terrigenous sedimentary successions. It outcrops between the Po River and the southern boundary of the region and can be subdivided in different domains: Monferrato and Torino Hill to the north, Langhe, Alto Monferrato and Borbera-Grue domains to the south (Biella et al. 1997). The Plio-Pleistocene depression of the Asti-Alessandria basin is interposed between the northern and the southern sectors. The TPB successions unconformably cover Alpine units of different composition and structural level (Alpine metamorphic units and Ligurian sedimentary units), which were juxtaposed during the Eocene mesoalpine collisional stage (Castellarin 1994; Piana and Polino 1995).

Turin urban geological heritage

In the following, an overview of the the three great categories of rocks (i.e. metamorphic, magmatic and sedimentary) used as architectural elements in Turin is provided. For each type the geological domain of provenance and the main buildings where it was used are reported. Fig. 3 portrays the downtown of Turin with the location of the main historical buildings reported in the text.

Metamorphic rocks: gneisses

This category of stone is mainly represented by gneisses coming from the Alpine valleys. Among these, the material most widely used in the city is certainly the *Luserna Stone*, an orthogneiss of Permian age. It belongs to the Penninic unit of the Dora Maira Massif, a tectonic unit of continental crust which suffered an eclogitic metamorphic event in the Eocene partially re-equilibrated under greenschist facies conditions in the Oligocene (Gasco et al. 2011, with bibl.). It outcrops in a quite large area (approximatively 50 km^2) in the Cottian Alps, on the border between Turin and Cuneo provinces. The quarry district of *Luserna Stone* was historically the Pellice valley (1 in Fig. 2). The *Luserna Stone* is characterized by a prominent tectonic foliation defined by the iso-orientation of phyllosilicates, predominantly white mica crystallized under high pressure and, in smaller quantities, biotite and chlorite There are also magmatic porphyroclasts of potassium feldspar, in addition to quartz and albite, partially recrystallized during the Alpine metamorphic event

(Sandrone et al. 2000). On the hand sample, *Luserna Stone* shows a light gray color and a good fissility, being easy to split along the schistosity planes (Fig 4.1). Over time, the uses of *Luserna Stone* in the Turin city have been many, from the slabs covering the dome of the Mole Antonelliana (Fig. 5.1), which was the tallest masonry building in the world when it was inaugurated in 1889. Other applications relate to the façade of the Automobile Museum, recently restored, and the paving of many city streets and squares, such as Castello Square, the main square of the city.

In the Susa Valley (2 in Fig. 2) many other varieties of gneisses similar to *Luserna Stone* were extracted in the past from the Dora Maira Massif (Fiora and Gambelli 2003). Among these we may mention the *Borgone Stone*, the *Vajes Gneiss*, used for the columns of the façade of Santa Cristina Church, and the *Villarfocchiardo Gneiss*, used in piers of Isabella Bridge over the Po River. This is a leucocratic orthogneiss of white to grayish – light colour, characterized by the presence of tourmaline, which defines a mineralogical lineation (Fig. 4.2). The fundamental components are quartz, microcline, albite and phengite. Another orthogneiss of the Dora Maira Massif, extracted slightly to the southeast, is the *Cumiana Stone* (3 in Fig. 2). It was used at the beginning of 19th century to make the Vittorio Emanuele I Bridge, the first stone bridge over the Po River, which connects Vittorio Veneto Square with the Turin Hill (Fig 5.2). A variety of slightly darker *Luserna Stone* is represented by the *Malanaggio Stone* (Fig. 4.3), represented by an amphibolic - biotitic orthogneiss, dioritic in composition, intruded in the monometamorphic graphite-bearing sequence of the Dora Maira Massif (4 in Fig. 2). This stone was used for the columns of the Gran Madre Church (Fig. 5.3), the piers of the Umberto I bridge on the Po River, the façade of the Misericordia Church and the Mauritian Basilica, as well as the plinth of numerous palaces in Turin. The *Malanaggio Stone* was also used in the Fenestrelle Fortress, one of the best preserved military constructions all over Europe, built in the eighteenth century. In particular, *Malanaggio Stone* constituted the first 1250 of the 4000 steps of the “covered scale”, that exceeds a height difference of 525 meters (Fiora et al. 2006).

Another important historical Piemonte stone is the *Bargiolina quartzite*, coming from the western slope of the Monte Bracco, in the lower Po valley (5 in Fig. 2). Geologically it represents the metamorphic product in Alpine age of Permo-Triassic quartzarenites deposited above the Dora Maira Massif during the post-Variscan marine transgression (Vialon 1966). It is a micaceous fine-grained quartzite showing a tabular and homogeneous appearance (Fig. 4.4). Commercially three distinct varieties of colors can be distinguish: gray, green and gold. Of historical importance is the white variety "*Marmorina*" mentioned by Leonardo da Vinci (Fiora et al. 2002b). This rock was mainly used for flooring (internal stairs of the seat of the Regional Museum of Natural Science; atrium of San Filippo Church, pavement of Roma Street).

Two other important Alpine metamorphic rocks employed in the historic building of Turin are the two types of orthogneisses which are locally known as "*Serizzo*" and "*Beola*". They represent the most important dimension stones from the quarrying Ossola district (Sandrone et al. 2004). Most of these gneisses derived from Permian granites (270-280 Ma), pervasively equilibrated during the Alpine orogenic event.

Serizzo is represented by a granitic/granodioritic orthogneiss with a darker colour and larger grain size than those of *Luserna stone* (Fig. 4.5). It is characterized by magmatic centimeter-large augens of potassium feldspar as well as abundant biotite which defines the regional schistosity developed under amphibolite facies conditions during the last Alpine metamorphic event (Sandrone et al. 2004). Geologically it mainly belongs to the lower Penninic Antigorio unit, which represents the deepest structural levels of the western Alps (6 in Fig. 2). The main use of this lithologic variety consists of monolithic columns that characterize the arcades of Roma Street in the blocks between San Carlo and Carlo Felice Squares (Fig. 4.4).

The *Beola* is a variety of orthogneiss outcropping in the lower Ossola Valley (7 in Fig. 2) and pertaining to the Penninic Units. It is characterized by a sparkly grey to a silver white colour and a fine-to- medium grain size (Fig. 4.6). It shows a mylonitic structure and a strong mineralogical lineation defined by the main components such as potassium feldspar, quartz, plagioclase, white mica and biotite, as well as tourmaline present in accessory amounts (Cavallo et al. 2004). The *Beola* is used for covering buildings and street furniture.

Metamorphic rocks: white marbles

Among metamorphic rocks of carbonate composition the Alpine marbles (white and coloured) were widely used in Turin for both indoor and outdoor prestigious applications, especially till the end of 18th century, when the stones of carbonate composition, easier to work thanks to their lower hardness, were gradually replaced by silicate rocks.

Most Piemonte marbles from the Western Alps generally outcrop as small lenses intercalated with schists and gneisses belonging to various geological units characterised by different metamorphic conditions. Eight historical Piemonte marbles can be recognized from well-known quarry sites belonging to different metamorphic geological units of the Western Alps (*Ornavasso, Crevoladossola, Pont Canavese, Foresto, Chianocco, Prali, Brossasco* and *Frabosa Marbles*). They can be grouped in two classes: the marbles belonging to the pre-Triassic (Paleozoic) crystalline basement characterised by a polymetamorphic overprint, and the Triassic marbles coming from the meta-sedimentary cover with a monometamorphic overprint. The Paleozoic marbles include the *Ornavasso Marble*, the *Prali* and *Brossasco Marbles*, and the *Pont Canavese* *marble*. The Triassic ones consist of *Foresto* and *Chianocco Marbles*, *Crevoladossola*, and finally the *Frabosa Marble*.

Although these marbles were employed since ancient times in the field of cultural heritage, they have been poorly studied. In addition, their macroscopic and microscopic similarities make the identification of a specific Piemonte marble very difficult. Therefore, the provenance attribution of an archeological or architectural element in marbles from Piemonte cannot be inferred without archeometrical bases.

A recent multi-analytical approach, based on petrographic (optical and scanning electron microscope), electron microprobe and stable isotope analyses of each white Piemonte marble variety has been performed in order to define their diagnostic elements in terms of micro-textural, mineralogical and isotopic features (Borghi et al. 2009). Their different metamorphic conditions, ages and structural evolution allowed to draw a discriminative flow chart based on microscopic and minero-chemical data (Fig. 6).

The most important white Piemonte marble is the Susa Valley marble (*Foresto* and *Chianocco Marbles*) known and used since Roman times (see for example the Arch of Augustus at Susa, dating to 9 BC). It is a dolomitic white marble of Triassic to Early Jurassic age belonging to the Mesozoic cover of the Dora Maira Massif (8 in Fig. 2). It is characterized by a weak foliation of metamorphic nature defined by the iso-orientation of small flakes of white mica (Fiora and Audagnotti 2001). In Turin the main use of this marble is the façade of the San Giovanni Cathedral (Dome of the City), the only Renaissance building still preserved in the town (Fig. 5.5). The blocks of marble show a slightly variable color from creamy white to light gray and a metamorphic foliation defined by alternations of chromatically different centimeter-thick layers. These blocks, randomly placed on the façade of the Dome, produce a "checkerboard effect" .

Other important white marbles in the historic architecture of Turin are the *Prali, Brossasco* and *Ornavasso marbles*. For statuary purposes the *Pont Canavese Marble* and the *Frabosa* white *Marble* are remarkable. Historically the *Crevoladossola Marble* is less important as it is mainly used for private contemporary construction.

The *Brossasco Marble* belongs to the Dora Maira geological unit (9 in Fig. 2). It is a coarse-grained isotropic marble, which reflects the high metamorphic temperatures of formation (over 700 ° C). The most important historical application consists of neo-classical colonnade from the San Filippo Neri Church, the largest religious building in Turin (Fig. 5.6). These columns are made of superimposed blocks and decorated with grooves.

The *Prali Marble* belongs to the Dora Maira geological unit too (10 in Fig.. 2). It is a predominantly fine-grained calcitic marble of pre-Triassic age. Its aspect is banded being characterized by alternation of green and light levels. Along green domains femic minerals (amphibole, chlorite and fengite) are concentrated. The *Prali Marble* was employed in the stone basements in the gate of the Turin Royal Palace (Fig. 7.1).

Ornavasso Marble is a calcitic marble of pre-Triassic age, characterized by a coarse-grained size (> 5 mm), which reflect the high temperatures of formation. This marble outcrops on the right side of the Toce river and is geologically similar to the most famous *Candoglia Marble* (Fig. 4.7), outcropping in the left side (11 in Fig. 2). The *Candoglia Marble* has been for centuries at exclusive use of the "Veneranda Fabbrica del Duomo" in Milan for the restoration of the Cathedral (Ferrari da Passano 2000). The *Ornavasso* and *Candoglia Marbles* occur as lenses (up to 30 m of thickness) that are interlayered within the high-grade paragneisses of the Kinzigitic Complex of the Ivrea Verbano Zone (Zingg et al. 1990). The *Ornavasso Marble* was used in the '30s of the 20th century for the external coating of the apses of the Santa Cristina and San Carlo Churches (Fig. 7.2).

The *Frabosa Marble* (12 in Fig. 2) is calcitic and belongs to the metamorphic Middle Triassic succession of the internal Ligurian Briançonnais Unit and because of its compact appearance, the isotropic texture and the very fine crystal size (<1 mm) it was the Piemonte marble most widely used in statuary since '600. It is found in many historical buildings of Turin such as the Basilica Mauriziana (portal and jambs), the Churches of Santa Cristina (statues and decorations of the facade), San Filippo (pediment and tympanum), San Carlo (capitals and decorations façade), Gran Madre (capitals of the columns of the façade) and Carignano Palace (capitals, masks and key parapet of the crown). A variety of this marble is named *Verzino*, characterized by the occurrence of light green layers containing white mica and chlorite (Fig. 4.8)

Among the ornamental stones of Turin are worth mentioning the colored marbles coming from the Briançonnais unit in the Southern Piemonte (Cuneo Province), which have been employed over the centuries in many Baroque churches and residences of Savoy (Badino et al. 2001). Among these we may mention the *Bigio of Moncervetto* (12 in Fig. 2), which was used for the columns of the façade of the Crocetta Church (Fiora and Alciati 2006).

Metamorphic rocks: ophicalcites

With the term of green marbles are historically called serpentinites and ophicalcites, which show a mineralogy and genesis significantly different from that of marble *sensu stricta*, even if, due to their similar hardness, are grouped in the same commercial class as defined by the European Committee of Standardization. These are mainly silicate rocks consisting of serpentine (serpentinites) and serpentine + calcite (ophicalcites) and therefore belong to the category of ultrabasic metamorphic rocks. They derived from hydration and metamorphism of mantle peridotites.

From the geological point of view, the Alpine green marbles consist of metaophicalcites that mostly belong to the Combin unit and to a lesser extent to the Zermatt-Saas unit of the Piemonte Zone (Dal Piaz et al. 2001, with references). They were quarried in the Susa and Aosta Valleys since the '20s of the twentieth century and sold on the market with the generic name of *Verde Alpi* (Fiora and Ferrarese 1998; Ferrarese et al., 1999). They show a remarkable textural and chromatic heterogeneity (Fig. 8.1), as they include both tectonic breccias and, to a much lesser extent, sedimentary breccias (Sandrone et al., 2004). The former are made up of angular fragments of serpentinite separated by a whitish or greenish matrix of carbonates and silicates, whereas in the latter green serpentinite clasts occur together with white marble clasts.

The best known area of origin is the Montgenevre - Chenaillet ophiolitic unit, which extends along the French-Italian border in Susa Valley (13 in Fig. 2). Most ophicalcites that today we find in Turin were extracted from this locality. The best known use is in the Subalpina and San Federico Galleries. In the first case the *Verde Alpi* has been employed for the internal and external baseboards, for flooring and for rounds (Fig. 7.3). In the second case is used for pilasters, door jambs and frames of rounds.

Plutonic rocks

Intrusive rocks were also diffusely employed in Turin historic buildings. The *Pink Baveno Granite* is undoubtedly the most widespread magmatic rock used in the city. It is characterized by a typical pink color due to hematite inclusions in the K-feldspar crystals and shows a medium to fine grain size (Fig. 8.2). From a geo-petrographic point of view it comes from the quarrying district of Ossola Valley and pertain to a composite complex of plutonic bodies of Early Permian age (Boriani et al. 1992) that intruded, at a shallow depth, the Southern Alps basement of the Serie dei Laghi (14 in Fig. 2). Among the most prominent examples in the city, the columns of the Mole Antonelliana, the façade of the San Carlo Church and columns and pilasters of the nineteenth century façade of Carignano Palace, the seat of the first Italian Parliament, can be remembered (Fig. 7.4). Another plutonic rock commonly employed is the *White Montorfano Granite*, also coming from the quarrying district of the lower Ossola Valley. It is a granite similar to *Pink Baveno Granite*, from which it is distinguished by the overall light gray colour, given by the white colour of the potassium feldspar (Fig. 8.3). The *White Montorfano Granite* has been used, for example, in the nineteenth century façade of Carignano Palace, in the columns of the arcades of Pietro Micca, Sacchi and Roma Streets.

Among the intrusive rocks may be also included the *Balma Syenite* and *Canavese Diorite*. Both represent two small post-metamorphic intrusive bodies of Oligocene age, intruded in the eclogitic micaschists complex of the Sesia Lanzo Zone and outcropping respectively along the Cervo Valley (15 in Fig. 2) and Chiusella Valley (16 in Fig. 2). According to Bigioggero et al. (1994), the pluton of Cervo Valley consists of monzo-granitic rocks in the core surrounded by a discontinuous rim of syenitic rocks and, finally, by a wide rim of monzonitic rocks.

The *Balma Syenite* shows a typical grey-violet colour, medium grain size and a well developed magmatic flow fabric (Fiora et al. 2000). Its mineralogical composition consists of violet potassium feldspar crystals showing Carlsbad twinning and perthitic exsolutions, which mainly influences the typical colour of the rock, with lesser amounts of plagioclase and very low content of quartz (Fig. 8.4). Amphibole and biotite occur among the femic minerals. Sphene is the distinctive accessory mineral; the others are apatite, zircon and ores. Although syenitic rocks are relatively rare, their use in the city, due to the relative proximity of the quarrying sites, is remarkable. Syenite is the material in which were made the Monument to Emanuele Filiberto Duca d'Aosta, located in Castello Square in front of the Royal Theatre (Fig. 7.5), the columns of Roma Street, in the San Damiano block, and part of the floor.

The *Canavese Diorite* shows a granular texture and varies in colour from light gray to very dark depending on the grain size and the percentage of femic minerals, represented by amphibole and biotite and rare pyroxene (Fig. 8.5). Among the sialic minerals, plagioclase mainly occurs in addition to rare quartz and poikilitic K-feldspar. The rock often presents igneous and metasedimentary xenoliths that negatively influence the general aspect. The fine grained samples have orthopyroxene (hypersthene) associated with clinopyroxene. The accessory minerals are apatite, zircon, sphene and ores (Sandrone et al. 2004). Its use in Turin is smaller compared to the *Balma Syenite*. The most striking example is represented by the columns of the Sant'Emanuele block along Roma Street. It was also used in the paving of the blocks of the second section of the Roma Street, between the San Carlo and Carlo Felice squares.

Another peculiar intrusive rock used in Turin is the so called *Anzola Black Granite* (Fig. 8.6). This rock, no longer quarried, consists of a gabbro - norite of Permian age intruded in the Ivrea Verbano Zone (Perissini et al. 2007). It was the only "black granite" quarried in Italy (17 in Fig. 2). In the city, it has been employed in the outside wainscot and the steps of the Annunziata Church along Po Street and in the floor of the Santa Maria Maddalena block along Roma Street.

Sedimentary rocks

The ornamental stones of sedimentary origin in Turin are much less abundant than magmatic and metamorphic ones. They are mainly represented by carbonate rocks of Cenozoic age cropping out in different parts of the Tertiary Piemonte Basin.

The most widely used carbonate sedimentary rock is certainly the Calcare di Gassino (Campanino and Ricci 1991), also known as the *Gassino Stone* or *Gassino Marble* (Fig. 7.7*).* It is represented by a biocalcirudite texturally ranging from floatstones to rudstones mainly containing red algae (fragments or rhodoliths), benthic foraminifera (nummulitids, discocyclinids), bivalves, echinoids, and mm- to cm-sized lithoclasts of biocalcarenites that are locally abundant. In the rudstones the matrix is absent and the coarse grains (rhodoliths and lithoclasts) are sutured along pressure-dissolution surfaces where clay minerals are concentrated. The *Gassino Stone* is dated to the Eocene and belongs to the Tertiary Piemonte Basin, more in particular to the Torino Hill Domain (18 in Fig. 2). Although it has not been extracted for more than a century, its occurrence in the city is still considerable. In particular, the colonnade of the courtyard of the Rectorate of the Turin University as well as the portals of Carignano Palace and of the Academy of Sciences were made with Gassino Stone (Fig. 7.6).The same stone is also found in the façade of the Santa Cristina Church and of the Town Hall. Out of the city it has been used in the exterior colonnade of the Basilica of Superga. Because of its particular aspect due to the presence of nodules consisting of calcareous red algae (rhodoliths) and of the presence of thin clay seams due to pressure dissolution, this stone is easily degraded by weathering and, more recently, by smog.

Another sedimentary rock used as ornamental stones in Turin is the *Finale Stone* (Fig. 8.8), a bioclastic calcirudite belonging to the Pietra di Finale formation of Miocene age (Boni et al. 1968, 19 in Fig. 2). It consists of a porous matrix-free rudstone with a coarse debris of corals and mollusks with abundant sparry calcite cement. In the city of Turin it has been used for the exterior of the FIAT Company seat and San Federico Gallery (Donati, 2000).

The Pietra da Cantoni or *Cantoni Stone* (20 in Fig. 2) is a Lower Miocene biocalcarenite employed in the construction of Romanesque churches, such as the Vezzolano Abbey, in central-eastern Piemonte (Alciati and Fiora 2004). It has also been used for ornamental elements of façades of Turin churches such as San Gaetano da Thiene. The Pietra da Cantoni shows a wide spectrum of lithofacies over its outcropping area, ranging from rudstones with decimetre-sized rhodoliths, to glauconitic calcareous sandstones, to calcareous marls (Clari et al. 1995). The rocks historically quarried and used for architectural purposes mainly consist of marly, fine grained biocalcarenites rich in planktonic foraminifera.

Sedimentary rocks of Alpine provenance have been mainly used for internal decorations and will not be treated here. An exception is represented by the *Verde Roja* (21 in Fig. 2) which pertains to the stratigraphic succession of the Dauphinois Domain (Serie de Merveilles: Faure Muret 1955). It consists of green fissile silty claystones of Permian age, deposited in a continental environment. It shows millimeter-sized patches of darker green colour probably due to bioturbation. The *Verde*

Roja has been used in the external façing of the Royal Theatre and in the floor of a tract of Roma Street.

Discussion

From what has been described in the previous section, it is clear that the architectural heritage of Turin is characterized by a wide variety of ornamental stones that mirrors the extreme lithologic diversity of the rocks exposed in the areas that surround Turin on all sides including the Alpine chain and the hilly regions of Monferrato and Langhe that geologically belong to the Tertiary Piemonte Basin (TPB). The great majority of these rocks are metamorphic and magmatic and come from the Alps; only a minor part is of sedimentary origin and was mostly quarried in the TPB. A strict relationship exists between the present day geological features of Piemonte, that result from its geological evolution, and the stone materials historically used for relevant buildings and monuments. Consequently, if the rocks employed in Turin architecture are considered not as single examples of stone material regardless of their provenance but in a unifying framework in which the common element is the geographic and geologic pertinence, then the occurrence of rocks of very different composition and genesis in nearby monuments or even in the same one, mirrors their primary association also in the sourcing mountain chain. This bears a particular added value in a town such as Turin that boasts places very close to the downtown (Mole Antonelliana) or to the hill, (Mountain Museum) offering spectacular views of a great part (hundreds of kilometers long) of the western Alps chain made up of different geological units and of the Tertiary Piemonte basin. This aspect is worth evidencing and explaining. Stone materials employed as facings, floorings, and ornamental features may be regarded as “urban outcrops” of Alpine rocks that may tell us a tale not only dating back to the last centuries history of architecture in Turin but to one hundred million years long story of complex geological evolution. This “rock collection” is obviously not exhaustive of the all lithotypes present in Piemonte because it is biased by the suitability of rocks to be quarried and used for ornamental purposes. It is complete enough, however, to disseminate the basic principles of geology and the essential facts of the evolution of the Alps and of the adjacent hilly regions in a fascinating synergy of science, history and architecture. In this way, serpentinites and ophicalcites document the former existence of an ocean consumed in a subduction process during lithospheric plate convergence, gneisses and marbles are the result of the involvement of plutonic and sedimentary carbonate rocks in continental collision, whereas granites and syenites are the products of magmatic events following collision, and, finally, sedimentary rocks testify process of deposition within basins adiacent to the chain and only slightly affected by deformation.

It is worth noting that stone materials employed in urban architecture, similarly to natural outcrops, are subjected to physico-chemical processes driven by abiological and biological forces or related to

air pollutants, yielding mineral weathering, microstructural damages and aesthetic decay (Prieto et al 2007). The knowledge of minero-petrographic features of ornamental stones in Turin allows the evaluation and modelling of potential deterioration patterns (e.g. Favero-Longo et al 2009; Accattino et al 2012), finally addressing conservation strategies and restoration priorities.
The great variety of stone materials used in the construction of Turin also reflects the technological evolution of extraction that developed through time from the use of explosives up to that of diamond wire for soft materials and to the technique of continue drilling (with detonating cord) for harder ones. Also the techniques of surface finish were gradually refined over time from natural surfaces or from artisan mechanical treatments (e.g. bush-hammering and trimming) to more and more technological surface treatments such as sanding, flame – jet and water – jet. In this way, the façades of historic and contemporary buildings in Turin also show an almost complete array of the different processes and surface treatments applied to ornamental stones over the centuries.

Conclusions

There are many leitmotivs around which, in the past years, thematic networks of the Turin city tourism have been interwoven. So far, however, one of the main characteristics of Turin has been neglected: the wealth of stone materials, employed in the centuries for paving, for monuments and public buildings, and to embellish churches, commercial windows, and passages representing wonderful works of engineering and reflecting perhaps better than any other topic the link of the city with its territory and the role of the laboratory of knowledge, culture and economic wealth production covered by the capital of the past reign of Savoy, then of Italy, and finally of the domestic industry.
In this paper a representative list of the ornamental stones from Piemonte used in the historic and contemporaneous buildings of Turin city, in order to emphasize their cultural and scientific value for enhancement of urban geological heritage through Geotourism, is reported.
This study perfectly fits in the frame of the "PROGEO-Piemonte" research project, that is aimed to the management of the geological heritage of the Piemonte Region. The expected results of this research consist in the completion of the database of Piemonte rocks used in buildings of historical and contemporary age in the city of Turin and to the dissemination of knowledge on stone from both the scientific-educational and cultural tourism standpoints. A specific final target will be the set up of historical-petrographic trails along the streets of the historic downtown of Turin with information made easily accessible not only to professionals but also to a wider audience including local administrators and touristic operators.
The diffusion of the project on the territory, achievable with appropriate signage, explanatory brochure and specially trained guides, does not preclude the dissemination through other

technologies. Multimedia applications in fact are able to integrate the potentialities of existing sites with the experiences of the projects of the Academic knowledge, easily available on tablets and smartphones. This would allow the realization of thematic trails and the involvement of the widest range of users, helping to build a project in constant expansion and synergistically shared by experts from different sectors for a continue development of the City. At this regard, the realization of virtual tours supported by self-guided trails based on the use of virtual applications for palm-pc, tablets, and smartphones is planned. The use of smart devices would allow direct access to information stored in the PROGEO-Piemonte web-site, or via QR-codes readable on-site in each historical building or on tour-guides provided by "Museo Torino", a virtual network of the main museums of the city managed by the Turin Municipality.

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Captions

Fig. 1 Geologic sketch map (a) and schematic cross section (b) of the Alpine chain (modified after Escher et al. 1988). Yellow = Southalpine Domain, green = Austroalpine Domain, blue = Penninic domain, pink = Helvetic-Dauphinois Domain.

Fig. 2 Geological sketch map of the Western Alps and quarrying sites of the ornamental stone reported in the text (modified after Fiora et al. 2002).

Legend: 1) Plio-Quaternary deposits, 2) Tertiary Piemonte Basin, 3) Northern Appennines. ALPS: 4) Southalpine Domain, 5) Canavese Zone, 6) Austroalpine Domain, 7) External Piedmont Zone, 8) Internal Piedmont Zone, 9) Internal Crystalline Massifs, 10) Briançonnais and *Helminthoides* Flysch Units, 11) Lower Penninic Units, 12) Helvetic-Dauphinois Domain. 13) Tectonic line: LCE = External Canavese Line, LCI = Internal Canavese Line, LS = Simplon Line, PL = Periadriatic Line, RF = Rio Freddo deformation zone, VV = Villalvernia Varzi Line. Quarry localities: 1) Luserna Stone; 2) Susa Valley gneisses, 3) Cumiana Stone; 4) Malanaggio Stone; 5) Bargiolina; 6) Serizzo; 7) Beola; 8) Chianocco and Foresto Marbles; 9) Brossasco Marble; 10) Prali Marble, 11) Candoglia and Ornavasso Marbles, 12) Frabosa and Mocervetto Marble; 13) Verde Alpi; 14) Baveno and Montorfano Granites; 15) Balma Syenite; 16) Traversella Diorite; 17) Anzola Black Granite; 18) Gassino Stone, 19) Finale Stone; 20) Cantoni Stone; 21) Verde Roja

Fig. 3 Satellite toponomastic map of Turin (from Google Earth®, 20/11/2012) with location of the main historic buildings reported in the text.

Fig. 4 Representative images of the main ornamental stones quarried in the Western Alps. 1) Luserna Stone: Alpine orthogneiss of the central Dora Maira Massif equilibrated under eclogite facies metamorphic conditions; 2) Villarfocchiardo Stone: Tourmaline-bearing leucocratic orthogneiss of the northern Dora Maira Massif; 3) Malanaggio Stone: Amphibole – biotite bearing Alpine orthogneiss of the northern Dora Maira Massif; 4) Bargiolina Quartzite: Permo-Triassic quartzite of the Dora Maira Massif; 5) Serizzo: Alpine orthogneiss of the Lower Penninic Nappes equilibrated under amphibolite facies metamorphic conditions; 6) Beola: mylonitized orthogneiss of the Lower Penninic Nappes; 7) Candoglia Marble: Calcite marble of Paleozoic age from Ivrea Verbano Zone; 8) Frabosa Marble: chlorite-phengite bearing marble of Triassic age from Briançonnais Unit

Fig. 5 Representative examples of historic buildings in Turin mainly made of Piemonte stones. 1) Mole Antonelliana, symbol of the city of Turin, built in the late 19th century with material from the Alpine valleys: the Dome is covered with the Luserna stone and the colonnade are made of granite of Baveno. 2) Vittorio Emanuele I Bridge built on the Po River using the Cumiana Stone; 3) Colonnade of the Gran Madre Church. Columns are made of Malanaggio Stone and the capitols in Frabosa Marble; 4) Colonnade of Roma Street consisting of Serizzo; 5) Façade of San Giovanni Battista Church made of Chianocco and Foresto marbles; 6) San Filippo Neri Church colonnade built in Brossasco Marble

Fig. 6 Discriminative flowchart of the Piemonte white marbles (from Borghi et al. 2009, modified). HP = high pressure, LP = low pressure, LT = low temperature, MT = medium temperature, MGS = maximum grain size

Fig. 7 Representative examples of historic buildings in Turin mainly made of Piemonte stones..1) Details of the railing of Royal Palace consisting of Prali marble; 2) San Carlo church apse faced with Ornavasso marble; 3) Detail of the Subalpina Gallery showing the use of the Verde Cesana ophicalcite 4) XIX century façade of Carignano Palace. Baverno and Montorfano granites were employed for columns and pilasters and Frabosa Marble for capitols and other architectonic details. 5) Emanuele Filiberto Duca di Aosta Monument built in the Balma Syenite; 6) Courtyard of the Rectorate Palace. Columns are made of Gassino Stone

Fig. 8 Representative images of the main ornamental stones quarried in the Western Alps. 1) Verde Alpi: ophicalcite of the External Piemonte Zone; 2) Pink Baveno Granite: Permian granite of the Serie dei Laghi; 3) White Montorfano Granite: Permian granite of the Serie dei Laghi; 4) Balma Syenite: Quartz monzosyenite of Oligocene age intruded in the Sesia Lanzo Zone; 5) Traversella Diorite: quartz diorite of Oligocene age intruded in the Sesia Lanzo Zone; 6) Anzola Black Granite: Gabbro-norite of Permian age of the Ivrea Verbano Zone; 7) Gassino Stone: Eocene litho-bioclastic calcirudite of the Turin Hill; 8) Finale Stone: bioclastic calcirudite of Miocene age

Figure 1
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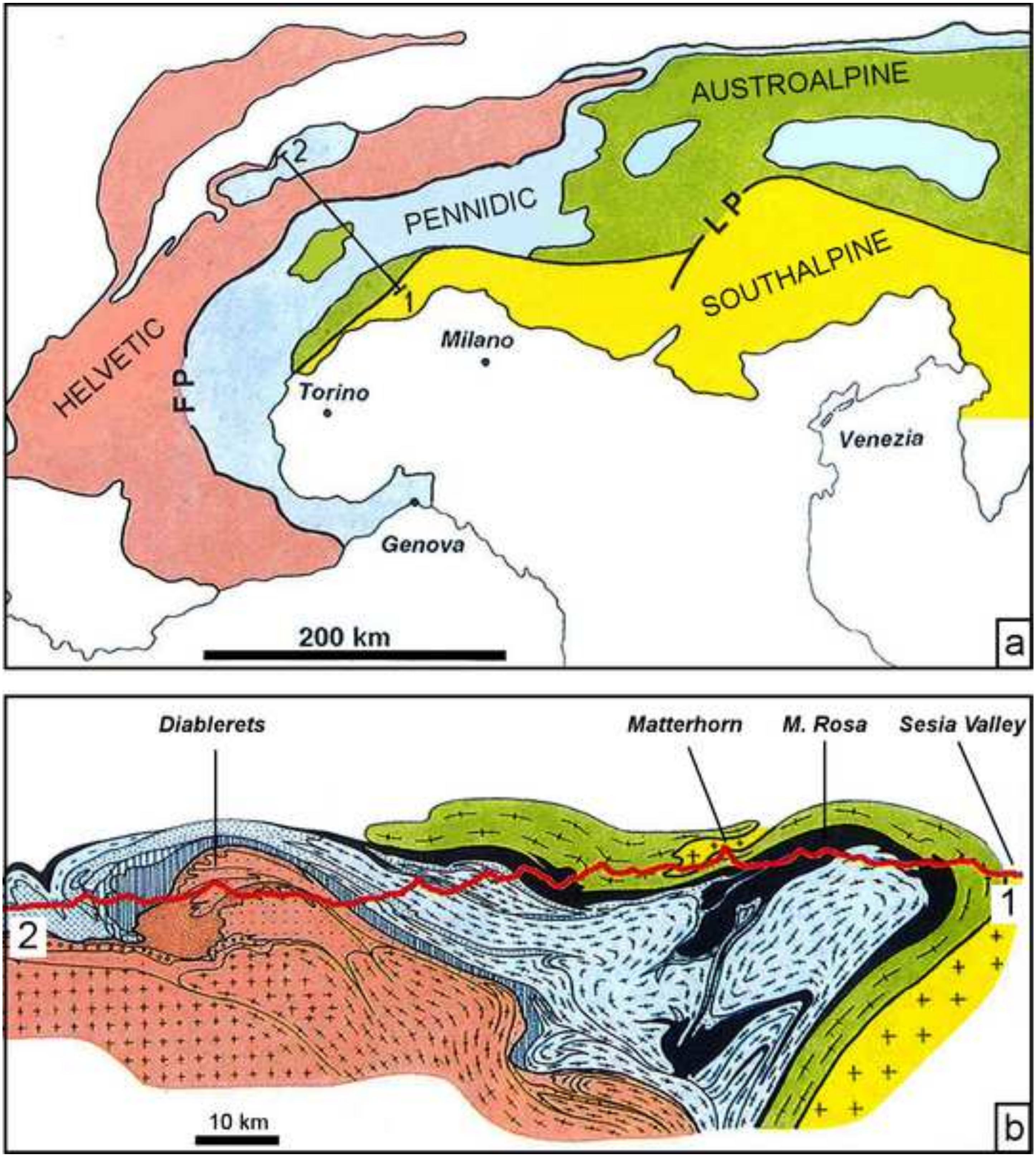

Figure 2
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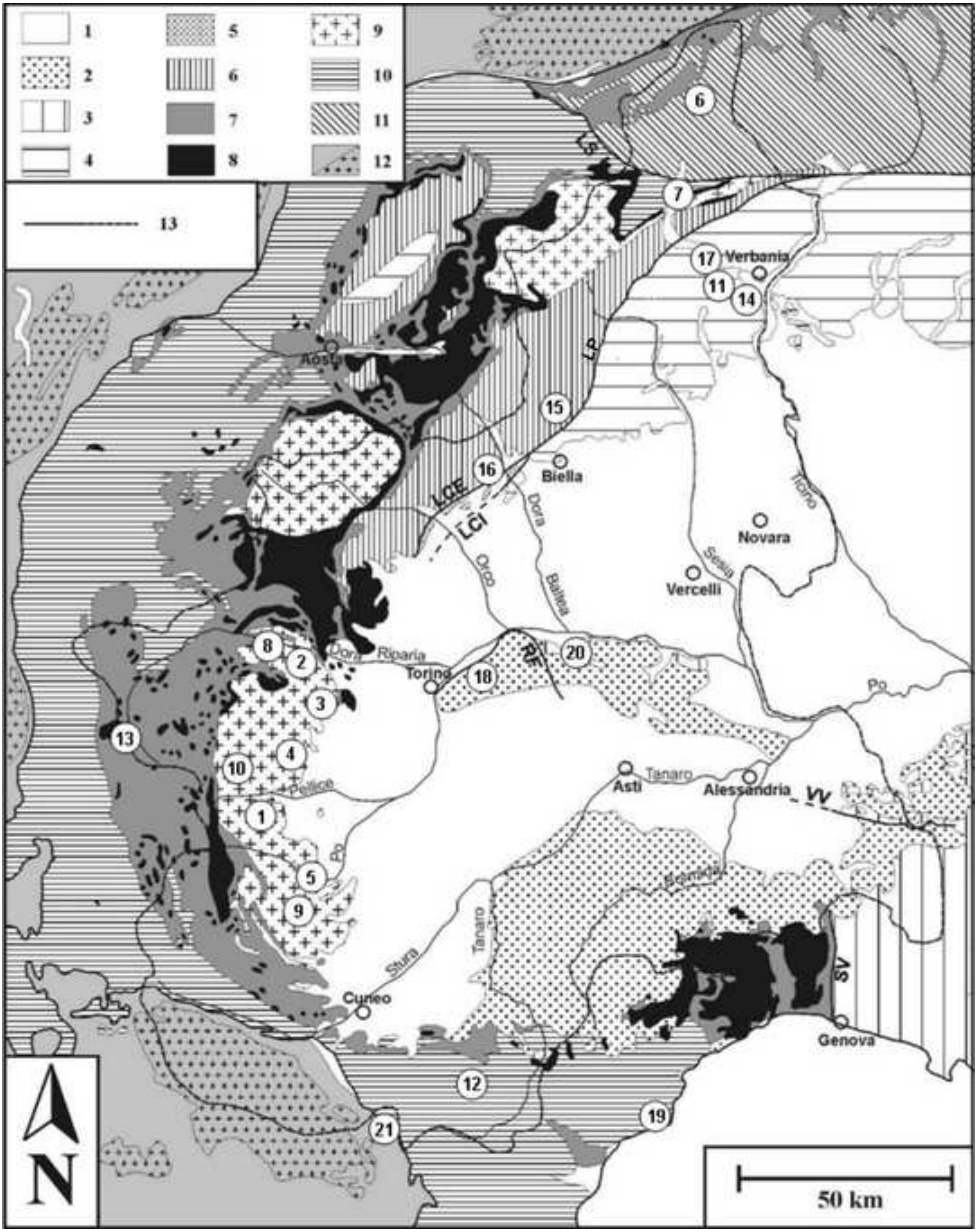

Figure 3
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Figure 4

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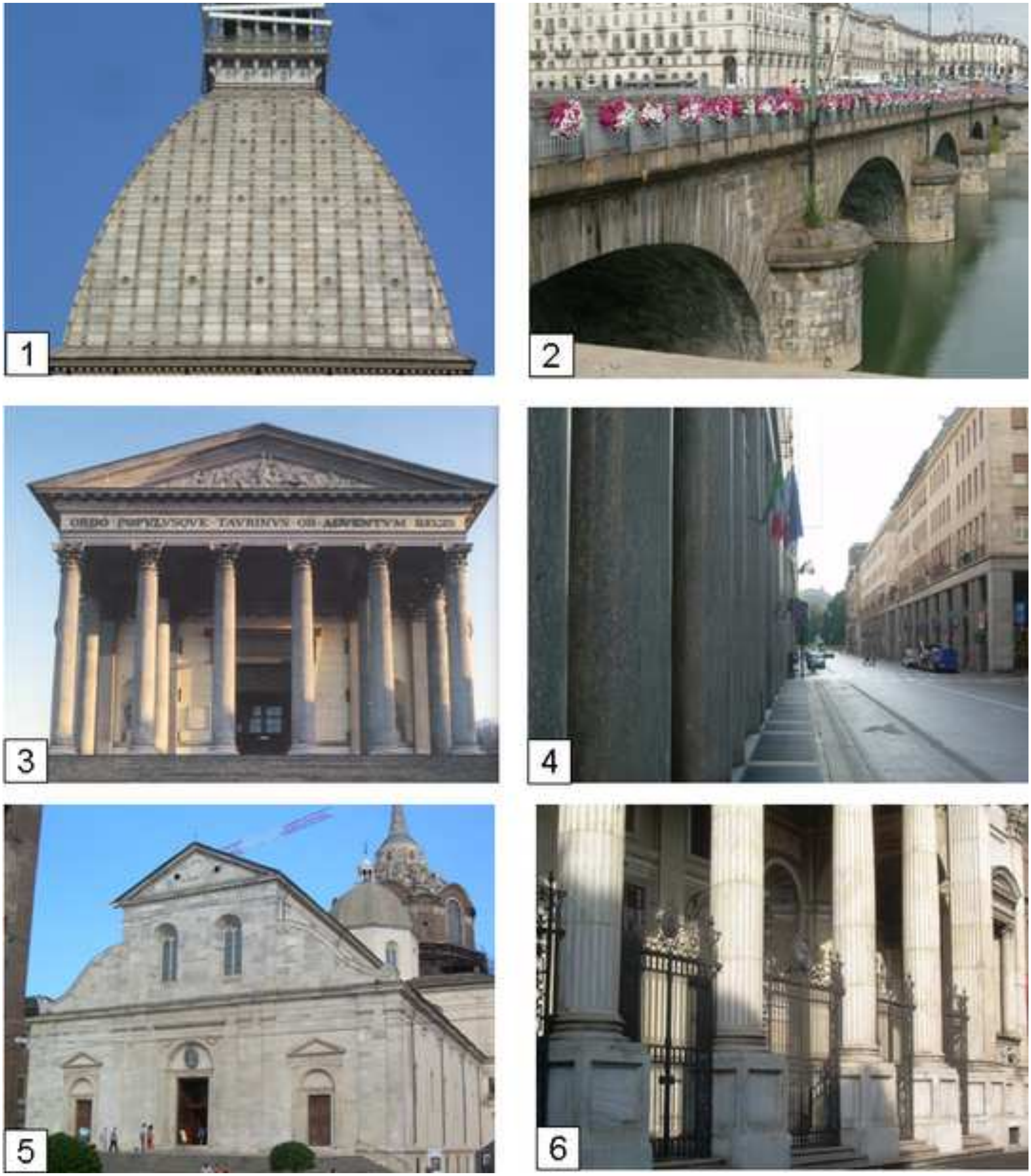

Figure 5

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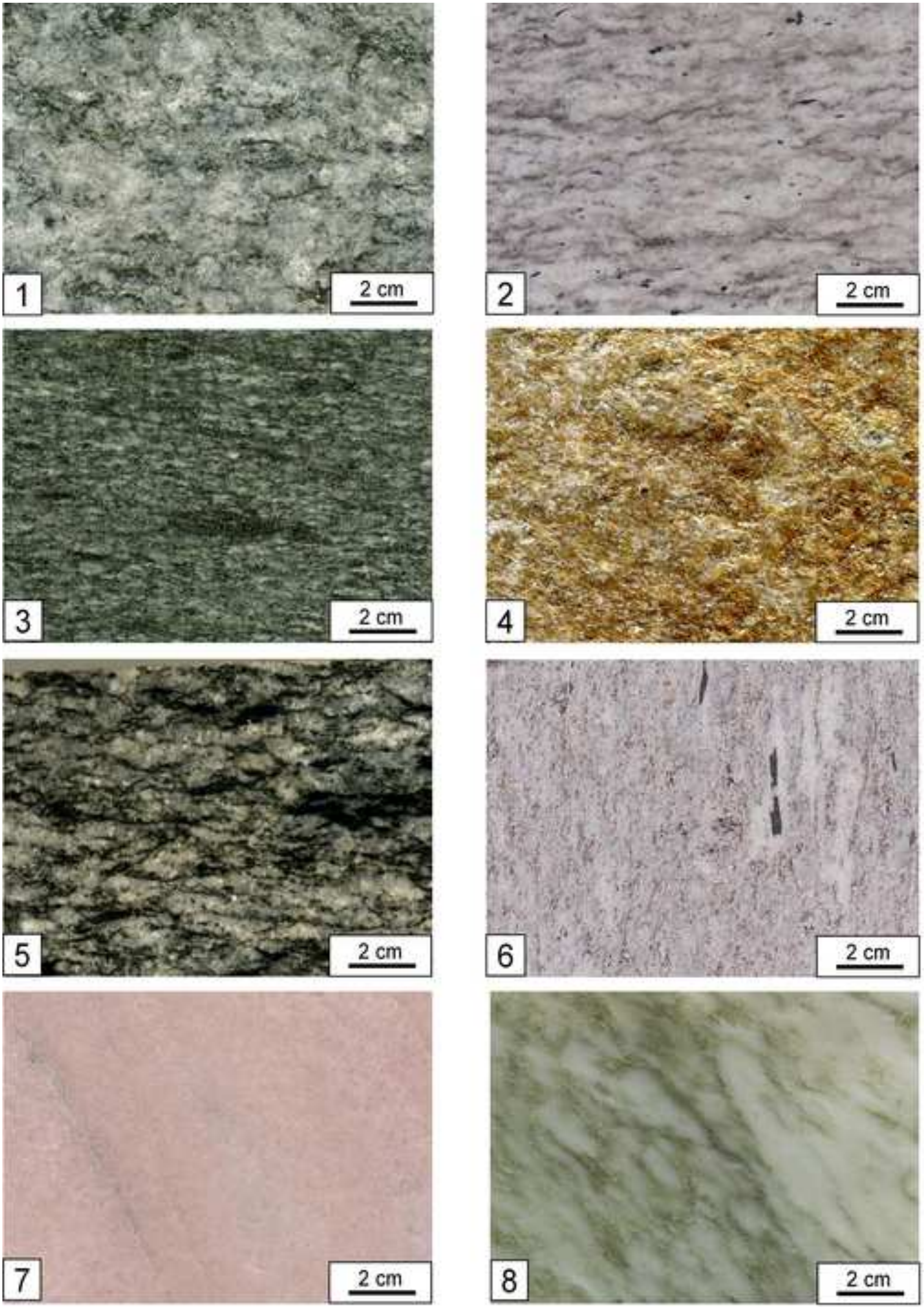

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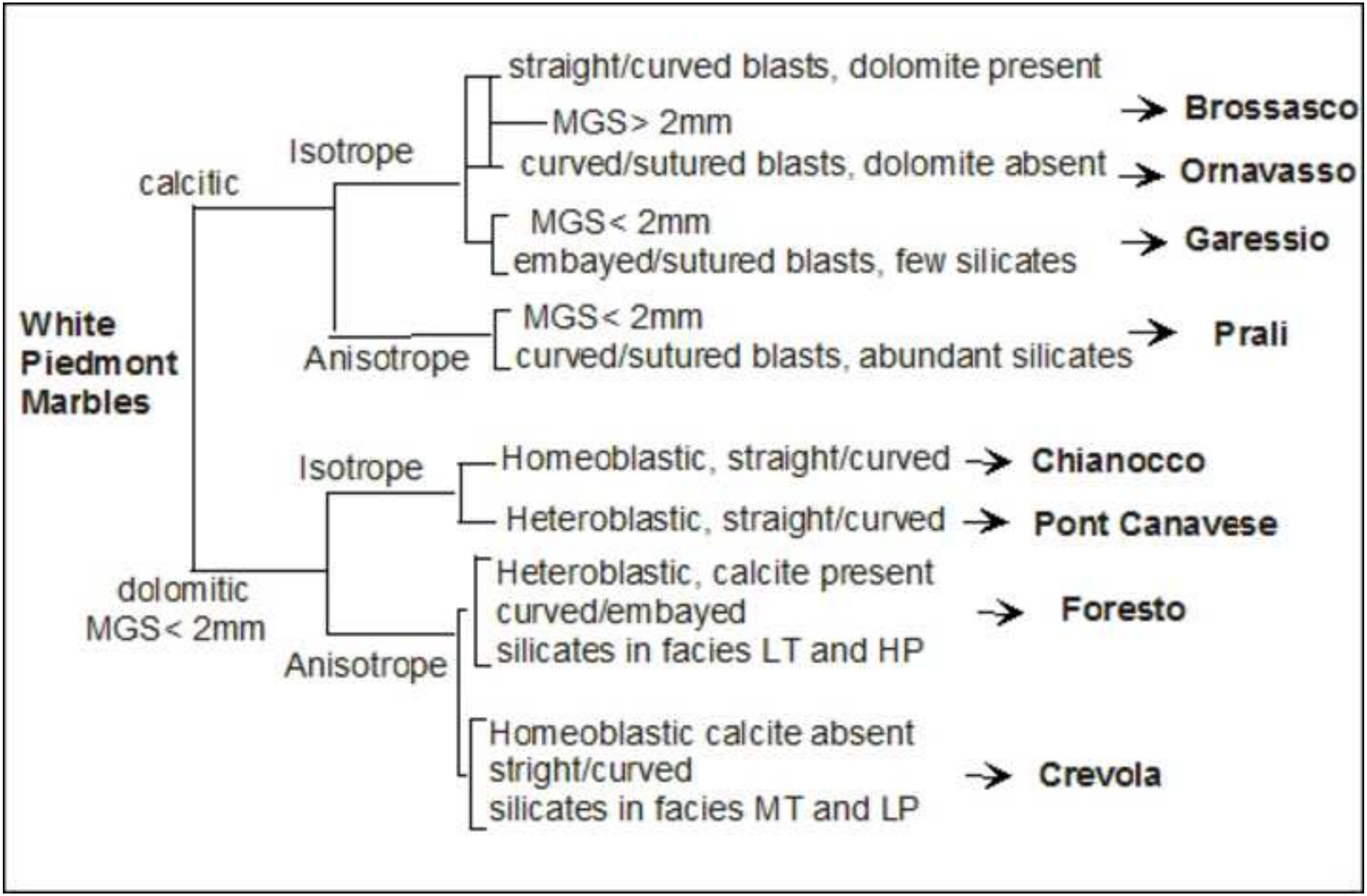

Figure 7

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Figure 8

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