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THE EDUCATIONAL COLLECTION OF THE MONTI PISANI METAMORPHIC ROCKS: THE PALEOZOIC-OLIGOCENE SEQUENCE

Abstract - G. Musumeci, T. Ciomei, *The educational collection of the Monti Pisani metamorphic rocks: the Paleozoic-Oligocene sequence.*

The educational collection of lithotypes belonging to the Tuscan Metamorphic Basement exposed in the Monti Pisani massif (Tuscany, Italy) is described. The collection consists of 40 samples representative of the Paleozoic-Oligocene lithostratigraphic sequence of the low metamorphic grade Monte Serra Unit and Santa Maria del Giudice Unit. The sequence documents the evolution of sedimentary facies from continental to marine environment. In the supplementary material (Supplementary S1), available on the page http://www.stsn.it/it/memorie-serie-a/13-stsn/143-memorie-serie-a-anno-2021.html, the location and the description of outcrops and samples at meso and microscale are reported.

Key words - Northern Apennines, Monti Pisani, metamorphic unit, metamorphic rocks educational collection

Riassunto - G. Musumeci, T. Ciomei, *La collezione didattica delle rocce metamorfiche dei Monti Pisani: la successione Paleozoica-Oligocenica.*

Viene descritta la collezione delle litologie appartenenti alle unità tettoniche di basso grado metamorfico del Monte Serra e di Santa Maria del Giudice. Queste unità tettoniche esposte nel massiccio dei Monti Pisani appartengono al Basamento Metamorfico Toscano. La raccolta è stata realizzata a scopo didattico ed è costituita da 40 campioni rappresentativi di formazioni appartenenti alla sequenza Paleozoico-Oligocene del Dominio Toscano. La sequenza è rappresentativa dell'evoluzione delle facies sedimentarie dall'ambiente continentale a quello marino. Nel supplemento (Supplementary S1) disponibile, alla pagina http://www.stsn.it/it/memorie-serie-a/13-stsn/143-memorie-serie-a-anno-2021.html, sono riportate la localizzazione e la descrizione degli affioramenti e dei campioni alla meso e microscala.

Parole chiave - Appennino Settentrionale, Monti Pisani, unità metamorfiche, collezione didattica di rocce metamorfiche

Introduction

The Monti Pisani or Monte Pisano (Fig. 1) is a NW-SE trending massif that belongs to the Northern Apennines chain. The massif is located at the north of the city of Pisa from which derives its name (the correct name is in the singular form, even if the plural form is more common; Fig. 1a). With a maximum elevation of 917 m (Monte Serra), it represents the natural separation between the alluvial plain of Arno River, to the south, the Serchio valley, to the west and first relief of Apennine to the north. Morphologically, the Monti Pisani is a massif characterized by a sequence of peaks (from NW to SE: Monte Faeta, Monte Serra, Monte Cimone, Monte Verruca) with steep slopes separated by NE trending valleys, the main of which is represented by the Calci valley (Figs 1a, b).

Since medieval times some lithotypes, especially marble and quartzite have been extracted and used in building construction such as the Cathedral of Pisa and in other monumental buildings of medieval age (Franzini & Lezzerini, 2003; Lezzerini *et al.*, 2016; Lezzerini *et al.*, 2019). The largest quarries, which have partly modified the appearance of the southern slopes of the massif, are located at San Giuliano Terme (the oldest quarries), Monte Castellare, Agnano, Caprona and Uliveto. Geologically, the Monti Pisani massif belongs to the Tuscan ridge, a group of NNW-NW trending massifs extending from the Apuan Alps at north to the Monte Argentario at south (Fig. 2), characterized by the occurrence of Triassic-Oligocene metamorphic units (Tuscan Metamorphic Complex; Conti *et al.*, 1991; Carmignani *et al.*, 1994), including Paleozoic formations.

In the following sections, after a geological outline of the Monti Pisani, the lithological features of geological units/formations will be described according to the stratigraphic order from the Paleozoic to the Oligocene.

Monti Pisani: Geological outline

According to the seminal geological map of Rau & Tongiorgi (1974), the geological structure exposed in the Monte Pisani massif is a stack of three tectonic units that starting from the bottom to the top are: (i) Monte Serra Unit, (ii) Santa Maria del Giudice Unit and (iii) Falda Toscana (Fig. 3). The first two units belong to the Tuscan Metamorphic Basement and are affected by lower greenschist metamorphic facies conditions. These units consist of Cambrian? - Oligocene (Monte Serra Unit) and Permian - Oligocene (Santa Maria del Giudice Unit) lithostratigraphic sequenc-

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es (Fig. 4) and share the same lithostratigraphic sequence of Triassic age. The Jurassic-Oligocene lithostratigraphic sequence is complete only in the Santa Maria del Giudice Unit (Fig. 4). Apart this difference in the lithostratigraphic sequence, Rau & Tongiorgi (1974) defined the two units based on their tectonic relations recognized along the "Asciano - Vorno" lineament (1st order thrust in Fig. 3). The tectonic contact corresponds to a NE-trending and west dipping thrust zones and tectonic slices (2nd order thrusts in Fig. 3) with the Permian and Jurassic formations of Santa Maria del Giudice Unit that tectonically overlies the Middle Triassic formations of Monte Serra Unit (Fig 3). The overlying unit, the Falda Toscana consists of a Triassic-Oligocene sequence of sedimentary rocks that show a very limited exposure in the Monti Pisani massif at northwest, along the Serchio valley, and at southeast, in the Caprona area (Giannini & Nardi, 1965).

Historical background

The first significant contribution to the knowledge of the Monti Pisani geology is attributed to Paolo Savi (1832) that recognized the sedimentary origin and the metamorphic nature of the siliciclastic rocks constituting most of the Monti Pisani massif. Paolo Savi (1832) establishing the term "Verrucano" for this siliciclastic succession to which attributed a Triassic age (Savi, 1846). In the early thirties of the twentieth century, the "Nappe theory" began to be accepted in the Italian geological community and the German geologist Tillmann (1930) identified in the northernmost area of Monti Pisani (Rupe Cava, Ripafratta locality) two superimposed tectonic units: the allochthonous Toscanide II (Falda Toscana) located above the "native" Toscanide I (Santa Maria del Giudice Unit and Monte Serra Unit). The overthrust between the two tectonic units was located at the base of the Verrucano. Moreover, in the same years Kober (1931) and Staub (1932), recognized the allochthonous nature of both Toscanide I and Toscanide II overthrusting on the "Carraridi". These latter represent the sequence of metamorphic rocks cropping out in the northermost portion of the Apuan Alps massif.

In the following years, Trevisan (1955) distinguished a late Paleozoic Verrucano (the current *Scisti di San Lorenzo*) and a Triassic Verrucano (the current *Formazione della Verruca*), separated by a stratigraphic gap.

The research of the stratigraphy was further improved by Schiaffino & Tongiorgi (1962). These authors distinguish seven cartographic members in the siliciclastic sequence of the Triassic Verrucano and establish a new formation: the "*Filladi e Quarziti di Buti Fm.*" for which was attributed a Paleozoic age based on radiometric data (Kligfield *et al.*, 1986).

In the 1970s, Rau & Tongiorgi (1974) compiled a complete monograph with two geological maps (an outcrops map and an interpretative map) at a scale of 1:25.000, which represents a milestone in the geology of the Monti Pisani (Fig. 5). Rau & Tongiorgi (1974) by means of the field survey and the first detailed structural analysis, defined the geological structure of Monti Pisani with the characterization of three overlapping tectonic units (Monte Serra Unit, Santa Maria del Giudice Unit and Falda Toscana). The main thrust between Santa Maria del Giudice and Monte Serra metamorphic units was identified by Tongiorgi *et al.* (1977) in correspondence with the Asciano-Vorno tectonic lineament, which delimits to the north-west an area of "tectonic slices" called "zona a scaglia del Faeta", that the authors attributed to Monte Serra Unit (Fig. 5a, c). Moreover, Rau & Tongiorgi (1974) and Tongiorgi *et al.* (1977) give a complete description of the Triassic silico-clastic succession with the subdivision of the sequence in seven members and a description of their sedimentation environments. Recently, the occurrence of metavolcaniclastic layer in the Permo-Carboniferous sequence has been reported by Marini *et al.* (2020) as record of late Paleozoic volcanic activity.

According to Rau & Tongiorgi (1974), the deformation of tectonic units, is characterized by at least two ductile compressive phases of Apennine age and relics of Variscan deformation (these latter only preserved within the *Filladi e Quarziti di Buti Fm.*, that is exposed at the core of anticlines (e.g., Verruca anticline; Fig. 5b, d).

Regarding the metamorphic conditions recorded by the siliciclastic lithotypes of tectonic units, Franceschelli *et al.* (1986, 2004) define the metamorphic association and identify the metamorphic peak thermo-baric conditions. Based on the Si content Franceschelli *et al.* (1986) identified two possible pressure ranges, the first between 0.3-0.4 GPa and the second between 0.6-0.8 GPa. However, Franceschelli *et al.* (1986) considering the lithostatic load due to the stratigraphic thickness of the overlying Ligurian and Tuscan Units, believed that a pressures of 0.3-0.4 GPa was reached during the metamorphic peak.

In the ninenties, Carosi *et al.* (1992) and Montomoli (2002) by means calcite-dolomite geothermometry and fluid inclusion investigations give better constraints to PT conditions experienced by the Santa Maria del Giudice Unit and Monte Serra Unit. More recently Lo Pò & Braga (2014) using the phase equilibria modelling on chloritoid report a pressure of 0.9-1.0 GPa, with a temperature of 475 °C. Moreover, detailed structural investigations (Carosi *et al.*, 1997, Carosi & Montomoli, 1999; 2002) allow to define polyphase tectonics characterized by two orthogonal shortening directions that controlled the development of two folds systems. A new geological map of the Monti Pisani massif at the scale 1: 50.000 that reports all new data is in press (Ispra, Sheet 273, Pisa).

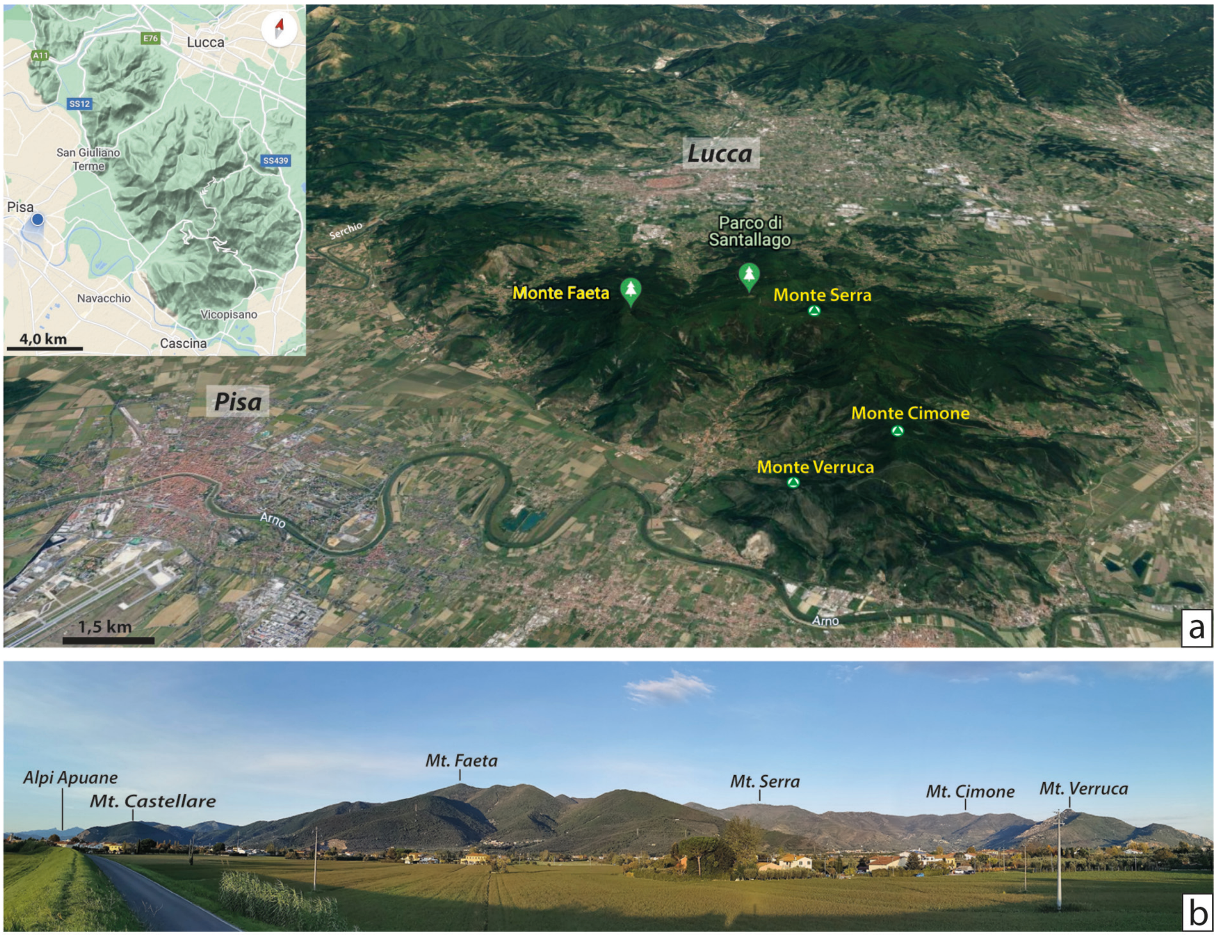

Figure 1. a) Google image of Monti Pisani massif showing its position on the northern side of Arno River alluvial plain; b) panoramic view of the massif from Monte Castellare at NW to Monte Verruca at SE.

Educational collection

A complete collection of rock samples representative of the lithostratigraphic sequence of the Monte Serra Unit and Santa Maria del Giudice Unit was set up. Sample position is reported in the tectonic sketch map (Fig. 3) and in the lithostratigraphic columns (Fig. 4). Similarly, the position of the samples is also reported in the Supplementary (S1), where the samples are illustrated and described. Samples were collected in well-exposed and accessible outcrops, most of them located along roads and/or tracks, these latter belonging to the trekking network of Monti Pisani (see https://webmapp.it/la-mappa-dei-monti-pisani-e-online/).

The lithostratigraphic succession of Monte Serra and Santa Maria del Giudice Units is represented by (1) siliciclastic deposits of Paleozoic (Cambrian and Permian age) and Triassic (Ladinian to Lower Norian age) and (2) carbonate, siliciclastic and terrigenous deposits ranging in age from the Upper Trias to the Oligocene. In the Monte Serra Unit, the Mesozoic carbonate and siliciclastic formations have a reduced thickness, and the upper Cretaceous-Oligocene deposits are almost completely lacking (Fig. 4). In the following paragraphs, a brief description of the main compositional, textural and metamorphic characteristics of the lithotypes is reported. For an extensive and complete discussion of the lithotypes refer to the monography of Rau & Tongiorgi (1974) and Trevisan *et al.* (1968; 1971).

This educational collection of Monti Pisani lithologies is stored, visible and available for studies at the Department of Earth Sciences of the University of Pisa. The description and photographic images of the lithologies can be consulted in the attached supplement (Supplementary S1), and is also available on the page http://www.stsn.it/it/memorie-serie-a/13-stsn/143-memorie-serie-a-anno-2021.html.

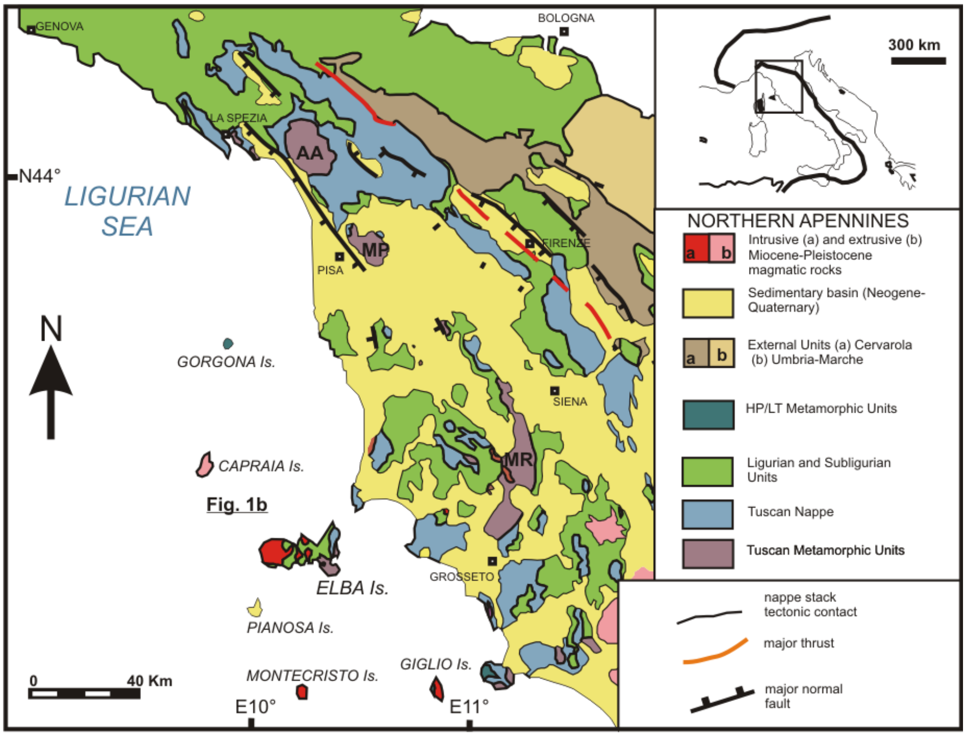

Figure 2. Tectonic sketch map of Northern Apennines.

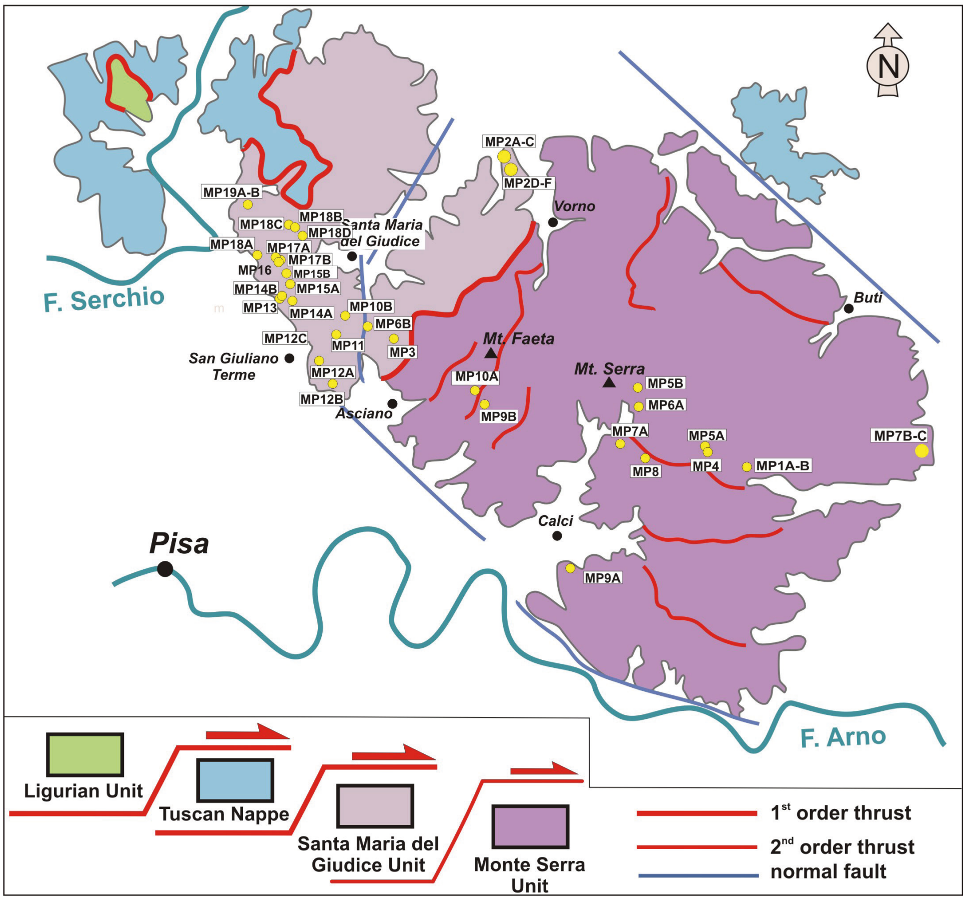

Figure 3. Tectonic sketch map of Monti Pisani with sample location (modified after Frassi, 2020).

Lower Paleozoic - Upper Triassic sequence

In Monte Serra Unit, the Lower Paleozoic *Filladi e quarziti di Buti Fm.*, correlated with the *Filladi inferiori Fm.* of the Apuan Alps, represents the oldest lithotypes cropping out in the Monti Pisani. In the Santa Maria del Giudice Unit, the Paleozoic formations correspond to the Upper Carboniferous - Permian *Scisti di San Lorenzo Fm.* and *Brecce di Asciano Fm.* In both units, the triassic sequence consists of the same lithostratigraphic sequence. In the Monte Serra Unit, the Upper Paleozoic - Upper Triassic sequence consists of the *Formazione della Verruca* e *Formazione delle Quarziti del Monte Serra*, and lies in discordance with the *Filladi e quarziti di Buti Fm.*
Both formations are subdivided in members and corresponds to a continental - delta plain sedimentary environment. The first member (*Anageniti grossolane*) of the *Formazione della Verruca* was deposited during the first stage of a "continental rift". It consists of coarse-grained sediments, deposited in a fluvial environment with crossed channels, close to the source area. The subsequent *Scisti viola and Anageniti minute* members are characterized by medium to fine-grained deposits corresponding to alluvial plain with braided river. In this sedimentary environment, clastic deposits represent braided channels facies and the fine-grained pelitic deposits correspond to flood events with alluvial flooding. The sedimentary environment during time evolves toward tidal plain deposits (*Membro degli Scisti Verdi*), coastal beach (*Membro delle Quarziti Verdi*), shallow water platform (*Membro delle Quarziti bianco rosa*) and delta plain (*Membro delle Quarziti viola zonate*). The sedimentation of terrigenous deposits evolves from continental to lagoon and shallow water marine environment.

Paleozoic sequence

Filladi e quarziti di Buti (BUT) Cambrian? - Upper Ordovician?

This Paleozoic formation is exposed at the core of some anticlines (e.g., Buti, Monte Verruca, Montemagno, Monte Cascetto, Castelmaggiore, Monte della Conserva and Monte del Carrara anticlines). It consists of intensely deformed and well foliated grey-white quartzite and grey phyllite with relics of an older foliation of Variscan age, transposed from Alpine foliation. Radiometric data give an Upper Carboniferous age of 285 ± 12 Ma (Rb/Sr whole rock; Kligfield *et alii*, 1986) that is interpreted as the closure age of Variscan metamorphism. As regards to the age of deposition, Bagnoli *et al.* (1979) attributed it to a Silurian-Devonian age. Successively, Conti *et al.* (1991) correlates these rocks with the Lower Paleozoic (Cambrian? - upper Ordovician?) *Filladi inferiori Fm.* of Apuan Alps metamorphic unit. Sedimentary environment turbiditic deposits, *Sample MP1* (Fig. 4).

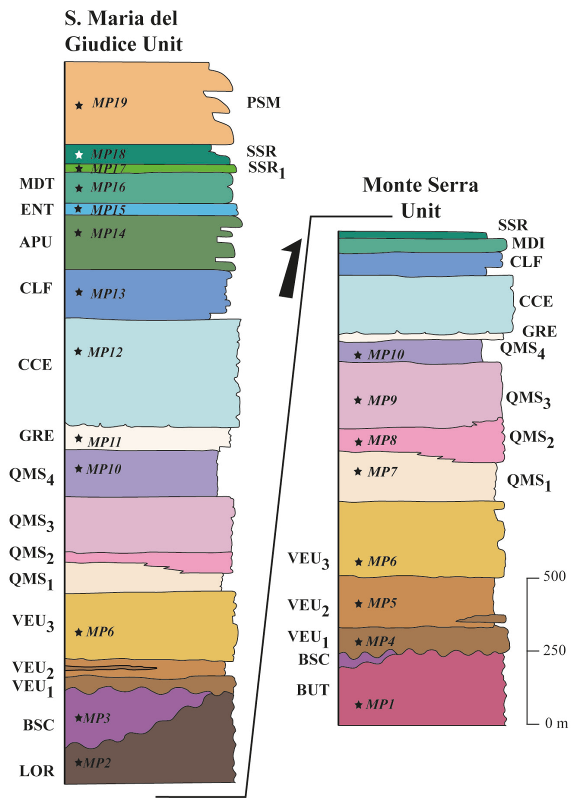

Figure 4. Lithostratigraphic sequence of the Monte Serra and Santa Maria del Giudice tectonic units with sample location (modified after Frassi, 2020).

Scisti di San Lorenzo (LOR) Upper Carboniferous - Lower Permian

This formation of Upper Carboniferous-Lower Permian age has been recognized only in the Santa Maria del Giudice Unit, and it is mainly exposed to the east sides of the Rio Guappero Valley, between Santa Maria del Giudice and Vorno (Fig. 3). This formation consists of continental terrigenous deposits with a prevalence of metapelite, often dark in colour for the presence of organic substance, and less frequently metasandstone and metaconglomerate. Upper Carboniferous and the Lower Permian fossil remains of plants are frequent within the dark metapelite. The sampled outcrops are characterized by the occurrence of grey and dark grey metapelite with discontinuous centimetre thick microconglomerate levels (samples MP2A and MP2B) and metre-thick sequence made up from the bottom to the top of microconglomerate to metasandstone and metapelite (samples MP2C-MP2F). The lower portion of formation corresponds to a continental and coastal marine sedimentary environment. *Sample MP2* (Fig. 4).

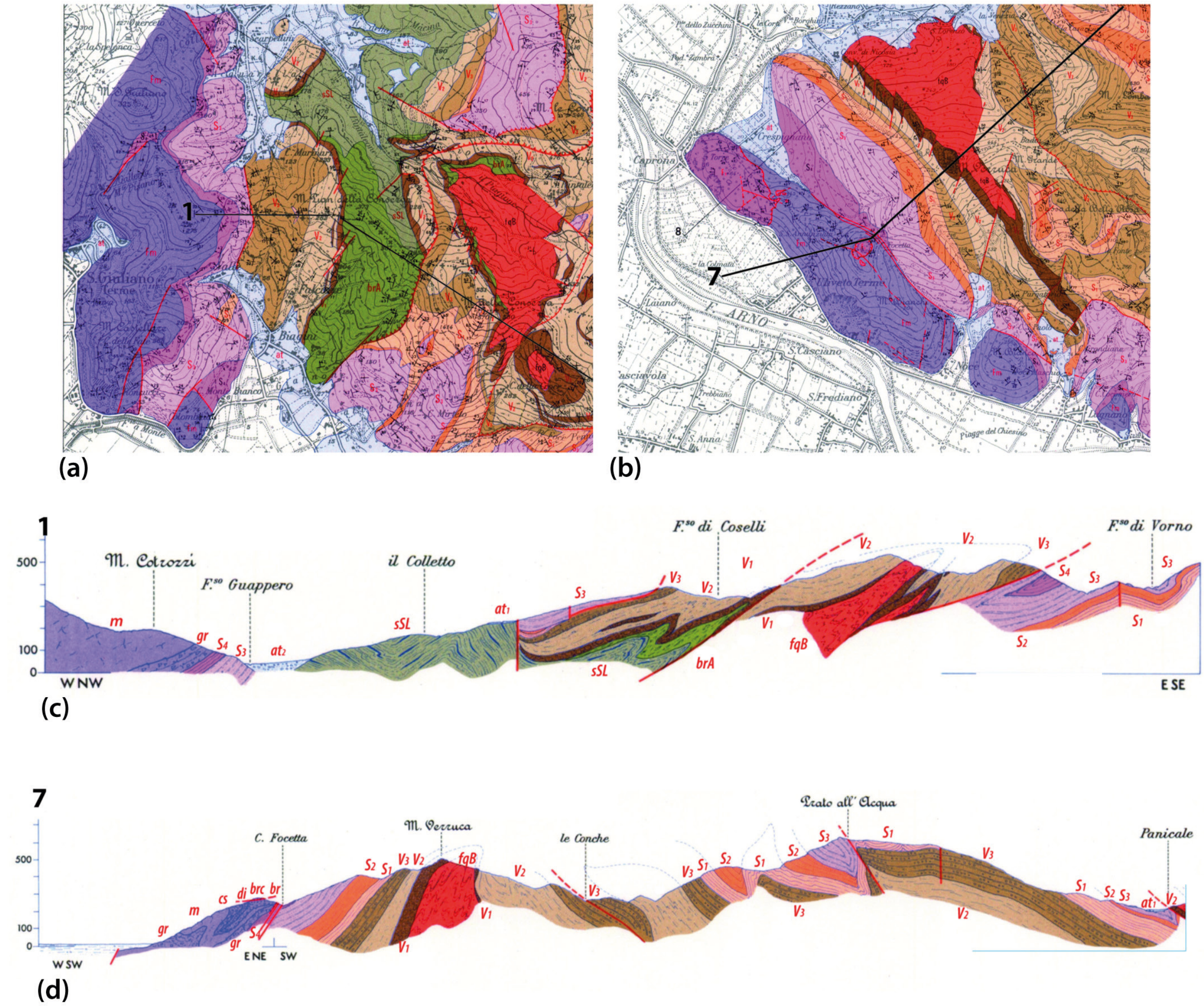

Figure 5. Details of the geological map of Monti Pisani (Rau & Tongiorgi, 1974). a) Monte Pian della Conserva area; b) Monte Verruca area; c) geological cross section of Monte Pian della Conserva (5a); d) geological cross section of Monte Verruca (5b).

Brecce di Asciano (BSC) Permian

They are terrigenous deposits that consist of phyllite, containing subrounded to elliptical clasts, ranging from millimetre to centimetre in size, of quartzite and phyllite deriving from the underlying formations. The clasts show a well-developed preferred orientation with long axis parallel to the metamorphic foliation highlighted by fine-grained phyllosilicate crystals (white mica). The thickness of this formation varies from 50 to 80 m. It belongs to the Santa Maria del Giudice Unit (Rau & Tongiorgi, 1974) and are only exposed in the Monte Faeta tectonic slice zone, on the tectonised west limb of the Monte della Conserva anticline (sample MP3; Fig. 4). Sedimentary environment continental slope, *Sample MP3* (Fig. 4).

Triassic sequence

Formazione della Verruca (VEU) Ladinian - Lower Carnian

This formation of the Ladinian-early Carnian age consists of terrigenous deposits of continental environment and is classically divided into three members (Rau & Tongiorgi, 1974):

1) *Membro delle Anageniti grossolane (VEU_1) Ladinian*

These rocks, exposed at the core of anticlines (e.g., Monte Verruca anticline; Fig. 5b, d), are fluvial deposits that at the base, consist of medium to coarse-grained metaconglomerate mostly containing millimetre to centimetre thick rounded to subrounded quartz and feldspar clasts. A noteworthy feature is the pink colour of matrix and clasts, indicative of continental environment.

Upward, metaconglomerate pass to metasandstone and microconglomerate. The transition with the overlying *Membro degli Scisti Violetti* can occur on few metres with alternances of metaconglomerate and fine-grained metasandstone. Sedimentary environment braided and/or meandering fluvial, *Sample MP4* (Fig. 4).

2) *Membro degli Scisti Violetti (VEU$_2$) Ladinian*

In stratigraphic contact with the underlying *Anageniti grossolane*, this member consists of fine-grained, violet-coloured quartzitic phyllite and phyllite, sometimes with chlorite plates and/or aggregates that appear as greenish spots on the foliation surface. Sedimentary environment corresponds to wide alluvial plain characterized by meandering rivers with high sinuosity. *Sample MP5* (Fig. 4).

3) *Membro delle Anagenite minute (VEU$_3$) Lower Carnian*

This member consists at the base by alternations of metasandstone and whitish quartzite upward followed by violet phyllite and phyllitic quartzite that are dominant at the top. These rocks have gradual transition with the underlying *Scisti Violetti* member and locally it makes difficult to establish the limit between the two members. Metasandstone and whitish quartzite preserve sedimentary structures such as cross stratifications and, sometimes, recognizable channelling surfaces. The sedimentary environment corresponds to a plain with meandering rivers in subarid climate subject to seasonal floods (flood plain) with deposition of fine-grained sediments (violet phyllite). *Sample MP6* (Fig. 4).

Quarziti del Monte Serra (QMS) Lower Carnian - Upper Carnian

The formation is divided into four members and consists of siliciclastic deposits indicative of transition between the Middle Triassic continental sedimentary environment (Verruca Group) to the Upper Triassic lagoon and marine deposits environment.

1) *Membro degli Scisti Verdi (QMS$_1$) Lower Carnian*

It consists of alternations of greenish phyllite and whitish quartz-micaceous metasandstone. More rarely, the formation appears reddish in colour. The stratification is generally well preserved along with sedimentary structures such as ripple marks, and occasionally the presence of marine lamellibranchs fossils and traces of animal origin. At the microscopic scale, the phyllite are rich in sericite and chlorite, with quartz and albite in the coarse levels. Tourmaline, oxides, carbonate, and pyrite grains are often present as accessories. The deposits have been attributed to the Lower Carnian for the discovery of lamellibranch associations, especially in the Agnano area (Rau & Tongiorgi, 1966). These deposits are interpreted as the result of sedimentation in a flat tidal environment subject to seasonal storms that produced the fining sequences upward with erosive bases (Tongiorgi *et al.*, 1977). *Sample MP7* (Fig. 4).

2) *Membro delle Quarziti Verdi (QMS$_2$) Carnian*

It consists of quartzite of a greenish grey to purplish-grey colour, generally characterized by a centimetre to a decimetre-thick strata with a fine lamination, wedge-shaped type cross-stratification, and characteristic fracturing of angular blocks. Conglomerate levels are rarely observed within this member. At the microscopic scale, these rocks consist of well sorted quartzite with an almost exclusively quartz composition, and grain-like texture with a relative scarcity of phyllosilicates, which makes it difficult to recognize metamorphic foliation. The sedimentary environment corresponds to coastal beach with flat morphology and characterized by sandy bars that were subject to occasional periods of emergence and oxidation. *Sample MP8* (Fig. 4).

3) *Membro delle Quarziti Bianco-Rosa (QMS$_3$) Carnian*

The *Quarziti Bianco-Rosa* member is characterized by heterogeneous sedimentary features, presenting itself as a series of whitish well sorted and well stratified mature quartzite and quarzitic metasandstone in centimetre-decimetre thick strata. Metasandstone similar to those of *Anagenite minute* member and conglomeratic levels are also present (Monte Aspro, Monte Pianello, at Sant'Andrea di Compito). The upper part of this member consists of fine-grained quartzite with purplish phyllite intercalations that indicate the gradual passage to the next member (*Membro delle Quarziti viola zonate).* In this portion (the uppermost part), the green phyllite are gradually replaced by progressively thicker layers of purplish phyllite, locally characterized by ripples, joint structures from desiccation and footprints of tetrapods. Sedimentary environment corresponds to a shallow continental platform, locally affected by delta sedimentation. The deposits of the upper portion of the member indicate a reduction of the terrigenous contribution and the subsidence of the basin with the development of a wide delta plain. *Sample MP9* (Fig. 4).

4) *Membro delle Quarziti viola zonate (QMS4) Upper Carnian - Lower Norian*

The *Quarziti viola zonate* member is characterized by a 1-2 cm thick tight lamination made up by very fine-grained quartzite and hematite-rich micaceous layers. The base of the member mainly consists of quartzite with sporadic occurrence of conglomerate levels, while phyllite layers are dominant toward the top of the member. The transition with the underlying *Quarziti Bianco-Rosa* member is extremely gradational and the boundary is in correspondence with the first appearance of the purple phyllite intercalations.

The numerous tetrapod footprints found in the outcrops north of Agnano indicate an Upper Carnian and a Lower Norian age. The sedimentary environment corresponds to deltaic plane flooded by thin water level and characterized by periodic emersion with the development of erosive channels. *Sample MP10* (Fig. 4).

Upper Triassic - Oligocene sequence

The complete sequence of formations in Santa Maria del Giudice Unit corresponds to the evolution of a passive margin starting with "pre-rift Upper Triassic - Early Jurassic platform carbonate deposits (*Grezzoni* and *Marmi dei Monti Pisani*) followed by "syn-rift" carbonate deposits of pelagic domain (*Metacalcari con selce, Calcescisti and Metacalcari ad Entrochi*) and "post-rift" bathyal plane siliceous (*Metaradiolariti*) carbonate-terrigenous (*Cipollini and Scisti Sericitici*) and foredeep turbiditic deposits (*Pseudomacigno*).

Grezzoni (GRE) Norian-Rhaetian

The *Grezzoni* consists of light grey to dark grey recrystallized dolomite, that varies from a centimetre to a metre thick layers, separated by wavy dissolution surfaces. The stratigraphic contact with the underlying quartzite is marked by phyllitic metasandstone and phyllitic quartzite with rare conglomerate levels, while a metre thick breccia horizon characterizes the transition to the overlying formation. These deposits of Norian-Rhaetian age, represent the record of carbonate platform margin sedimentation in a sub- to supra-tidal environment. *Sample MP11* (Fig. 4).

Marmi dei Monti Pisani (CCE) Hettangian - Lower Pliensbachian

With a maximum thickness of 250 metres, it consists of massive marble ranging in colour from white grey to dark grey, and pink varieties. The stratigraphic transition to the overlying *Metacalcari con selce* is marked by chert lenses and pink marble with pelitic intercalations. The formation is characterized by the presence of fossil remains as fragments of gastropods, crinoids, echinids, worm tubules, brachiopods, anthozoans, lamellibranchs and cephalopods. The sedimentary environment corresponds to a shallow water carbonate platform. *Sample MP12* (Fig. 4).

Metacalcari con selce (CLF) Pliensbachian - Toarcian

This formation is made up of decimetre thick (20-40 cm) grey metacalcilutite, with rare grey or light brown metacalcarenite. Frequent occurrence of chert layers and lenses of centimetre thickness. The stratigraphic contact with the overlying *Calcescisti* is marked by a reduction of carbonate layers thickness and more diffuse occurrence of pelitic intercalations. Sedimentary environment corresponds to pelagic domain. *Sample MP13* (Fig. 4).

Calcescisti (APU) Toarcian - Bathonian

This formation consists of alternance of grey impure marble and grey to yellowish grey metapelite. Marble layers of centimetre thickness alternating with thin metapelite levels are more diffuse at the base of the formation, while metapelite with thin marble mainly characterize the upper portion where some breccia levels locally occur. The stratigraphic contact with underlying *Metacalcari con Selce* is gradual, while a sharp stratigraphic contact marks the passage to overlying *Metacalcari ad Entrochi*. Sedimentary environment corresponds to pelagic domain. *Sample MP14* (Fig. 4).

Metacalcari ad Entrochi (ENT) Bathonian - Tithonian

This formation is made up of grey marble and calcarenite characterized by abundant fragments of crinoid articles, which give the rock a "pattered" appearance. Dark chert nodules are rarely present. The base of formation is characterized by alternance of metalimestone and finely foliated metamarl, upward followed by weakly stratified and fossiliferous grey metalimestone that becomes the dominant lithology. Sedimentary environment corresponds to turbid currents in pelagic domain. *Sample MP15* (Fig. 4).

Metaradiolariti (MDT) Bathonian p.p. - Upper Tithonian p.p.

This formation consists of centimetre and decimetre thick metaradiolarite layers ranging in colour from reddish to green, with locally thin metapelitic intercalations. The lower contact with the *Metacalcari ad Entrochi* is heteropic. The contact with the overlying *Scisti Sericitici* is characterized by intense deformation and regarded as tectonic. The tectonic contact leads to the complete elision of the *Maiolica* and of the basal part of the *Scisti Sericitici* with the superimposition of the *Cipollino* member (SSR1) directly on the metaradiolarite. Sedimentary environment corresponds to bathyal plane below the carbonate compensation depth (CCD). *Sample MP16* (Fig. 4).

Scisti Sericitici (SSR) Turonian - Maastricthian

This formation consists of greenish phyllite, more rarely purplish red or grey, with rare and thin levels of carbonate phyllite. The basal part of the formation is mainly calcareous while the top is dominated by pelitic deposits. Environment corresponds to bathyal plane at a depth close to the carbonate compensation depth (CCD). *Sample MP17* (Fig. 4).

Cipollini (SSR1) ?Aptian p.p. - ?Albian p.p.

The *Cipollini* member, that marks the tectonic contact with the underlying Metaradiolarite, consists of finely laminated grey to reddish or greenish calcschist with alternance of carbonate and marls layers. Sedimentary environment corresponds to bathyal plane at a depth close to the CCD. *Sample MP18* (Fig. 4).

Pseudomacigno (PSM) Upper Oligocene p.p. - Lower Miocene (Chattian p.p. - Aquitanian p.p.)

The formation consists of weakly metamorphosed positive turbiditic sequence ranging from medium-coarse metasandstone to fine-grained pelite or siltstone. The sequences are organized in layers up to 1-2 metre-thick that are characterized by planar and weakly erosive bases and direct gradation. The top of each positive sequence is made up of thin layers of dark grey metasandstone or quartzitic phyllite. Sedimentary environment corresponds to foredeep basin located in an abyssal plain. *Sample MP19* (Fig. 4).

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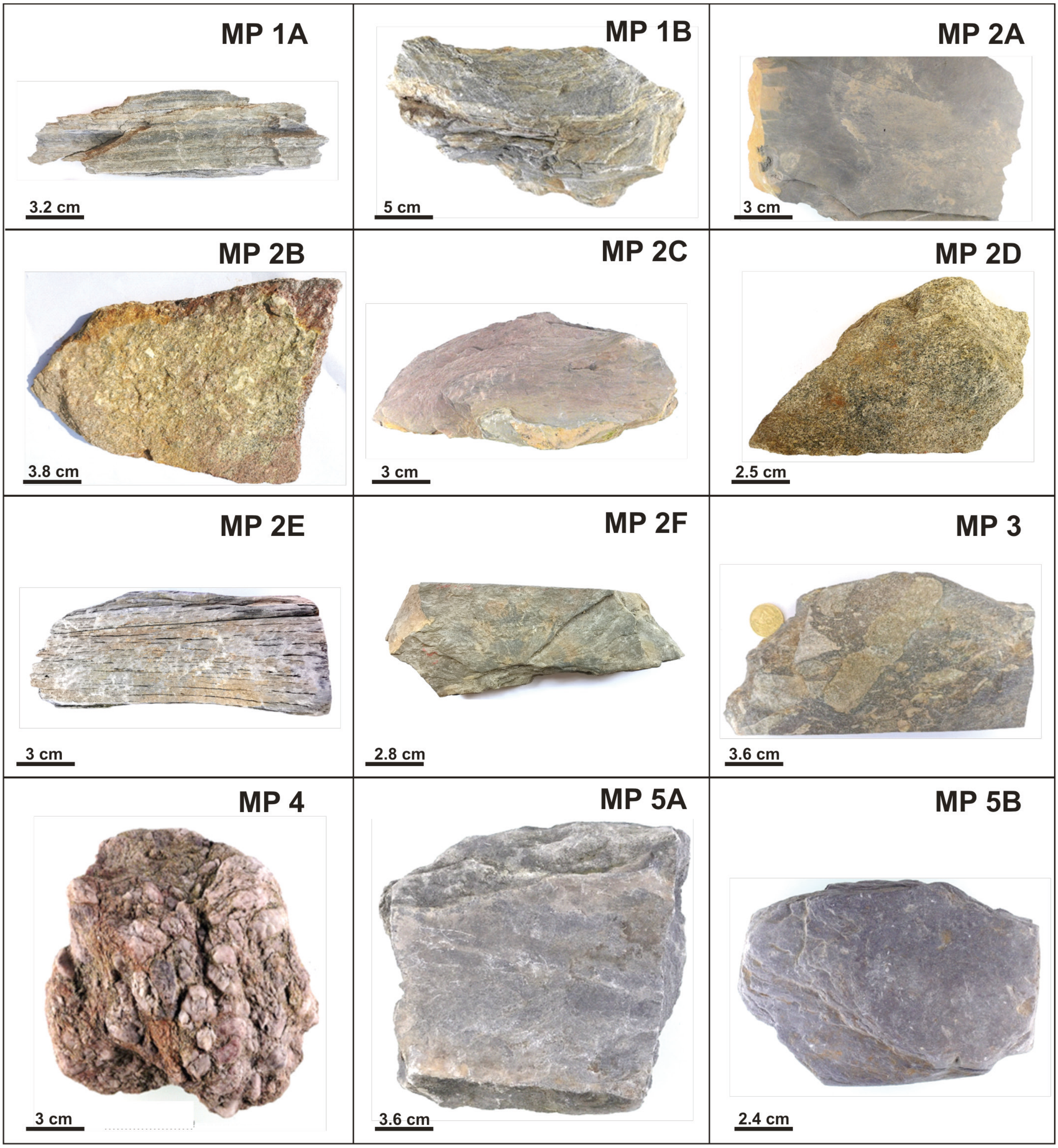
Table 1. List of samples with geographical coordinates.

Sample	Lithology	Formation/Member	coordinates
MP1A	Phyllitic quartzite	Filladi e Quarziti di Buti	43°44'04.41"N, 10°34'06.70"E
MP1B	Grey phyllite	Filladi e Quarziti di Buti	43°44'04.41"N, 10°34'06.70"E
MP2A	Grey phyllite	Verruca Fm. - Scisti di San Lorenzo	43°47'44.39"N, 10°29'33.33"E
MP2B	Microconglomerate	Verruca Fm. - Scisti di San Lorenzo	43°47'44.39"N, 10°29'33.33"E
MP2C	Grey phyllite	Verruca Fm. - Scisti di San Lorenzo	43°47'44.39"N, 10°29'33.33"E
MP2D	Grey metasandstone	Verruca Fm. - Scisti di San Lorenzo	43°47'32.68"N, 10°29'32.98"E
MP2E	Metasiltite	Verruca Fm. - Scisti di San Lorenzo	43°47'32.68"N, 10°29'32.98"E
MP2F	Phyllite	Verruca Fm. - Scisti di San Lorenzo	43°47'32.68"N, 10°29'32.98"E
MP3	Polygenic breccia	Verruca Fm - Brecce di Asciano	43°45'43.13"N, 10°28'10.76"E
MP4	Metaconglomerate	Verruca Fm - Membro delle Anageniti	43°44'05.40"N, 10°33'36.03"E
MP5A	Purple schist	Verruca Fm - Membro degli Scisti Violetti	43°44'05.40"N, 10°33'36.03"E
MP5B	Purple phyllite	Verruca Fm - Membro degli Scisti Violetti	43°45'03.32"N, 10°33'02.31"E
MP6A	Quartzite	Verruca Fm - Membro delle Anageniti Minute	43°44'48.9"N, 10°33'02.1"E
MP6B	Quartzite	Verruca Fm - Membro delle Anageniti Minute	43°45'49.80"N, 10°27'50.78"E
MP7A	Quartzitic phyllite	Quarziti del Monte Serra Fm - Membro degli Scisti Verdi	43°44'15.80"N, 10°32'01.94"E
MP7B	Metasandstone	Quarziti del Monte Serra Fm - Membro degli Scisti Verdi	43°44'53.60"N, 10°36'59.80"E
MP7C	Phyllite	Quarziti del Monte Serra Fm - Membro degli Scisti Verdi	43°44'53.60"N, 10°36'59.80"E
MP8	Greenish-grey quartzite	Quarziti del Monte Serra Fm -Membro delle Quarziti Verdi	43°44'10.11"N, 10°32'16.90"E
MP9A	Grey-pink quartzite	Quarziti del Monte Serra Fm - Membro delle Quarziti Bianco-Rosa	43°42'45,80"N, 10°31'01.40"E
MP9B	Dark grey quartzite	Quarziti del Monte Serra Fm - Membro delle Quarziti Bianco-Rosa	43°44'34.48"N, 10°29'27.19"E
MP10A	Violet quartzite	Quarziti del Monte Serra Fm - Membro delle Quarziti Viola Zonate	43°44'43.72"N, 10°29'26.12"E
MP10B	Purplish grey phyllite	Quarziti del Monte Serra Fm - Membro delle Quarziti Viola Zonate	43°45'56.04"N, 10°27'28.39"E
MP11	Grey dolomite	Grezzoni	43°45'44.50"N, 10°27'16.90"E
MP12A	White- grey marble	Marmi dei Monti Pisani	43°45'30.19"N, 10°26'41.33"E
MP12B	Marble	Marmi dei Monti Pisani	43°45'15.76"N, 10°26'47.87"E
MP12C	Grey marble	Marmi dei Monti Pisani	43°45'45.11"N, 10°27'02.54"E
MP13	Metalimestone	Metacalcari con selce	43°46'19.57"N, 10°26'18.47"E
MP14A	Yellowish grey metalimestone	Calcescisti	43°46'18.00"N, 10°26'22.52"E
MP14B	Grey phyllite	Calcescisti	43°46'18.89"N, 10°26'21.58"E
MP15A	Phyllite marl	Metacalcari ad Entrochi	43°46'31.12"N, 10°26'19.36"E
MP15B	Metalimestone	Metacalcari ad Entrochi	43°46'38.07"N, 10°26'17.42"E
MP16	Dark red metaradiolarite	Metaradiolarite	43°46'43.97"N, 10°26'15.81"E
MP17A	Red-violet calcschist	Cipollini	43°46'44.33"N, 10°26'15.27"E
MP17B	Grey calcschist	Cipollini	43°46'44.90"N, 10°26'14.92"E
MP18A	Grey phyllite	Scisti Sericitici	43°46'56.04"N, 10°25'46.22"E
MP18B	Greenish phyllite	Scisti Sericitici	43°47'15.70"N, 10°26'18.16"E
MP18C	Brownish metalimestone	Scisti Sericitici	43°47'10.95"N, 10°26'22.78"E
MP18D	Grey phyllite	Scisti Sericitici	43°47'14,21"N, 10°26'19.98"E
MP19A	Metasandstone	Pseudomacigno	43°47'36.70"N, 10°25'41.10"E
MP19B	Dark grey phyllite	Pseudomacigno	43°47'36.70"N, 10°25'41.10"E

Table 2. Photos of rocks collection.



MP 6A

2,5 cm

MP 6B

3 cm

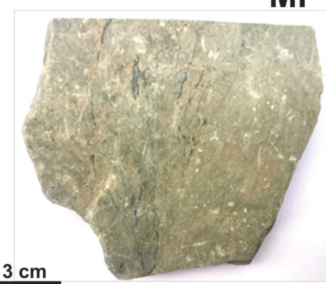
MP 7A

5.5 cm

MP 7B

4 cm

MP 7C



3 cm

MP 8

4.5 cm

MP 9A

2 cm

MP 9B

4.8 cm

MP 10A

2.8 cm

MP 10B

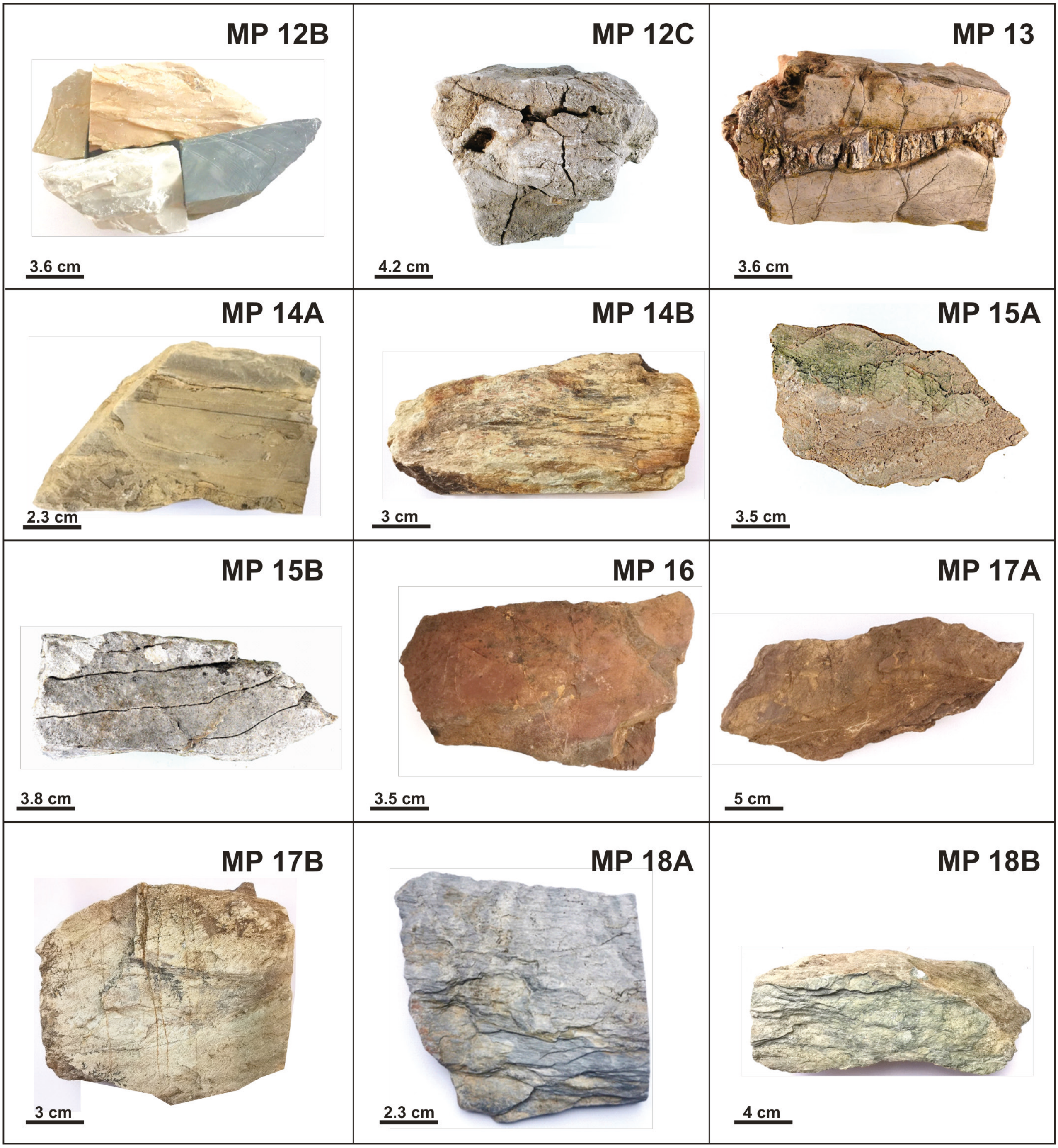
4.5 cm

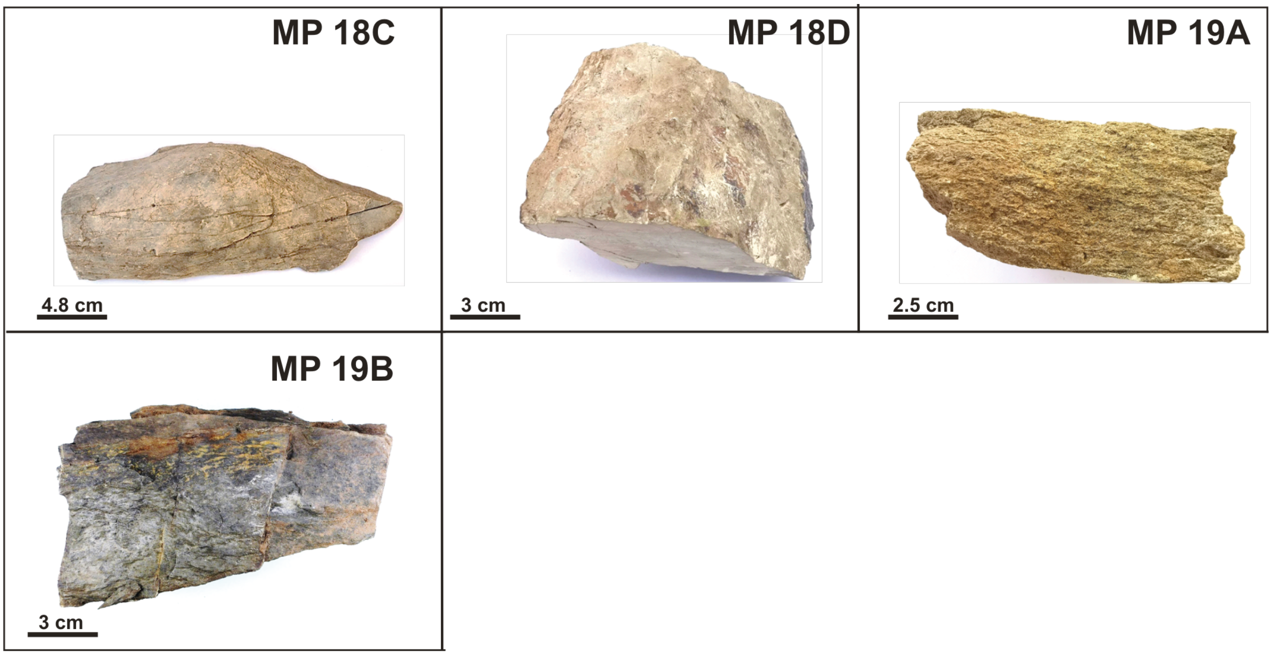
MP 11

3.1 cm

MP 12A

3.7 cm


MP 12B
3.6 cm
MP 12C
4.2 cm
MP 13
3.6 cm
MP 14A
2.3 cm
MP 14B
3 cm
MP 15A
3.5 cm
MP 15B
3.8 cm
MP 16
3.5 cm
MP 17A
5 cm
MP 17B
3 cm
MP 18A
2.3 cm
MP 18B
4 cm


MP 18C
4.8 cm
MP 18D
3 cm
MP 19A
2.5 cm
MP 19B
3 cm

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