Geoheritage (2026) 18:129
https://doi.org/10.1007/s12371-026-01339-x

ORIGINAL ARTICLE

Brecce di Seravezza s.l. (Including *Breccia medicea*): A Treasure Stone in the Marble Heritage of the Alpi Apuane (Tuscany, Italy)

F. Fratini[1] · E. Pandeli[2] · A. Bartelletti[3] · E. Cantisani[4] · E. Pecchioni[2]

Received: 27 June 2025 / Accepted: 5 May 2026

Abstract
The *Brecce di Seravezza* s.l. (including *Breccia medicea* = Medici's Breccia) represent a geological and commercial peculiarity in the heritage of the Alpi Apuane (Tuscany, Italy). The appearance of this ornamental stone varies, due to the size of the clasts and their colour, to the provenance from one quarry to another and within the same quarry depending on the stratigraphic level, giving rise to different typologies. In this contribution, samples coming from two historical quarries of the typical Stazzema area (Cava del Rondone c/o Pontestazzemese and Cava Grotte Bianche c/o Volegno) were studied. The Brecce of these two sections are stratigraphically interposed between the *Marmi a Megalodontidi*, at the bottom, and *Marmi* of Alpi Apuane, at the top. The "classical" feature of the *Brecce di Seravezza* s.l. used in art and architecture (consisting in a "disorganized" breccia with whitish to reddish marble and minor dolomitic marble pebbles to boulders in a reddish/violet, foliated carbonatic-phyllitic matrix) is recognizable only in some parts of the sections. Lithostratigraphic-structural, petrographic and microstructural observations in polarized light (PLM), mineralogical qualitative analyses with X-ray powder diffraction (XRPD), Scanning Electron Microscope Energy-Dispersive Spectroscopy (SEM-EDS) analyses allow us to identify the main features for 14 representative samples (8 from Cava del Rondone section and 6 from Cava Grotte Bianche section). Furthermore, the main uses of these materials in the cultural heritage context and the main decay phenomena observed in the outdoor and indoor areas will be presented.

Keywords *Brecce di Seravezza* · *Breccia medicea* (Medici's Breccia) · Alpi Apuane · Petrography and mineralogy · Cultural heritage

Introduction

The Alpi Apuane (northern Tuscany) is well known all over the world for its marbles that were carved and used in Italy and abroad since Etruscan period and Roman times (Antonelli and Lazzarini 2013), through the Middle Ages and Renaissance (e.g. *marmo statuario* of Michelangelo) up to now. In this frame, the *Brecce di Seravezza* s.l. (including *Breccia medicea* = Medici's Breccia) represent a geological and commercial peculiarity in the geoheritage of the Alpi Apuane metamorphic core. The aim of this paper is to detail the features of the *Brecce di Seravezza* s.l. in two historical quarries of the typical Stazzema area (Cava del Rondone c/o Ponte Pontestazzemese and Cava Grotte Bianche c/o Volegno) through geological, petrographic and mineralogical studies.

Historical Heritage

Brecce di Seravezza s.l. (s.l. = in a broad sense) is an umbrella term including many commercial types and commercial varieties of historical marbles, that have taken on a multitude of different names over the centuries (Carmignani et al. 2007a, b; Bartelletti and Amorfini 2010–2011, 2013; Bartelletti et al. 2022–2023). They are definable as polymictic and polychrome metabreccias, exclusively extracted for ornamental uses from the geological formation named

✉ E. Pecchioni
elena.pecchioni@unifi.it

[1] Freelance Scientist, Florence, Italy

[2] Department of Earth Science, University of Florence, via G. La Pira 4, Florence 50121, Italy

[3] Freelance Scientist, Pietrasanta, Lucca, Italy

[4] C.N.R. – CNR Institute of Heritage Science, Via Madonna del Piano, Sesto Fiorentino, Florence, Italy

Published online: 22 May 2026

Brecce di Seravezza-Scisti a Cloritoide (belonging to the Apuan Unit).

The archaeological literature describes occasional uses of these breccias during the Roman Imperial Age, especially (but not only) in Rome (Pilla 1845; Lazzarini 1990; De Vecchi and Lazzarini 1994; Pensabene and Bruno 1998; Bruno 2002; Bartelletti and Amorfini 2003; Taelmann et al., 2019). Such information was supported by an archaeometric investigation of mineralogical-petrographic compatibility on Roman finds bearing autoptic resemblance (Bartelletti and Amorfini 2003); Taelmann et al., 2019documented the earliest in situ large-scale attestation of the *Breccia Medicea* in a Roman archaeological context, in the flooring decoration of the Roman Theatre of *Urvinum Mataurense* (Urbino, Marche, central Italy).

It is necessary to highlight an important archaeometric aspect, namely the strong similarity between *Breccia di Seravezza s.l.* and the famous Greek marble from Skyros, also known as *Breccia di Sciro* or *Breccia di Settebasi*, which is one of the most widely used coloured stones throughout the Roman period (Lazzarini and Turi 1999) and sometimes reused during the Middle Ages (Bartelletti et al. 2005–2006).

The importance and fame of these polychrome marbles began to spread rapidly in Italy and Western Europe with the decision of Grand Duke Cosimo I de' Medici to make them an ornamental stone, first exclusive and then symbolic of his gran-ducal power. The careful exploitation of the Brecce began in 1563 in Monte di Stazzema, in a quarry called *Filone del Granduca* (Grand Duke Vein) or *Filone bandito* (reserved Vein). The material was supplied for sculpture and architecture works to some of the greatest artists of Tuscan Mannerism (Bartolomeo Ammannati, Giambologna, Giovanni Fancelli, Francesco Mosca, Antonio and Battista Lorenzi, etc.) (Fabretti and Guidarelli 1980). The best example of the value of this lively and meaty marble can be read in Michelangelo's tomb in Santa Croce in Florence, where Giorgio Vasari designed and made the sarcophagus with the *Brecce di Seravezza* s.l. (Bartelletti et al. 2022–2023).

The Medici's quarrying activity imposed these polychrome breccias everywhere among the main ornamental stones of the Baroque, especially when the chromatic explosion of the coloured marbles was most intense. From that time onwards, private individuals opened other quarries to extract similar lithotypes, near the *Filone del Granduca* (Rondone, Piastraio, Tino) and in other places in Alta Versilia (Petarocchia, Grotte Bianche, Montalto, Corchia, Polla dell'Altissimo, ecc.), supporting a further diffusion of these materials. In the same periods, new types and varieties of *Brecce di Seravezza* s.l. were researched and exploited also in other areas of the Alpi Apuane (e.g. in Massa and Fivizzano areas). Today, we find them used mainly in altars, balustrades and floors of Catholic churches built or modified during the Counter-Reformation, but also in architectural elements (portals, columns, fountains, fireplaces, etc.) of villas, palaces and castles of noble and aristocratic families in Tuscany (Italy) and all over in the world. Therefore, the *Brecce di Seravezza* s.l. form currently a unique geo-cultural heritage esteemed internationally, together with the white and grey marble of the Alpi Apuane (Amorfini and Bartelletti 2013). Not for nothing, the same area has been recognized since 2015 as a UNESCO Global Geopark, within the International Geoscience and Geoparks Programme (IGGP), also for the contribution offered by its geomaterials to artistic and architectural productions inside and outside the UNESCO cultural sites (Bartelletti et al. 2015).

The first lithotype extracted in the *Filone del Granduca* was a particular variety of the *Brecce di Seravezza* s.l., called *Mistio* or *Mischio di Seravezza* already at the end of the 16th century (Del Riccio 1597). In this denomination, *Mischio/Mistio* (mixed) replaced the term *Breccia*, since this lithotype showed a "mass of simple and uniform limestone paste, with veins and shades of different colours variously arranged" and not "angular limestone fragments in a matrix of variable nature" (Simi 1855) (Fig. 1a). Furthermore, the toponym *Seravezza* is still confirmed in this denomination – even if the *Filone* quarry is in the Stazzema area – because

Fig. 1 (**A**) *Mischio di Seravezza* variety belonging to the *Brecce di Seravezza* s.l (Collegiate Church of San Martino-Pietrasanta); (**B**) *Breccia Medicea* variety belonging to the *Brecce di Seravezza* s.l (Fountain of Neptune by Bartolomeo Ammannati, Florence); (**C**) *Breccia Medicea* variety belonging to the *Brecce di Seravezza* s.l (Collegiate Church of San Martino-Pietrasanta)

in the first location the Medici family had its seasonal residence and, from here, it followed the quarrying activity.

However, the *Brecce di Seravezza* s.l. appear more frequently, in almost all types and commercial varieties of the same formation, as polymictic and polychrome metabreccias, formed by predominantly white clasts, elongated in shape and different sized, often together with other grey to yellowish and something purple clasts, in a scarce matrix showing conspicuous colourations (red, yellow, green, but also purple of different shades) (Figs. 1b, c).

The most famous and appreciated commercial variety of *Brecce di Seravezza* s.l. is the *Breccia medicea* (=Medici's Breccia) that always has an evidently brecciated appearance. Over time, the same name has also been attributed to different lithotypes and sometimes even belonging to other geological formations, increasing the confusion in its autoptic determination. More correctly, the *Breccia medicea* is recognized by the purple-violet coloration of the matrix and of some clasts, confirming the general descriptive characteristics of the *Brecce di Seravezza* s.l., reported above. Another fundamental indicator is its provenance from quarries located near Monte di Stazzema. Furthermore, in the typical *Filone del Granduca* or *Filone bandito* outcrop, the *Breccia medicea* is adjacent to the *Mistio/Mischio di Seravezza*, suggesting a possible lateral or vertical variation of facies, from which a clast-dominant texture in the first case and a matrix-dominant texture in the second (Bartelletti 2022-23).

Geological Background

The Apuan core ("Autoctono Apuano" Auctt.) is made up of different Tuscan-type metamorphic units (Apuan Unit covered by Massa, Stazzemesi and Panie Units) that represent the deepest outcropping ones of the Northern Apennines. These Tuscan Metamorphic Units includes Paleozoic to late Oligocene formations (Fig. 2) that suffered low grade metamorphism during the late Oligocene-early Miocene syn-collisional stages of the chain (Carmignani and Kligfield 1990; Conti et al. 2019a; Vai and Martini 2001 and references therein). In this frame, the *Breccia di Seravezza-Scisti a Cloritoide* formation of Norian/Rhaetian-Hettangian p.p. age (Fig. 3) is a peculiarity not only for the geo-lithological point of view of the.

Alpi Apuane metamorphic "core", but also in the paleoenvironmental and sedimentological evolution of the Mesozoic carbonate platform in Tuscany (Giglia and Trevisan 1966; Ciarapica and Passeri 1978, 2005). This formation crops out discontinuously as lenticular bodies, usually less than 100 m long and with a thickness from decimetric to about 40–50 m only in the central-eastern and southern parts of the Apuan Unit (Ciarapica and Passeri 1978; Conti et al. 2019b; ISPRA 2007), whereas it is lacking in the other coeval Tuscan-Umbrian successions of the Northern Apennines (Fazzuoli et al. 1985, 1994; Ciarapica and Passeri 2005). From a stratigraphic point of view, the *Brecce di Seravezza-Scisti a Cloritoide* formation is present in different unconformable position in the upper part of the Late Triassic epimetamorphic successions of the Alpi Apuane (Fig. 3): (a) between the Triassic *Grezzoni* and *Marmi a Megalodontidi*; (b) between the *Marmi a Megalodontidi* and the overlying Liassic *Marmi dolomitici/Marmi*; (c) between *Grezzoni* and Liassic *Marmi* where *Marmi a Megalodontidi* are lacking (Ciarapica and Passeri 1978; Carmignani et al. 2006; Conti et al. 2019). The lower contacts are erosive with paleosoils and modeled by paleokarst. The *Brecce di Seravezza-Scisti a Cloritoide* formation traditionally is linked to the tectonic-sedimentary evolution of thedolomitic *Grezzoni* hiperhaline carbonate platform (Ciarapica and Fazzuoli 1976; Ciarapica and Passeri 1978). This platform was mostly characterized by shallow water conditions, apart from a local emersion and karst shown by the *Brecce di Seravezza-Scisti a Cloritoide* formation. From a lithological point of view, this unit is made up of a polymictic metabreccia including deformed heterometric (millimetric to pluridecametric/metric in size) white, pink, red, yellow, light green or grey mostly carbonate clasts (marble, impure marbles i.e. *Marmi Cipollini* and minor dolostone and carbonatic phyllites), rare metabauxite/laterite, Mn-rich rocks and cherts in a red-violet, white greenish, greenish to yellow whitish calc-phyllitic matrix often with Fe-oxides pigment and, at times, with chloritoid and/or epidote. Franceschelli et al. (1996) demonstrated the continental nature of the matrix of the breccias which originally derived from residual lateritic soils highly enriched in titanium, iron and alumina formed in a hot, arid/semi-arid subtropical climate. Locally (see Monte Corchia area in Franceschelli et al. 1996), the matrix is manganese-rich (up to MnO 69%, mostly braunite, piemontite and hollandite) or Mn is concentrated in massive homogeneous compact metallic black beds and ores, decimetric in thickness.

The features of these ornamental stones vary, due to the size of the clasts and the colour, to the provenance from one quarry to another and within the same quarry depending on its statigraphic level, giving rise to different typologies of breccias (see also Franceschelli et al. 1996).

In different places, a centimetric to metric horizon of dark grey-green, chloritoid-bearing phyllites and phyllitic quartzites (*Scisti a Cloritoide* o *Scisti ottrelitici* Auctt.), locally associated to metabreccias and impure marbles, occurs at the top of the *Brecce di Seravezza-Scisti a Cloritoide* or they are interposed between *Grezzoni* and *Marmi* where the Breccias are lacking or strongly reduced (e.g. in the NE-E Apuan core) (Ciarapica and Passeri 1978; Franceschelli et al. 2003).

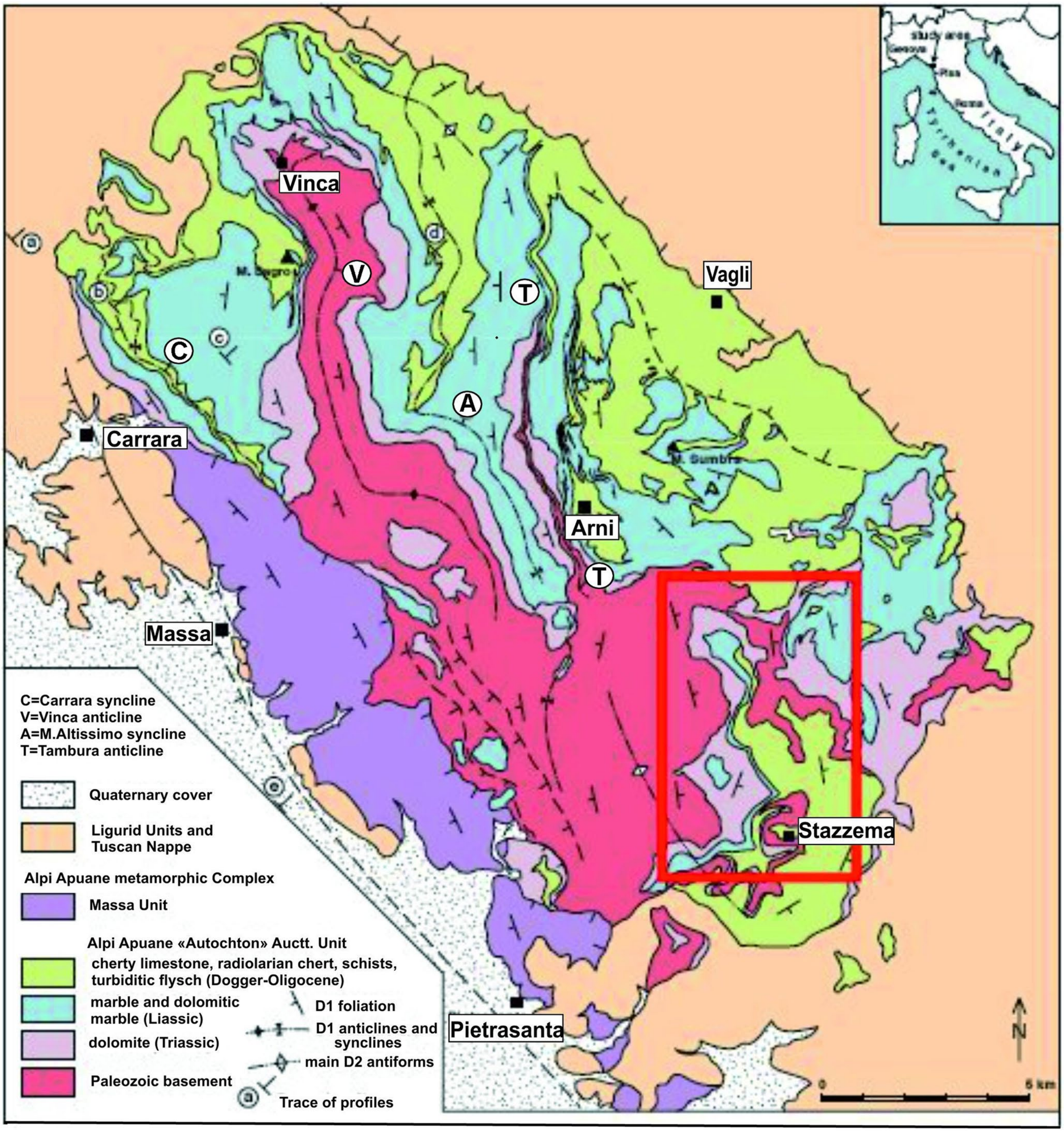

Fig. 2 Geological sketch map of the Alpi Apuane. The studied area is squared (after Conti et al. 2019a; Carmignani et al. 2006; modified)

Together with the other Palaezoic to Tertiary formations of the Apuan core (Tuscan Metamorphic Units), the *Brecce di Seravezza-Scisti a Cloritoide* suffered a low grade polyphase high pressure-low temperature metamorphism (P=0.4–0.6 GPa and temperatures of T=350°-380 °C, according to (Franceschelli et al. 1996, 1997) or about 0.8 GPa and T=340°–410 °C, according to (Jolivet et al. 1998 and Franceschelli et al. 2004) and three main superimposed deformation phases (see Kligfield 1979; Coli et al. 1988; Moratti et al. 1989; Coli and Pandeli 1992) and references therein:

D1 27 Ma in (Kligfield et al. 1986) - It represents the main shortening event characterized by the metamorphic peak and producing isoclinal folding at every scale with a very transpositive continuous schistosity (S1) with a tectonic transport to the NNE/NE.

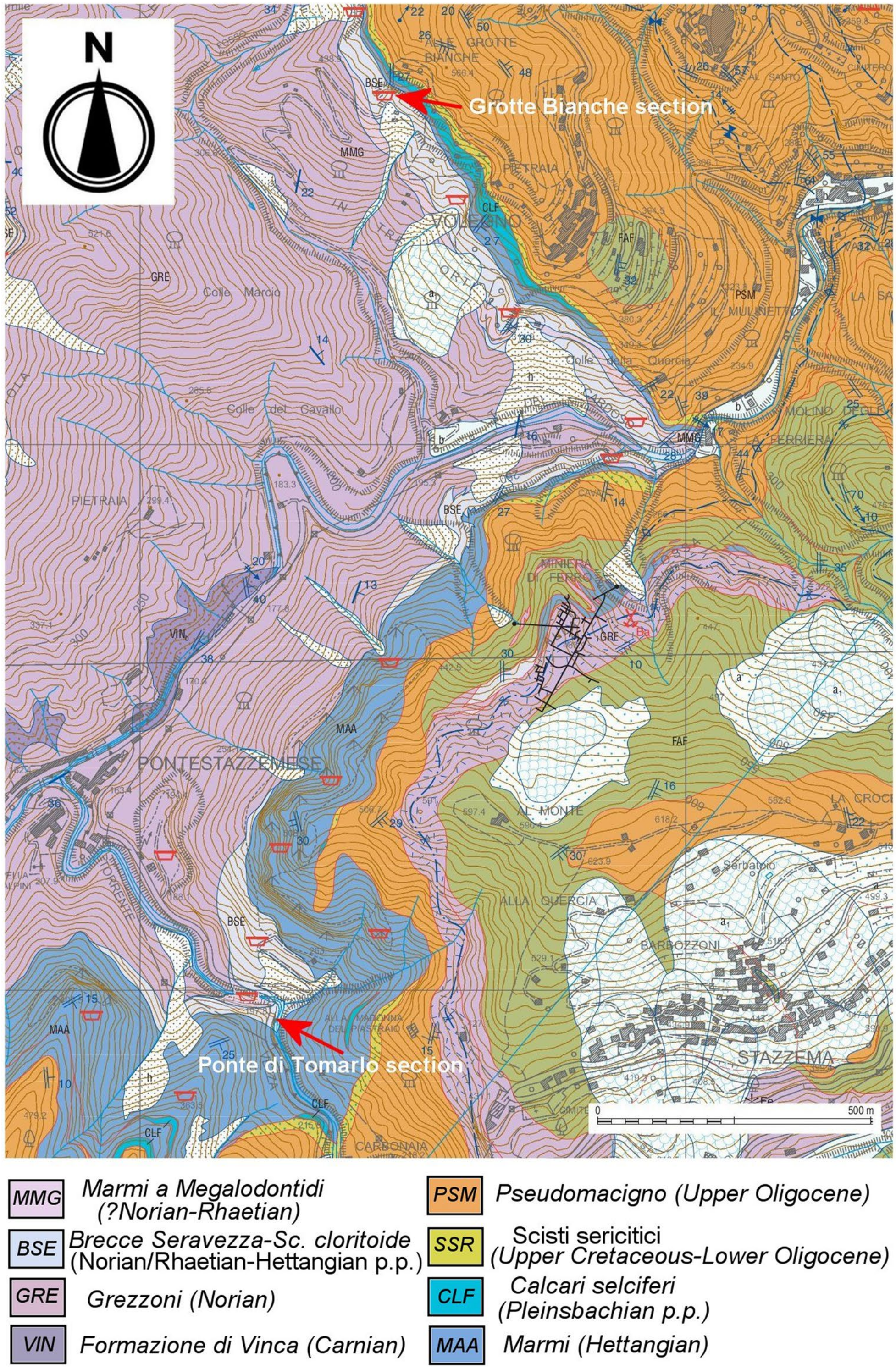

Fig. 3 Geological map of the Pontestazzemese-Stazzema-Vologno area with the location of the two studied sections (after Conti et al. 2010, modified)

D2 14−12 Ma in (Kligfield et al. 1986) – It generally consists of a close to tight folding with a sub-centimetric to centimetric, zonal to discrete crenulation cleavage (S2). These folds are generally coaxial with F1 and with both NNE and SSW vergences on the two sides of the Apuan core (*Doppia vergenza apuana* Auctt.).

D3 about 12−10 Ma in (Kligfield et al. 1986) – it is characterized by metric to decametric, open to gentle folds that undulate the previous tectonic framework with a weak centimetric-spaced fracture or zonal cleavage.

In the classical view of Carmignani and Kligfield (1990) considered D2 and D3 due to the extension and uplift of the metamorphic “Apuan Core complex”; instead, other Authors put also D2 in a polyphase shortening evolution coupled with syn-orogenic extension (Fazzuoli et al. 1994; Jolivet et al. 1998; Bortolotti et al. 2001 a; Carosi et al. 2004).

The *Brecce di Seravezza* are considered as the evidence of the local emersion and karst of a part of the late Triassic carbonate platform due to sin-sedimentary tectonics (i.e. block faulting) just active also in the underlying *Grezzoni* (Ciarapica and Passeri 1978). They can be interpreted as debris flow deposits at the base of the footwall scarp of normal faults bordering extensional marine coastal basins and dismantling local tectonic highs made up of karstified carbonate successions and paleosoils (Carcangiu et al. 1992; Franceschelli et al. 1996). Instead, the *Scisti a Cloritoide* represent a continental paleosoil (metabauxites) referable to weathering of the underlying breccias or the other Late Paleozoic-Triassic rocks in sub-aerial conditions after the general emersion of the late Triassic carbonate platform and before the beginning of the Liassic transgression that produced a new carbonate platform (*Marmi dolomitici/Marmi* formations) (Franceschelli et al. 1996; 1998; 2003).

Materials and Methods

Sampling Area and Selected Materials

The locations of the two studied and sampled sections are reported below (see geological map in Fig. 3):

- Cava del Rondone section c/o Pontestazzemese (32T 604214.40E 4871928.35 N, 210 m asl) (Fig. 4A). The section was measured along the road from Pontestazzemese to Mulina (west of Stazzema) just after the Ponte del Tomarlo. Additional observations were performed in the correspondent nearby latomia-type Cava del Rondone (Fig. 4B) and in other historical *Breccia medicea-Mischio di Seravezza* quarries on the other side of the valley. The quarries provided most of the material used for coverings and decorations during the Medicean times in Tuscany, especially at the court of Cosimo I de’ Medici, Grand Duke of Tuscany (XVI century AD).
- Cava Grotte Bianche section c/o Volegno (32T 604450.39E 4873607.42 N, 515 m asl). This quarry is to the NW of Volegno and consists in a lower and an upper part (Fig. 4C, D). This quarry was opened in the second half of the nineteenth century and its great fortune was during the Liberty period between the two World Wars. The excavations were finished during 1970s.

Considering the evident vertical lithological variations present inside the examined sections, the different lithotypes were sampled and described together with their mesoscopic structural features. From these we chose 14 representative samples (8 from Cava del Rondone section and 6 from Cava Grotte Bianche section, see Figs. 5 and 6 respectively) to perform detailed laboratory analyses of them.

Methods

After the mesoscopic analyses, petrographic and microstructural observations in polarized light (PLM) were performed through thin sections of the samples using the microscope Zeiss Axioscope A.1 (Carl Zeiss, Jena, Germany), equipped with a 5-megapixel resolution video camera and Zen lite 3.1 image analysis software defining texture/structure and mineralogical characteristics of the rocks (UNI EN 2007).

In addition, mineralogical qualitative analyses were obtained by X-ray powder diffraction (XRPD) on bulk powder samples, using a Philips PW 1050/37 diffractometer (Philips, Almelo, The Netherlands) coupled with a Philips X’Pert PRO system for data acquisition and interpretation. The detection limit for this method is 4%. The operating conditions included 40 kV and 20 mA, a Cu anode, a graphite monochromator, and a goniometer speed of 2 μ/min goniometry in the range of 5–70° 2Θ (UNI-EN 2006; UNI-EN 13925-2 (2006); UNI-EN 13925-3 (2006)).

Scanning Electron Microscope Energy-Dispersive Spectroscopy (SEM-EDS) analyses were performed to obtain semi-quantitative microchemical composition and textural characterizations [29]. A scanning electron microscope (SEM) ZEISS EVO MA 15 (Carl Zeiss, Jena, Germany) equipped with a W filament and an analytical system in the dispersion of energy (EDS/SDD), specifically the Oxford Ultimax 40 (with a 40 mm2 area and resolution of 127 eV 5.9 keV), was employed. The measurements were conducted on thin sections after carbon-metallized treatment. The operating conditions were as follows: 15 kV acceleration potential, 500 pA beam current, 9–8.5 mm working distance. For point analyses, a 20 s live-time acquisition rate was employed to achieve at least 600,000 cts on a Co standard, a processing time of 4 was used for map acquisition, and a 500 μs pixel dwell time with a resolution of 1024×768 pixels was used. The microanalysis was carried out using Aztec 5.0 SP1 software, utilizing the XPP matrix correction scheme developed by Pouchou and Pichoir (1991). The process used acquired standard elements for calculations, enabling “standard-less” quantitative analysis. The use of numerous analyses of a cobalt metallic standard permitted the documentation of constant analytical conditions (i.e., filament emission).

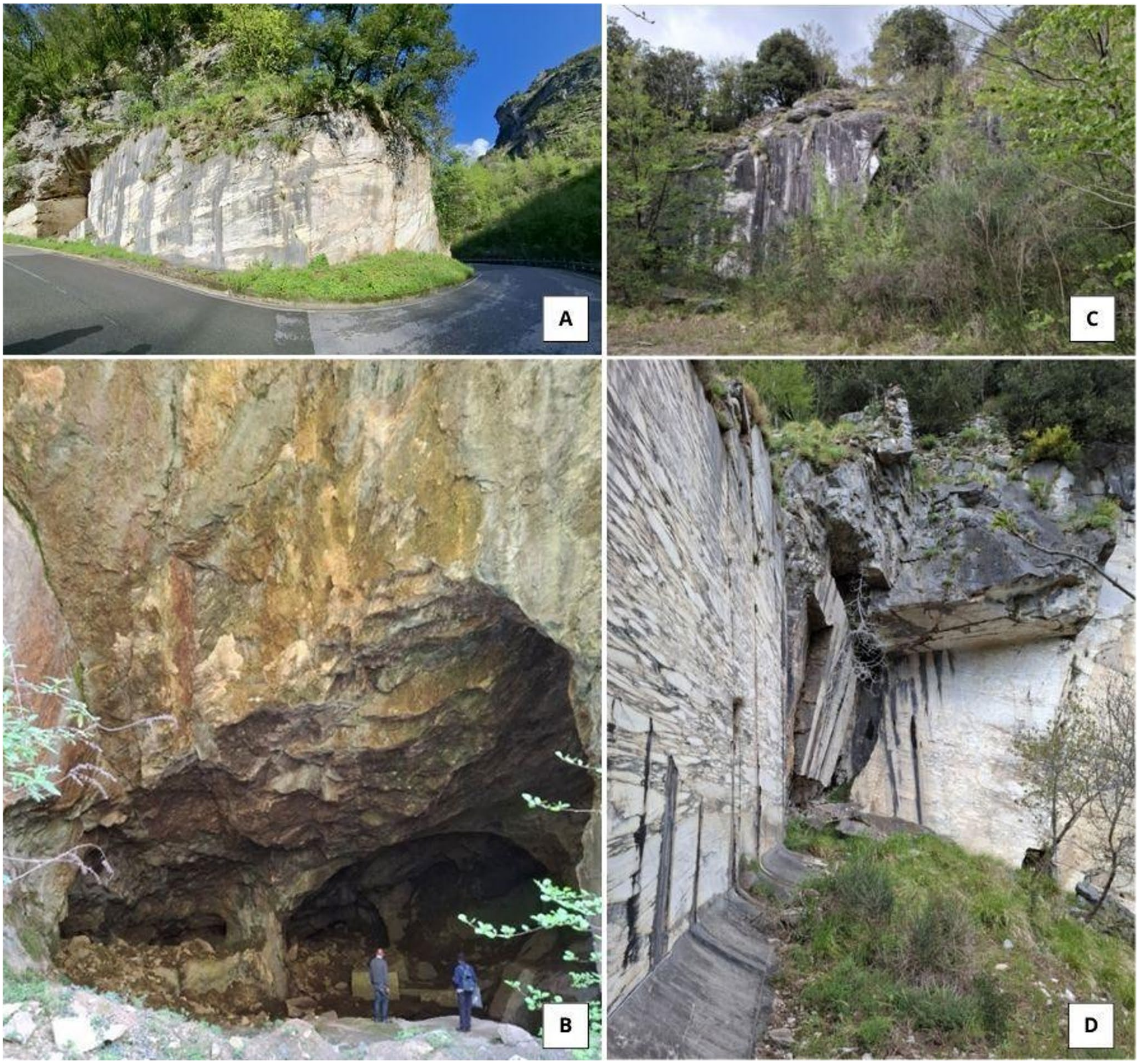

Fig. 4 (**A**) Cava del Rondone section along the road from Pontestazzemese to Mulina just after the Ponte del Tomarlo (c/o Pontestazzemese); (**B**) Latomia-type Cava del Rondone close to the Ponte del Tomarlo (c/o Pontestazzemese); (**C**) Lower part of the Cava Grotte Bianche (c/o Volegno); (**D**) Upper part of the Cava Grotte Bianche (c/o Volegno)

Results

Lithostratigraphic Data

The two sections of *Brecce di Seravezza-Scisti a Cloritoide* are stratigraphically interposed between the *Marmi a Megalodontidi* (massive or coarsely stratified white to light grey marbles that include small lenticular dark grey areas), at the bottom, and *Marmi* (white marble and grey *Bardiglio* marble with local dolomitic marble interbeds), at the top (see Fig. 3). The "classical" feature of the*Brecce di Seravezza* s.l. used in arts and architecture (consisting in a "disorganized" breccia with whitish to reddish marble and minor dolomitic marble pebbles to boulders in a reddish/violet, foliated carbonatic-phyllitic matrix) is recognizable only in some parts of the sections. The matrix/clast ratio is <1 to <<1 (often the matrix is between 35 and 15% in volume), but locally the clasts are in contact.

Commonly, the clasts of the Breccia are deformed and aligned along the main schistosity S1 that is very pervasive in the matrix; the S1-foliated matrix always wraps the clasts. S1 is then deformed by close D2 folds with zonal-type crenulation cleavages (see later Fig. 7E).


BM1
BM2
BM6
BM5
FB
10 cm
BM7
PT2bis
10 cm
10 cm
PT2

Fig. 5 Analysed samples from Cava del Rondone section

A synthetic lithological description of the two sections is below:

Cava del Rondone section (see Fig. 4A).

The total thickness is about 26 m. The following parts can be distinguished:

1. A Lower-middle part characterized by whitish-yellowish breccia. This is constituted by an heterometric breccia white and minor clasts with yellowish impregnations (Samples BM1 and BM2 in Fig. 5). In the basal portion, some whitish clasts include a peculiar gray/dark gray internal part (Fig. 7A). The size of the clasts varies from centimetric to decametric (up to 1.30 cm in length) (Fig. 7A and B) and sometimes they show a notable packing.
2. A varicoloured middle-upper part represented by:

a. basal and upper, 5–6 m-thick breccias with reddish and pinkish clasts in an ochre/reddish, but locally variegated (from light grey, silvery-pearlish, purple-red and sometimes greenish/dark grey) foliated matrix (Sample BM6 in Figs. 5 and 7B and Sample BM7 in Figs. 5 and 7F). The heterometric clasts can reach lengths of more than 80 cm (whitish marble boulders up to 120 cm thick and more than 2 m in length are also locally present, see Fig. 7B).
b. Intermediate about 260-thick horizon mostly consisting in breccias with white and pink marble elements (max lengths up to 90 cm), in a more foliate and locally prevalent, schistose greenish/grey to blackish matrix, often rich in epidote crystals (Sample BM5 in Figs. 5 and 7C). This horizon also includes two peculiar intercalations, made up of a 25 cm thick breccia characterized by elongated (generally 5–13 cm long) grey pinkish, rarely whitish clasts, strongly packed and with a scarce greenish to violet matrix (Fig. 7C and D) and a 30 cm breccia (*Filone del Granduca* or *Filone Bandito* typical level) that contains millimetric to centimetre-sized, well packed white to pink clasts often with typical purple-reddish cores (Sample FB in Figs. 5 and 7C and E).

c. An about 1 m-thick chloritoid-rich top level (Fig. 7G). It consists of a basal breccia with mostly white marble centimetric clasts in a grey-green, chloritoid-bearing matrix (Sample PT2bis in Fig. 5; CB in Fig. 7G) and a top 10–15 cm-thick granular "salt and pepper" – type, chloritoid-rich phyllitic quarzite level (Sample PT2 in Fig. 5; CQ in Fig. 7G).

Cava Grotte Bianche section (see Figs. 4C, D).

The total thickness is about 30–35 m, and it is represented by:

1. An about 10 m-thick lower part in which a metric whitish-yellowish breccia (Sample BM3 in Figs. 6 and 8A) similar to that of Cava del Rondone section passing upward into breccias with mostly white and subordinately pinkish/yellowish and reddish clasts, in a grey to greenish calcschist-phyllitic matrix sometimes with purple/reddish to pinkish areas (Samples BM4 and GB2 in Fig. 6).
2. Cover of about 4–5 m.
3. A middle-upper part. At the base there is about 1 m of breccia with mostly pink and subordinately whitish clasts of centimetre size (max 10–15 cm) that are mostly elongated and strongly packed with scarce dark green matrix (pb in Fig. 8B). It passes laterally to finer-grained breccias and coarse-grained sandy lenses in a locally abundant dark green matrix (Fig. 8C). Then, about 15 m thick, disorganized and strongly heterometric breccias with white, sometimes yellowish and subordinately pinkish marble clasts follow (Fig. 8B and C). They are strongly heterometric from centimeter-decimeter size to 90 cm in length and 25–30 in thickness (exceptionally 250 cm and 30–40 cm, respectively) and are mostly elongated with respect the main schistosity S1. The scarce matrix (max 25% respect to the clasts) is generally often micaceous and grey green in colour, but locally it is brown-yellowish and more carbonatic when the clasts are close or in contact (sample GB5 in Figs. 6 and 8D). Instead, in the breccias of the upper part of the interval, the matrix is usually phyllitic, dark green in colour and shining. This breccia body includes:

a) a lenticular horizon of about 80 cm-thick breccias (about 2 m from the base) similar to the basal ones (plh in Fig. 8E, F).

b) mainly phyllitic green/dark green lenticular horizons (glh in Fig. 8E) in the middle-upper part of the breccia body. This phyllitic horizons includes dispersed or variously packed whitish and pinkish clasts of centimetre/decimetre dimensions (max 30 cm long 15–20 thick) (Sample GB4 in Fig. 6) and lenses of breccias, over 3 m long and 30–40 cm thick, that are characterised by a high concentration of the centimetre- sized clasts (Fig. 8G).

A decimetric level of varicoloured, greenish to reddish/violet breccia characterizes the uppermost part (vb in Fig. 8H) of the interval 3.

4. The top part of the section consists of about 1.5 m of breccias with white and pink clasts of centimetre/decimetre size dispersed in a dominant greenish matrix (gh in Fig. 8H).

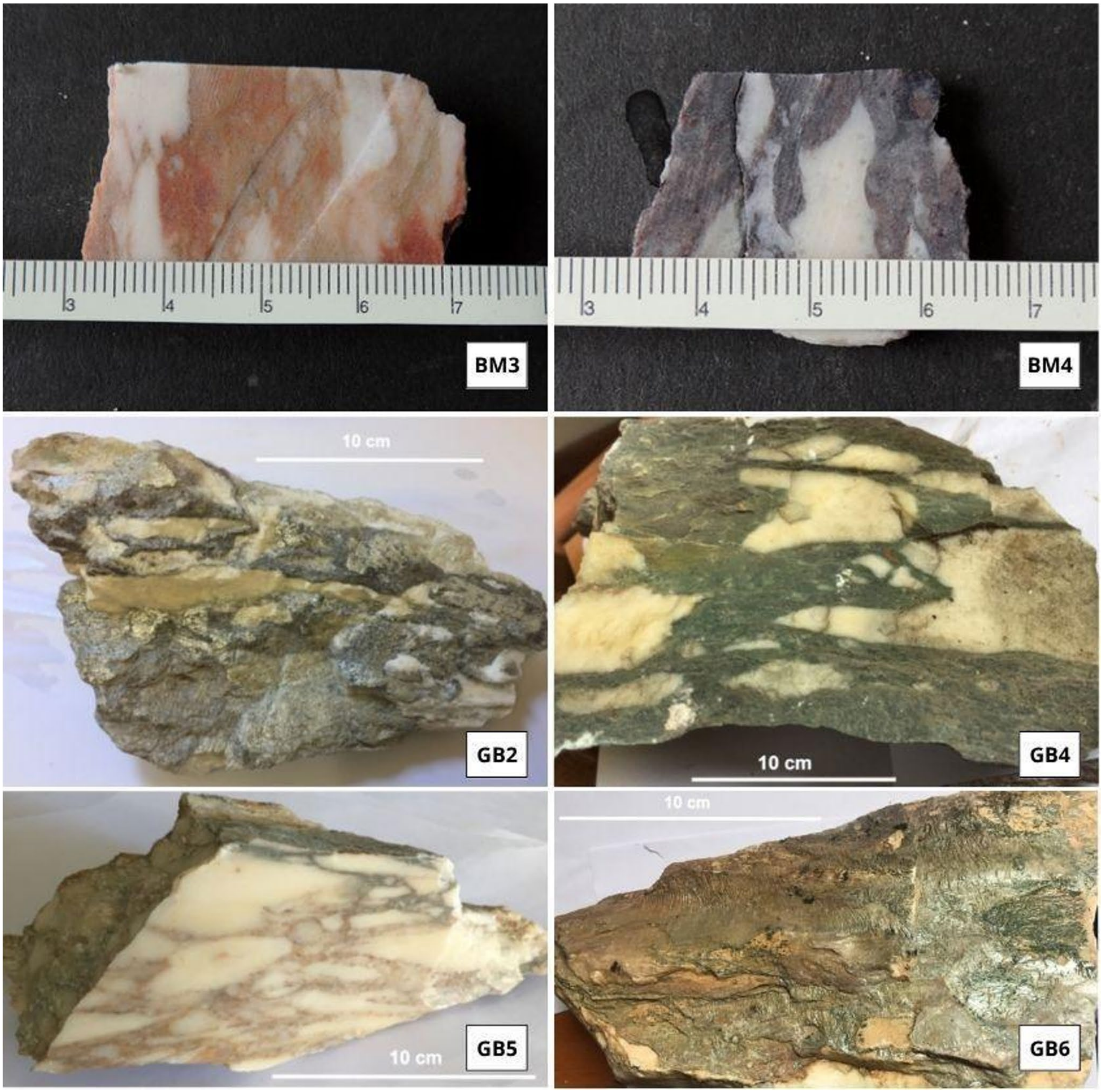

Fig. 6 Analyzed samples from Cava Grotte Bianche section

Petrographic and Mineralogical Data (PLM)

Some of the samples collected in the two quarries show strong similarities not only for a lithological, but also for a petrographic point of view. Others are peculiar of one quarry and of the stratigraphic level in the section. In Fig. 9A the typical blasto-psephitic texture of the *Brecce di Seravezza* s.l. is shown at a mesoscopic scale and at reflected light. The petrographic-mineralogical features of the different groups of similar samples are described below:

BM1, BM2, BM3

These whitish to yellow breccias, present in the basal part of the two sections, include mostly white hematite-free marble clasts characterized by the following textures: (a) Medium-grained (max 0.4 mm) granoblastic with polygonal texture with planar junctions (Fig. 9B); (b) Medium-to fine-grained (generally between 0.2 and 0.08 mm) granoblastic, often with concave/convex junctions, from homeoblastic to heteroblastic (Fig. 9C).

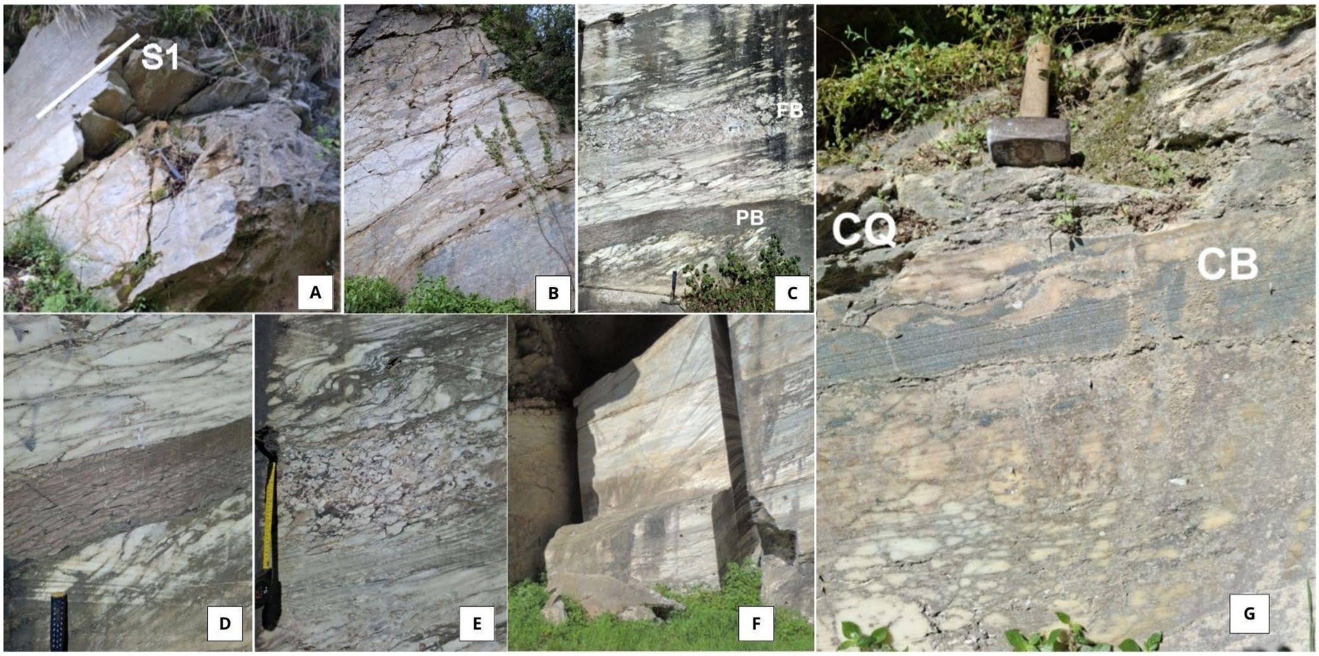

Fig. 7 Lithologies in the Cava del Rondone section. (**A**) Basal breccias; (**B**) Vertical passage from the whitish- yellowish breccia to heterometric breccia with whitish, reddish and pinkish clasts in a reddish foliated matrix including a marble boulders in the middle; (**C**) Pinkish grey breccia (PB) and *Filone Bandito* (FB) levels in the varicoloured horizon; (**D**) Pinkish grey breccia intercalation (PB in Fig. 7C); (**E**) *Filone Bandito* intercalation (FB in Fig. 7C), in the upper part of the picture some F2 close folds deform S1; (**F**) Heterometric breccias with predominantly whitish, yellowish and pink-red clasts in a varicoloured matrix; (**G**) Chloritoid level at the top of the heterometric varicoloured breccias, CB=Chlorite, chloritoid-bearing breccia; CQ=Chloritoid-rich phyllitic quartzite

Rare fine-grained, granoblastic pink clasts with small scattered or rarely about isoriented muscovite and hematite pigment are also present.

The matrix between the clasts presents a prevalent calcitic heterometric blasto-psammitic texture with variable amount of scattered or aligned Fe opaque grains/ pigment and sericite/muscovite (Fig. 9D); muscovite flakes can be locally concentrated along clast/matrix contact. Rare areas of fine/very fine-grained calcitic/marly matrix with diffuse iron oxide/hydroxide pigments and small dispersed muscovite blasts can be locally present (Fig. 9E).

BM4 and GB2

It was defined only in the lower part of Cava Grotte Bianche just over the basal yellow breccias. These breccia with varicoloured matrix contains mostly marble clasts that are characterized by hematite-free, medium to medium-fine/ fine- grained granoblastic, approximately homeoblastic, texture with contacts from flat to concave/convex that include typical quartz porphyroblasts (from ipidiomorphic to granular xenomorphic), max 0.5–1 mm in size (Fig. 9F). The quartz porphyroblasts often contain calcite granulations at the core and are cut by the borders of the clasts. Pinkish, fine/very fine grained granoblastic marble clasts rich in small muscovite/sericite and with iron oxide pigment can be locally present. The foliated blasto-psammitic to phyllitic matrix of the breccia contains variable amounts of muscovite/sericite and Fe-oxides pigment.

BM5

This breccia is present only in the Cava del Rondone area and constitutes two horizons below and above the *Filone Bandito* level, respectively. The examined sample can be divided into two parts: a blasto-psephytic one (a) where large whitish clasts are present, stretched along S1, in contact or separated by a very reduced calcitic-phyllitic matrix, and a lepidoblastic (b) of dark grey/black colour with locally scattered few small white marble clasts.

The clasts are hematite-free and are medium- to medium/ fine- grained, from homeoblastic to locally heteroblastic with concave-convex junctions, sometimes with scattered small muscovite. Rare heteroblastic, medium grained marbles with often twinned blasts characterized polygonal to concave/convex junctions were also distinguished.

In b) the texture is mostly lepidoblastic consisting of sericite + abundant iron oxide pigment ± fine-grained calcite, but often is nematoblastic to diablastic for the presence of numerous epidote (clinozoisite) blasts (Fig. 9G). Their size is max about 2 mm and frequently they show boudinage structure filled by fine-grained calcite. Often, they appear

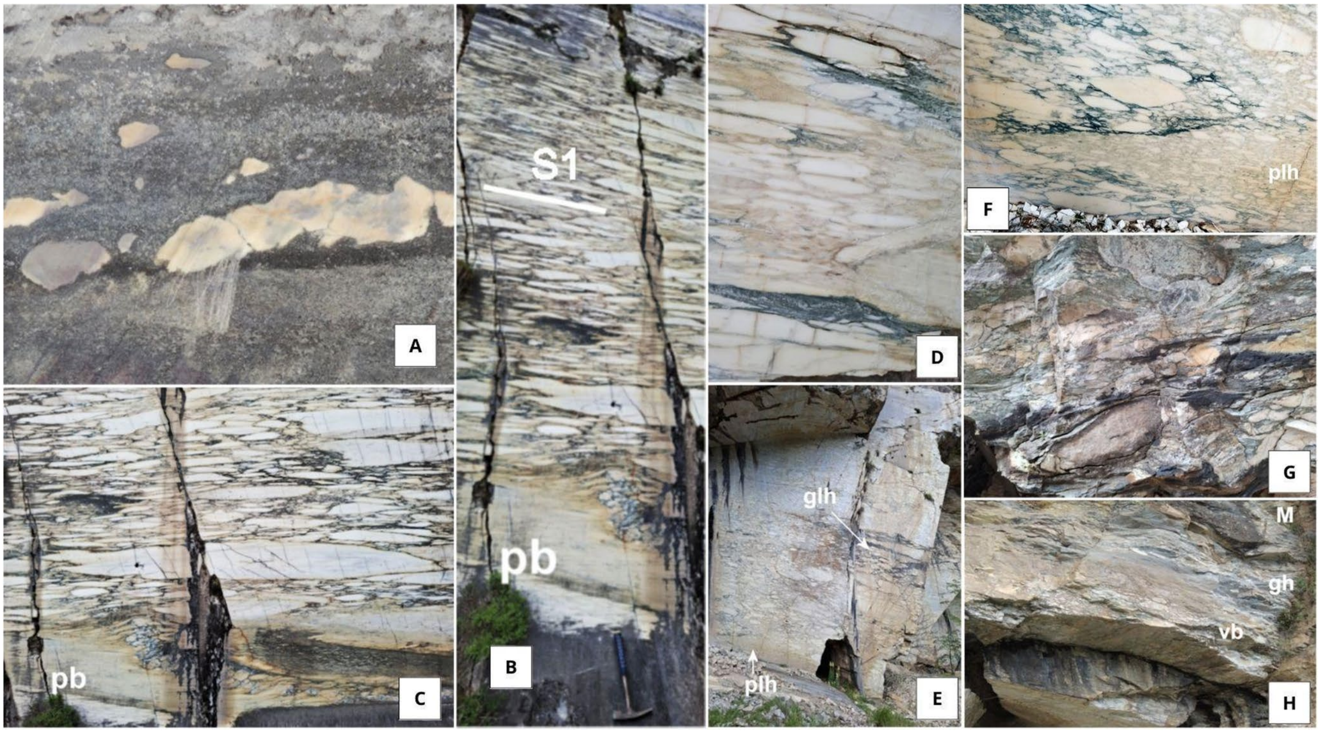

Fig. 8 Lithologies in the Cava Grotte Bianche section: (**A**) Basal yellowish breccia; (**B**) Pinkish breccia (pb) passing upward in the disorganized heterometric breccia in the lower part of the upper quarry; (**C**) Pinkish breccia (pb) passing laterally to finer-grained breccias and coarse-grained sandy lenses; (**D**) Magnification of the disorganized strongly heterometric breccia with dark green foliated or mostly carbonatic matrix; (**E**) Lenticular horizon of pinkish breccia (plh) and the mainly phyllitic, dark green horizon (glh) in the middle upper part of the upper quarry; (**F**) Magnification of the pinkish breccia lenticular horizon (plh in Fig. 7E); (**G**) Mainly phyllitic green/dark green lenticular horizon with whitish and pinkish clasts (glh in Fig. 7E); (**H**) Uppermost part of the Cava Grotte Bianche section: vb= varicoloured, greenish to reddish/violet breccia; gh = top greenish matrix-dominated breccias; M= Hettangian Marbles

partially or entirely opaque due to the replaced/ inclusions by abundant Fe pigment. Sometimes the epidotes cut the contact between clasts and matrix.

BM6 and BM7

These two samples, represented by a breccia with varicoloured clasts and matrix that are present in the middle and upper part of the Cava del Rondone section just below and above the black epidote-rich horizons.

Among the clasts the white ones with no hematite pigment and characterized by mostly medium- to medium/fine-grained, about homeoblastic texture, with plane to concave/convex contacts (Fig. 9H) prevail. The coarser-grained clasts sometimes show deformed twinnings and junctions also of sutured type.

The pinkish/reddish clasts (Figs. 9H) are generally homeoblastic, medium/fine grained to rarely medium/coarse-grained (max 1.6 mm), with junctions from plane to concave/convex and often show twinnings. Hematitic pigment tends to fill the interblastic spaces or partially diffuses in various blasts (also underling the twinning) (Fig. 9I). The phyllitic-carbonatic matrix includes Fe ox pigment, sericite, crystals and aggregates of muscovite, opaque grains and rare epidote.

PT2bis and PT2

These two samples represent the top part of the Cava del Rondone section. PT2 bis is a breccia with whitish, hematite-free, granoblastic with concave-convex junctions and medium/fine to fine-grained marble clasts in a locally dominant, foliated greenish chlorite-rich and muscovite-sericite (± calcite) matrix with scattered chloritoid and locally also epidote blasts.

Instead, the overlying PT2 is a foliated phyllitic (with muscovite-sericite and chlorite), medium/fine - grained quartzite which include many submillimetric sheaves of chloritoid (often opaque due to hematite pigment), hematite-pigment and rare blasts of epidote (Fig. 9J). The chloritoid sheaves are static above S1 but locally appear as deformed by S2. Chloritoid is also present within S1 and sometimes shows boudinage with fractures filled by fine-grained quartz.

GB5

It is the breccia of the intermediate-upper part of the Cava Grotte Bianche section. This matrix-poor breccia is characterized by whitish, hematite-free, marble clasts characterized by a medium to medium-fine/fine- grained granoblastic, approximately homeoblastic, texture with planar to concave/convex junctions. The matrix can vary from foliated muscovite/sericite and /or chlorite-rich to more carbonatic blastopsammitic and, yellowish-ochraceous in colour.

GB4

It represents the matrix-rich breccia associatedwith the lenticular greenish horizon in the middle-upper part of the Cava Grotte Bianche section. The clasts arelike a GB5 sample. They are included in a dominant foliated matrix constituted by chlorite and muscovite.

GB6

Also, this breccia, coming from the upper part of the Cava Grotte Bianche section, is made up of the same whitish marble clasts of GB4 and GB5. The greenish phyllitic matrix is reduced and locally purple/violet areas containing hematite pigment are also present.

Mineralogical Data (XRDP)

Mineralogical analyses were performed only on some bulk samples of Cava del Rondone and Cava Grotte Bianche above all, confirming the petrographic observations in thin sections. Samples belonging to Cava del Rondone contain calcite, quartz, clay minerals, mica (muscovite), and sometimes hematite with minor amounts of feldspars. A variable association of phyllosilicates (illite, chlorite and sometimes kaolinite) was identified. Epidote (the type of epidote cannot be discriminated by diffractometer analysis) and chloritoid were identified in the middle and the top samples of Cava del Rondone, respectively. Samples belonging to Cava Grotte Bianche show the presence of calcite, quartz, mica (muscovite), hematite, feldspars, clay minerals (illite) and dolomite.Some representative graphs of X-ray diffraction patterns of the Cava del Rondone and Cava Grotte Bianche samples, are reported in Supplementary Materials (S1).

Chemical Data (SEM-EDS)

In order to provide a more correct characterization of breccia's matrix and clasts composition, microchemical analyses were carried out in some samples to highlight similarities and differences (Lanterna, 1999). The selection of samples was based on macroscopical appearance of matrix and clasts colour. BM3 and BM4 samples from Cava Grotte Bianche have white clasts and respectively orange and violet matrix (Fig. 6). BM5 and BM6 samples of Cava del Rondone have white clasts and respectively black and red-purple matrix (Fig. 5).

The EDS layered maps of the samples BM3 (Cava Grotte Bianche, area in orange colour in the sample of Fig. 6) and BM4 (Cava Grotte Bianche, area in violet colour in the sample of Fig. 6) show that the matrix is mainly composed of carbonates and subordinate phyllosilicates for the presence of Fe, K, Ca, Si, Al, Mg; spots enriched in Fe content are widespread in most of the samples. The raster analysis of the areas shows that Fe is about 1% for sample BM3 and 3% for BM4. EDS maps also illustrate the presence of clasts in which Ca predominates (between 50 and 70%); a small amount of Mg (up to 2%) is present in sample BM3 (Figs. 10A, B).

The analysis of sample BM5 (Cava del Rondone, black area in the sample in Fig. 5) shows a phyllosilicatic matrix with a composition of Fe, Ca, K, Si, Al, Na. Theblack-coloured area also contains a high Fe amount (about 9% in the raster area) and epidote rhombohedral crystals with a composition of Si, Al and Fe; some spots are characterized by enrichment of Fe and Ti (Fig. 10C). The white coloured area in the macroscopic sample (Fig. 5) shows clasts in which Ca predominates (up to 70%) that are separated by a very reduced matrix, phyllitic in composition, with spots constituted by Fe and Ti (Fig. 10D). Also sample BM6 (red-purple area seen in the macroscopic sample of Fig. 5) is characterized by reduced phyllitic matrix consisting of Fe, Ca, K, Si, Al and Na (Fig. 10E). Locally, the latter shows a higher Fe content of 1.65–0.70% and small clasts with a Ca content of up to 60% (Fig. 10F). Anyway, no Mn was found in the examined samples.

Decay and Conservation Issue

The *Brecce di Seravezza* s.l., when polished and installed in cultural heritage buildings, exhibit a good state of conservation. This observation also applies to the *Breccia Medicea* and to the related variety known as *Mischio di Seravezza.* Nevertheless, these lithotypes can undergo alteration and decay, as is common with many other breccias, especially those exhibiting foliate textures due to dynamic-thermal metamorphism. Such textures lead to heterogeneity and discontinuity, which, in turn, represent points of mechanical weakness.

Regarding the alteration and decay of breccias, as with all rocks in general both internal and external factors should be considered. Internal factors depend on the mineralogical,

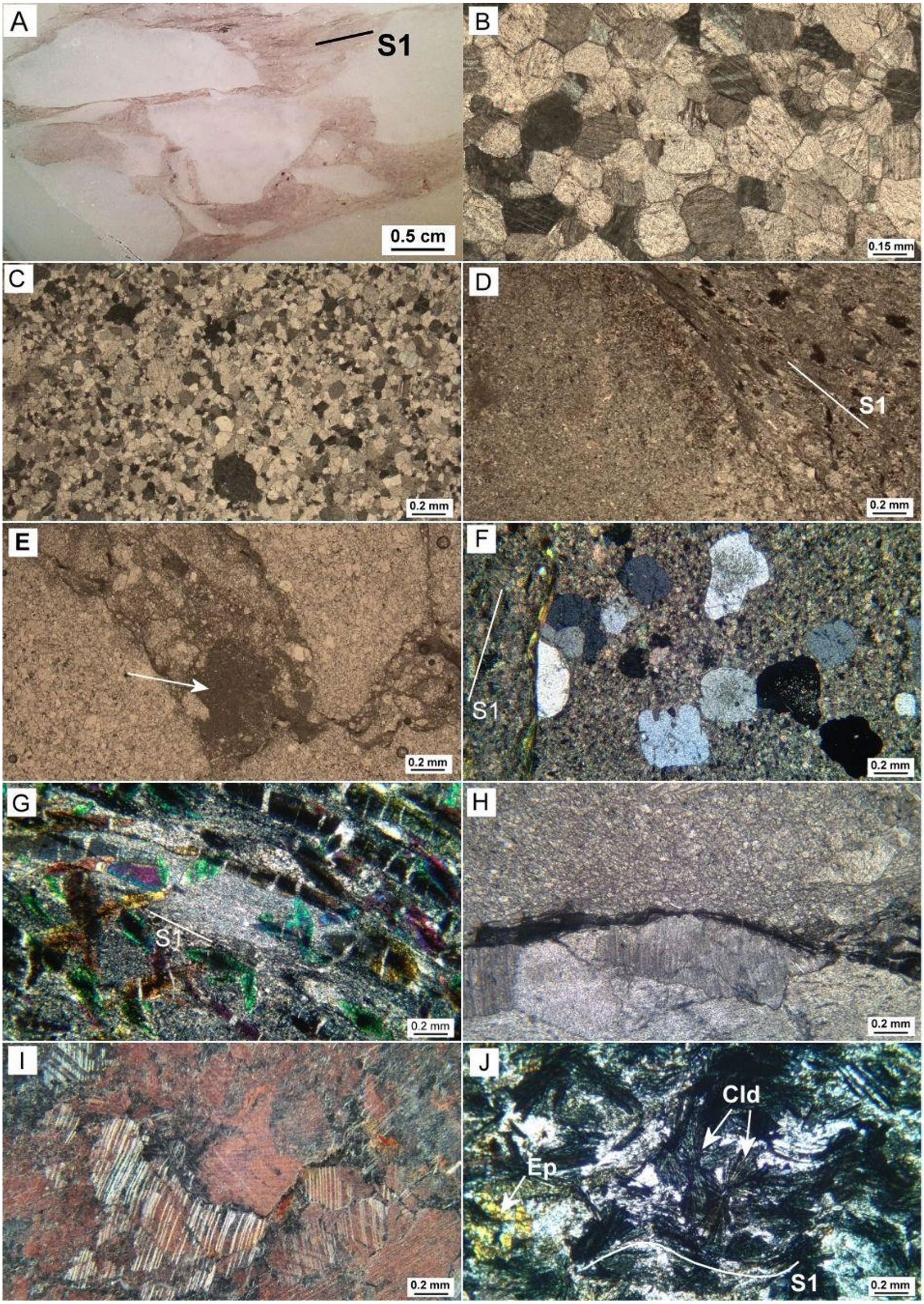
A
S1
0.5 cm
B
0.15 mm
C
0.2 mm
D
S1
0.2 mm
E
0.2 mm
F
S1
0.2 mm
G
S1
0.2 mm
H
0.2 mm
I
0.2 mm
J
Cld
Ep
S1
0.2 mm

Fig. 9 Photomicrographs of the *Brecce di Seravezza* samples : (**A**) Typical blastopsephitic texture at necked eye of the Sample BM4 in the Cava Grotte Bianche section (reflected light); (**B**) marble clast with medium grained granoblastic with polygonal texture in the Sample BM1 of the Cava del Rondone section (crossed polar); (**C**) marble clast with medium- to fine- grained, often with concave/convex junctions, heteroblastic texture in the Sample BM2 of the Cava del Rondone section (crossed polar); (**D**) sharp contact of a fine-grained, granoblastic impure pink marble clast and the foliated blasto-psammitic matrix in the Sample BM1 of Cava del Rondone section (crossed polar); (**E**) breccia with blastopsammitic matrix including an area of fine/very fine-grained calcitic/marly matrix (see arrow) in the Sample BM3 of Cava Grotte Bianche section (parallel polars); (**F**) marble clast including quartz porphyroblasts in the Sample BM4 of the Cava Grotte Bianche section (crossed polar); (**G**) darkish clinozoisite-rich, lepidoblastic/nematoblastic part of the BM5 Sample of the Cava del Rondone section (crossed polar); (**H**) contact between medium/fine-grained whitish marble clast and a medium/coarse-grained, reddish-pink marble including hematite pigment. Sample BM6 of Cava del Rondone section (parallel polars); (**I**) coarse-grained marble in Fig. 9h showing hematite-rich substitutions and inclusions. Sample BM6 of the Cava del Rondone section (reflected light); (**J**) chloritoid-rich phyllitic quartzite at the top of the Cava del Rondone section. Cld = chloritoid; Ep= epidote (crossed polars)

petrographic, chemical-physical and structural properties of the stone (Siegesmund and Snethlage 2014; Salvini et al. 2023). In the case of breccias, it is important that also the intrinsic characteristics of the clasts and rock fragments contained within are considered. Among the rock fragments, the microstructural and physical properties of the marbles are the most important parameters (Cantisani et al. 2009). Marble fragments can develop alteration and decay phenomena, such as discoloration, granular decohesion, that significantly influence the state of conservation of the breccias. Chemical and mineralogical composition, as well as the microstructure of the matrix, are other relevant key factors.

Among external factors we can include the methods of installation and setting of breccia's slabs, exposure to weathering or thermohydrometric conditions indoors, and unsuitable cleaning methods employed during restoration.

Thickness and orientation with respect to metamorphic foliation must be considered for breccias used as cladding slabs (Fig. 11A); that is, the greater the thickness, the more resistant the slab is to degradation.

The foliation, developed in the matrix that binds marble fragments, represents another point of weakness for chemical, mineralogical composition and microstructural features. Generally, the matrix consists of minerals that can easily altered by weathering such as hematite, phyllosilicates (micas, chlorite, kaolinite etc.) and calcite; furthermore, the presence of oriented structure can be a cause of fragment detachment. When this is parallel to the surface, matrix exfoliation and flake detachment can occur (Figs. 11B and C) while when it is perpendicular to the surface, intergranular disintegration can happen (Fig. 11D).

Moreover, in outdoor, breccias are often used in monumental fountains. In such cases, the continued exposure to water leads to the development of biological patina, often concentrated in cracked areas. The presence of cracks, in turn, can cause moisture stagnation and subsequent biological growth (Fig. 11E) (Warscheida and Braams 2000). While phenomena such as capillary rise or moisture from the masonry behind can cause phenomena of decohesion and colour alteration (discolouration) (Fig. 11F).

Conclusions

The *Brecce di Seravezza* s.l. include different varieties of ornamental stones of notable historical-monumental meaning, such as the *Breccia medicea* and the congener *Mischio di Seravezza*. Their lithostratigraphic, petrographic and mineralogical characterisation assumes a high connotative and distinctive value from both a geological and an archaeometric point of view, partly perceptible also in the autoptic analysis of the ornamentations and colours present in the several lithotypes of this heterogeneous group. The appearance of the *Brecce di Seravezza* s.l. varies, due to the size of the clasts, quantity of matrix and their colour, depending on the quarry origin and also within the same quarry, giving rise to different typologies with particular beauty. Despite their heterogeneity, these ornamental stones represent a peculiarity, universally recognized and appreciated, of the geodiversity and geoheritage of the Alpi Apuane. In this contribution, samples coming from the *Brecce di Seravezza* s.l. of two historical quarries of the typical Stazzema area (Cava del Rondone c/o Pontestazzemese and Grotte Bianche c/o Volegno) were fully studied for the first time. The lithostratigraphic, petrographic and microstructural observations, mineralogical and microchemical analyses allow us to identify the main features for 14 representative samples (8 from Cava del Rondone section and 6 from Grotte Bianche section). The study points that "classical" feature of the *Brecce di Seravezza* s.l. used in art and architecture, (consisting in a "disorganized" breccia with whitish to reddish marble and minor dolomitic marble pebbles to boulders in a reddish/violet, foliated carbonatic-phyllitic matrix) is recognizable only in some parts of the two sections that contain also other metabreccias that are characterized by different colours and textural/petrographiccharacteristics.

The low grade polyphase high pressure-low temperature metamorphism, testified by the chlorite+muscovite+quartz± chloritoid±clinozoisite and low deformation features, allow preserve the overall features of the *Brecce di Seravezza* protolith that can be defined a syn-tectonic sedimentary breccia derived by karst and dismantling of the Triassic carbonate platform (see also Franceschelli et al. 1996). Its characteristics

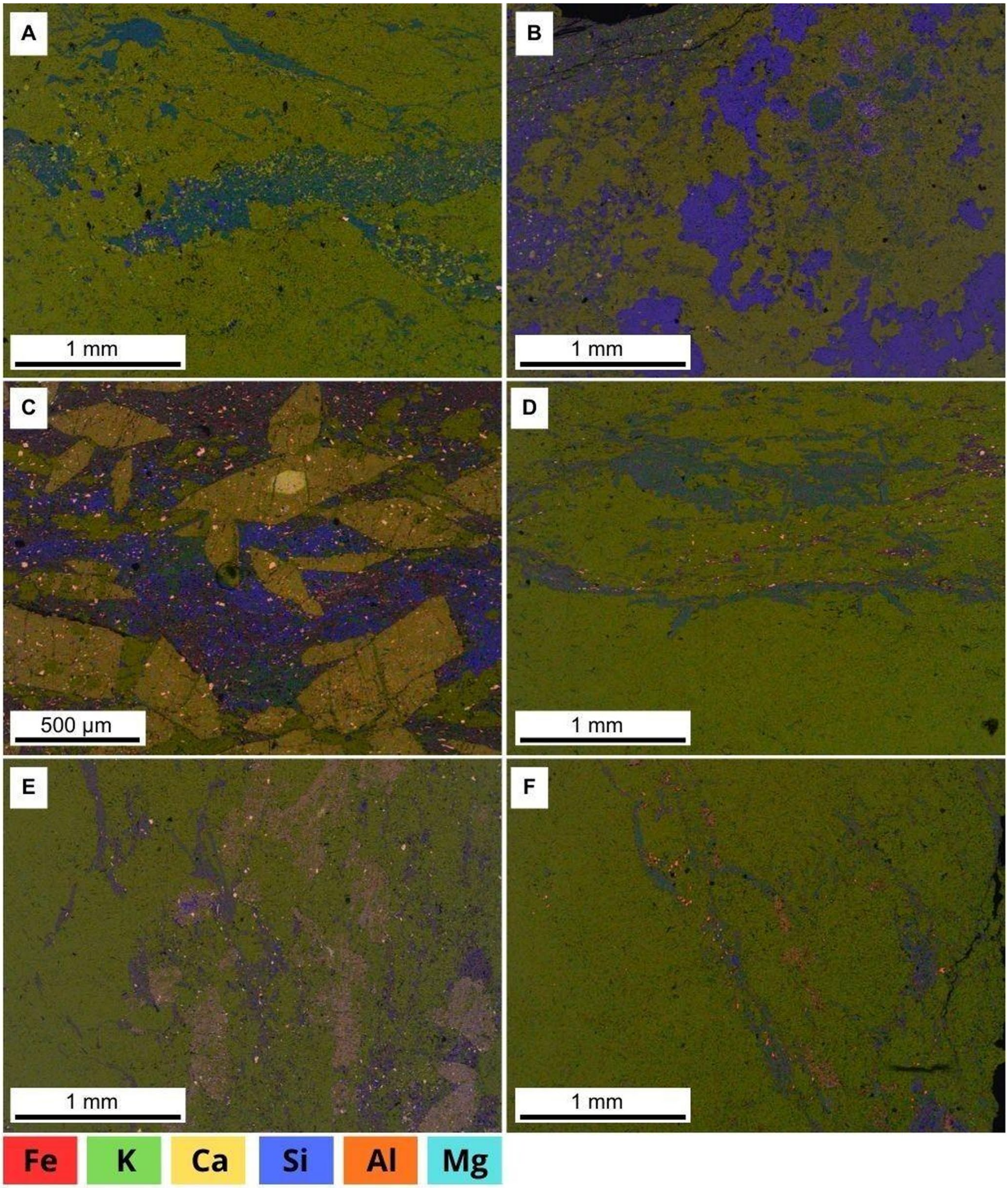

Fig. 10 EDS layered maps of: **A**) sample BM3 showing carbonates and subordinate phyllosilicatic matrix; **B**) sample BM4 where is always visible the phyllosilicatic component of the matrix and carbonates; **C**) sample BM5 with rhombohedral crystals (epidotes); **D**) sample BM5 with calcitic clasts; **E**) sample BM6, presence of reduced phyllitic matrix areas in violet-pink colour; **F**) sample BM6, in between small clasts rich in Ca, matrix areas with spots more rich in Fe (colour violet) are present

Fig. 11 (**A**) Church of the Santissima Annunziata (Florence): internal cladding in *Mischio di Seravezza* of the walls (pluri-centimetric thickness of the wall is evident); (**B**) Church of the Santissima Annunziata (Florence): internal cladding in *Mischio di Seravezza*, phenomenon of exfoliation of the matrix; (**C**) Church of the Santissima Annunziata (Florence): internal cladding in *Mischio di Seravezza-Breccia medicea*, the detachment of flakes is evident; (**D**) Obelisk Piazza Santa Maria Novella (Florence): granular disintegration of *Breccia medicea*; (**E**) Fountain in Piazza Santa Croce (Florence), development of biological patinas on *Mischio di Seravezza* in correspondence with cracks; (**F**) Cathedral of Santa Maria del Fiore (Florence): internal cladding in *Mischio di Seravezza-Breccia medicea* with phenomena of discoloration and decohesion due to humidity

are similar to the Greek *Marmor Scyrium* as already pointed out by Lazzarini and Turi (1999). Our breccias, sampled in the southern sections of the *Brecce di Seravezza* (Pontestazzemese-Stazzema- Volegno area), reveal the lack of Mn-rich levels and piemontite that are instead typical in the sections of the central Alpi Apuane (Mt. Corchia area) as shown by (Lazzarini and Turi 1999; Franceschelli et al. 1996, 2003).

Furthermore, taking into consideration the mineralogical, textural characteristics of the examined breccias, and the main uses of these materials in the cultural heritage context, it was possible to highlight the decay phenomena observed in the outdoor and indoor monuments and works of art in Florence.It is always fundamental to consider for decay problems: the thickness (greater thickness favouring more resistance to degradation) and the orientation (slab cut with respect to metamorphic foliation determines fragment detachment). Another source of degradation, due to external conditions is, as always, the presence of water or phenomena of capillary rise in the masonry, for the development of biological patinas or decohesion and discoloration.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12371-026-01339-x.

Acknowledgements The authors thank the Centro di Servizi di Microscopia Elettronica e Microanalisi (MEMA), University of Florence, for their kindly assistance in the use of a Scanning Electron Microscope.

Author Contributions The authors have no competing interests to declare that are relevant to the content of this article. All authors whose names appear on the submission (1) made substantial contributions to the conception or design of the work, the acquisition, analysis, and interpretation of data; (2) drafted the work and revised it critically; (3) approved the version to be published; and (4) agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. In particular: Bartelletti A. Sampling, Cultural heritage and historical notes; Pandeli E. Sampling, Lithostratigraphy and structural geology; Pandeli E., Pecchioni E., Cantisani E. Petrography; Pecchioni E., Cantisani E. Conceptualization, Mineralogy and Chemistry; Fratini F. Sampling and Decay phenomena.

Funding Open access funding provided by Università degli Studi di Firenze within the CRUI-CARE Agreement. This research did not receive any specific grant from funding agencies in public, commercial, or not-for-profit sectors.

Declarations

Competing Interest The authors declare no competing interests.

References

Amorfini A, Bartelletti A (2013) The Forgotten Marble in the Apuan Alps: an initial list of 'historical stone and marble' whose production is either abandoned or residual. In: Proceedings of 12th European Geoparks Conference. National Park of Cilento, Vallo di Diano e Alburni Geapark, Italy, pp. 1–16 Applying the Model PAP. In: Electron Probe Quantitation. Springer, Boston, MA, pp. 31–75

Antonelli F, Lazzarini L (2013) The Use of White Marble in the Central and Upper Adriatic Between Greece and Rome: Hellenistic Stelae from the Necropolis of Ancona (Italy). Camb J 23(2):149–162

Bartelletti A (2022) -23) l'Istoria delle pietre di Agostino del Riccio (1597 ca.) e i Marmi delle Alpi Apuane. In: Nelle Terre del Marmo. III. Il valore storico delle pietre ornamentali. Acta apuana 21–22:21–83

Bartelletti A, Amorfini A (2003) Le Brecce policrome apuane nell'Antichità. In: Ante et post Lunam. Splendore e ricchezza dei marmi apuani: I – l'evo antico. Acta apuana 2:63–67

Bartelletti A, Amorfini A (2013) Historical stone and marble in the Apuan Alps Geopark (Italy): a local strategy on the sustainable use of a non-renewable resource. ROL 28:15–18

Bartelletti A, Amorfini A (2011) – I marmi dimenticati delle Alpi Apuane: la definizione di lapideo storico tra uso sostenibile e valorizzazione qualitativa di una risorsa non rinnovabile. Acta apuana Vol. 9 and 10: pp 5–27

Bartelletti A, Amorfini A, Ottria G (2015) Apuan Alps Geopark' Dossier: protection and promotion activities for geological heritage. Acta apuana 12:5–67

Bartelletti A, Amorfini A, Cantisani E, Fratini F, Pucci F, Tenerini A (2005–2006) Il marmo nella Versilia del Medioevo: risultati da una prima indagine archeometrica, in Ante et post Lunam. Reimpiego e ripresa estrattiva dei marmi apuani: II – l'evo medio. Acta apuana, 4–5: 59–77

Bartelletti A, Amorfini A, Ottria G (2022–2023) Marmi antichi e Marmi storici delle Alpi Apuane, in Nelle Terre del Marmo. III. Il valore storico delle pietre ornamentali. Acta apuana, 21–22: 85–137

Bortolotti V, Fazzuoli M, Pandeli E, Principi G, Babbini A, Corti S (2001) -Geology of the central and eastern Elba Island. Italy Ofioliti 26(2):97–150

Bruno M (2002) Il mondo delle cave in Italia: considerazioni su alcuni marmi e pietre usati nell'Antichità. In: De Nuccio M, e Ungaro L (eds) I marmi colorati della Roma imperiale. Marsilio Ed., Venezia, Italy, pp 277–289

Cantisani E, Pecchioni E, Fratini F, Garzonio CA, Malesani P, Molli G (2009) Thermal stress in the Apuan marbles: Relationship between microstructure and petrophysical characteristics. Int J Rock Mech Min Sci 46:128–137. https://doi.org/10.1016/j.ijrmms.2008.06.005ijrmms.2008.06.005

Carcangiu G, Franceschelli M, Gattiglio M, Pannuti F, Fadda S, Lorenzoni V (1992) Le Brecce di Seravezza. In: e Coli E (ed) 76ª Riunione estiva S.G.I. L'Appennino settentrionale e Convegno S.I.M.P. Minerogenesi appenninica, Guida alla Traversata dell'Appennino settentrionale Descrizione degli stop del II giorno, Stop II.4. Centro Duplicazione Offset s.r.l., Firenze, pp 122–124

Carmignani L, Kligfield R (1990) Crustal extension in the Northern Apennines: the transition from compression to extension in the Alpi Apuane core complex. Tectonics 9:6: 1275–1303
Carmignani L, Conti P, Massa G, Vaselli L, Mancini S (2006) Lineamenti Geologici Delle Alpi Apuane. Acta apuana, Suppl. V, pp 9–23
Carmignani L, Conti P, Fantozzi P, Mancini S, Massa G, Molli G, Vaselli L (2007a) I marmi delle Alpi Apuane. Geoitalia, 21: 19–30
Carmignani L, Conti P, Meccheri M, Vaselli L, Mancini S, Massa G (2007b) Carta giacimentologica dei marmi delle Alpi Apuane a scala 1:10.000 e sua informatizzazione, Relazione finale. Regione Toscana-Università di Siena, Centro di Geotecnologie di S. Giovanni Valdarno, Italy
Carosi R, Montomoli C, Pertusati PC (2004) Late tectonic evolution of the Northern Apennines: the role of contractional tectonics in the exhumation of the Tuscan Units. Geodin Acta 17:4: 253–273. https://doi.org/10.3166/ga.17.253-273
Ciarapica G, Fazzuoli M (1976) Analisi sedimentologiche di due sequenze nei Grezzoni delle Alpi Apuane. Boll Soc Geol It 95:147–160
Ciarapica G, Passeri L (1978) I Grezzoni del nucleo Apuano: nascita, sviluppo e morte di una piattaforma carbonatica iperalina. Boll Soc Geol It 97(4):527–564
Ciarapica G, Passeri L (2005) Late Triassic and Early Jurassic sedimentary evolution of the Northern Apennines: an overview. Boll Soc Geol It 124(1):189–201
Coli M, Pandeli E (1992) Introduzione alle Alpi Apuane. In: Coli E, Pandeli E (eds) 76ª Riunione estiva S.G.I. L'Appennino settentrionale e Convegno S.I.M.P. Minerogenesi appenninica, Guida alla Traversata dell'Appennino settentrionale Descrizione degli stop del II giorno. Centro Duplicazione Offset s.r.l. Firenze, Italy, pp 79–103
Coli M, Grandini G, Matteini L (1988) Il bacino marmifero di Orto di Donna (AlpiApuane). Aspetti geologici, morfotettonici, strutturali e tecnici dei Marmi di Orto di Donna. San Gallo, Firenze, Italy
Conti P, Massa G, Meccheri M, Carmignani L (2010) Geological map of the Stazzema area (Alpi Apuane, Northern Apennines, Italy). Laboratorio di Cartografia digitale e G.I.S., Centro di Geotecnologie. Università di Siena, Italy
Conti P, Carmignani L, Massa G, Meccheri M, Patacca E, Scandone P, Pieruccioni D (2019a) Note illustrative della Carta geologica d'Italia alla scala 1:50.000, Foglio 249 Massa carrara. ISPRA, Servizio Geologico d'Italia
Conti P, Cornamusini G, Carmignani L, Molli G (2019b) The geological structure of the Emilia-Tuscany Northern Apennines and Alpi Apuane. Geol. F. Trips Maps, 11 (2, part 5): 1–78. https://doi.org/10.3301/GFT.2019.07
De Vecchi G, Lazzarini L (1994) Marmi e pietre di Padova romana. In: Zampieri C, e Nalon MC (eds) Padova romana. Testimonianze architettoniche nel nuovo allestimento del Lapidario del Museo Archeologico. Mondadori Electa, Milano, Italy, pp 106–116
Del Riccio A Istoria delle Pietre. Rist. anast. S.P.E.S, Firenze (1597) Italy 1977
Fabretti M, Guidarelli A (1980) Ricerche sulle iniziative dei Medici nel campo minerario da Cosimo I a Ferdinando I. In: Spini g (ed) Potere centrale e strutture periferiche nella Toscana del '500, Olschki, Firenze, Italy, pp139-217
Fazzuoli M, Ferrini G, Pandeli E, Sguazzoni G (1985) Le formazioni giurassico-mioceniche della Falda Toscana a Nord dell'Arno: Considerazioni sull'evoluzione sedimentaria. Mem Soc Geol Ital 30:159–201
Fazzuoli M, Pandeli E, Sani F (1994) Considerations on the sedimentary and structural evolution of the Tuscan Domain since Early Liassic to Tortonian. Mem Soc Geol It 48:31–50
Franceschelli M, Puxeddu M, Carcangiu G, Gattiglio M, Pannuti F (1996) Breccia-hosted manganese-rich minerals of Alpi Apuane, 1taly: A marine, redox-generated deposit. Lithos 37:309–333. https://doi.org/10.1016/0024-4937(95)00026-7
Franceschelli M, Memmi I, Carcangiu G, Gianelli G (1997) Prograde and retrograde chloritoid zoning in low temperature metamorphism, Alpi Apuane, Italy. Schweiz Mineral Petrogr Mitt 77:41–50
Franceschelli M, Puxeddu M, Memmi I (1998) Li- and B-rich Rhaetian metabauxite, Tuscany, Italy: reworking of older bauxites and igneous rocks. Chem Geol 144:221–242. https://doi.org/10.1016/S0009-2541(97)00133-2
Franceschelli M, Puxxedu M, Gattiglio M (2003) Geochemistry and origin of chloritoid schist from the Alpi Apuane, Italy: evidence of a prevailing lateritic signature. Eur J Mineral 15:575–588. https://doi.org/10.1127/0935-1221/2003/0015-0575
Franceschelli M, Gianelli G, Pandeli E, Puxeddu M (2004) – Variscan and Alpine metamorphic events in the Northern Apennines (Italy): a review. Per Mineral 73 Spec Issue 2:43–56
Giglia G, Trevisan L (1966) Genesi e significato paleogeografico delle brecce tra Grezzoni e Marmi delle Alpi Apuane. Atti Soc Tosc Sc Nat Mem Ser A 73(2):503–517. https://doi.org/10.1007/978-1-4899-2617-3_4
ISPRA (2007) Grezzoni. Carta Geologica Ital 1:50 000 Catalogo delle Formazioni(Fascicolo VII Unit– tradizionali 2):198–200
Jolivet L, Faccenna C, Goffé B, Mattei M, Rossetti F, Brunet C, Storti F, Funiciello R, Cadet J, D'Agostino N, Parra T (1998) Midcrustal shear zones in postorogenic extension: example from the northern Tyrrhenian Sea. J Geophys Res 103:12123–12160
Kligfield R (1979) The Northern Apennines as a collision orogen. Am J Sci 279(6):676–691
Kligfield R, Hunziker J, Dallmeyer RD, Schamel S (1986) Dating of deformation phases using K-Ar and 40Ar/ 39Ar techniques; results from the Northern Apennines. J Struct Geol 8:7: 781–798
Lanterna G (1999) L'uso del SEM nella Scienza della Conservazione/The Use of SEM in Science for Conservation. In: OPD Restauro n. 11. Centro Di Della Edifimi srl, Florence, Italy, pp 39–58
Lazzarini L (1990) Recensione Marmi Antichi. In: Borgini G (ed) Bollettino di Archeologia 5–6. Libreria dello Stato, Roma, Italy, pp 257–268
Lazzarini L, Turi B (1999) Characterization and differentiation of the Skyros marbles (Greece) and the Medici's Breccias (Italy). Proceeding ASMOSIA IV, Bordeaux, France, 9.13 October, 1995, pp. 117–123
Moratti G, Sani F, Poccianti C, Rosselli S (1989) Anal isi strutturale della zona di Gorfigliano (Alpi Apuane settentrionale). Boll Soc Geol It 107:255–267
Pensabene P, Bruno M (1998) Il Marmo e il colore. Guida fotografica. I marmi della collezione Podesti. L'Erma di Bretschneider, Roma, Italy
Pilla L (1845) Breve cenno sopra la ricchezza minerale della Toscana. Vannucchi R., Pisa, Italy
Pouchou JL, Pichoir F (1991) Quantitative Analysis of Homogeneous or Stratified Microvolumes Applying the Model PAP. Electron Probe Quantitation. Springer, Boston, MA, pp 31–75. https://doi.org/10.1007/978-1-4899-2617-3_4
Salvini S, Coletti C, Maritan L, Massironi M, Pieropan A, Spiess R, Mazzoli C (2023) Caratterizzazione petrografica e durabilità delle rocce carbonatiche utilizzate nei siti Patrimonio Mondiale UNESCO nell'Italia nord-orientale. Environ Earth Sci 82:1:1–24. https://doi.org/10.1007/s12665-022-10732-y
Siegesmund S, Snethlage R (2014) Stone in Architecture. Springer, London
Simi E (1855) Sull'Alpe della Versilia e la sua ricchezza minerale. Saggio corografico. F.lli Frediani, Massa, Italy
Taelman D, Delpino C, Antonelli F (2019) Marble decoration of the Roman theatre of *Urvinum Mataurense* (Urbino, Marche region, Italy): An archaeological and archaeometric multi-method provenance study. J Cult Herit 39:238–250
UNI EN 12407 (2007) Natural Stone Test Methods Petrographic Examination. Ente Nazionale Italiano di Normazione, Milano, Italy

UNI EN 13925-1 (2006) Non-Destructive Testing X-Ray Diffraction from Polycrystalline and Amorphous Material. Part 1: General Principles. Ente Nazionale Italiano di Normazione, Milano, Italy

UNI EN 13925-2 (2006) Non-Destructive Testing X-Ray Diffraction from Polycrystalline and Amorphous Materials. Part 2: Procedures. Ente Nazionale Italiano di Normazione, Milano, Italy

UNI-EN 13925-3 (2006) Non-Destructive Testing X-Ray Diffraction from Polycrystalline and Amorphous Materials. Part 3: Instruments. Ente Nazionale Italiano di Normazione, Milano, Italy

Vai GB, Martini IP (2001) Anatomy of an Orogen, the Apennines and Adjacent Mediterranean basin. Kluwer Academic, Amsterdam, Netherlands

Warscheid T, Braams J (2000) Biodeterioration of stone: a review. Int Biodeterior Biodegradation 46:4: 343–368. https://doi.org/10.1016/S0964-8305(00)00109-8