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Giovanni Musumeci ⁽¹⁾, Tiziana Ciomei ⁽¹⁾, Antonio Cascella ⁽²⁾

THE EDUCATIONAL COLLECTION OF MONTI D'OLTRE SERCHIO TRIASSIC-MIOCENE TUSCAN NAPPE LITOSTRATIGRAPHIC SEQUENCE (NORTHERN TUSCANY, ITALY)

Abstract - G. Musumeci, T. Ciomei, A. Cascella, *The educational collection of Monti d'Oltre Serchio Triassic-Miocene Tuscan Nappe lithostratigraphic sequence (Northern Tuscany, Italy)*.

The lithotypes belonging to the Tuscan Nappe tectonic unit exposed in the Monti d'Oltre Serchio massif (Tuscany, Italy), are described for educational purposes. The collection consists of 22 samples, with relative thin sections, representative of sedimentary formations belonging to the Upper Trias-Lower Miocene sequence of the Tuscan Nappe tectonic unit in the Tyrrhenian margin of the northern Apennines. The sequence documents the Mesozoic-Cenozoic evolution of the Adria plate passive continental margin, from lagoonal to pelagic marine environment. In the supplementary material, the location, a synthetic description of lithologies, and outcrop are reported along with meso and microscale sample descriptions, and also microphotographs of selected sample microfacies.

Key words - Northern Apennines, Monti d'Oltre Serchio, Tuscan Nappe unit, educational collection

Riassunto - G. Musumeci, T. Ciomei, A. Cascella, *La collezione didattica della sequenza litostratigrafica della Falda Toscana Triassica-Miocenica dei Monti d'Oltre Serchio (Toscana settentrionale, Italia)*.

Viene descritta la collezione delle litologie appartenenti all'unità tettonica della Falda Toscana (Tuscan Nappe) affiorante nel settore dei Monti d'Oltre Serchio. La collezione, realizzata a scopo didattico, è costituita da 22 campioni, con relativa sezione sottile per le osservazioni microscopiche. I campioni sono rappresentativi delle formazioni appartenenti alla sequenza Triassico Superiore-Miocene Inferiore della Falda Toscana lungo il margine tirrenico dell'Appennino settentrionale. La sequenza documenta l'evoluzione Mesozoica-Cenozoica del margine continentale passivo della placca Adria, da ambiente lagunare ad ambiente marino pelagico. Nel materiale supplementare, vengono riportate

la posizione, una breve descrizione degli affioramenti e dei campioni sia alla meso che alla microscala e le foto delle microfacies di alcuni campioni.

Parole chiave - Appennino settentrionale, Monti d'Oltre Serchio, Falda Toscana, collezione didattica

Introduction

The Monti di Oltre Serchio (**fig. 1**) is a NS trending massif in the inner sector (Tyrrhenian side) of the Northern Apenninic chain, characterised by a hilly morphology and locally covered by abundant vegetation. This massif is located northwest of Monti Pisani, from which it is separated by the Serchio River valley, and the northern limit corresponds to the Massacciuccoli-Balbano lineament (Giannini 1950). The Mesozoic-Cenozoic stratigraphic sequence of Tuscan Nappe is widely exposed in the Monti d'Oltre Serchio and in the northwesternmost portion of the Monti Pisani massif, east of the Serchio River valley, where it tectonically overlies the Santa Maria del Giudice Unit belonging to the Tuscan Metamorphic Complex (Giannini & Nardi 1965, Rau & Tongiorgi 1974). The Tuscan Nappe stratigraphic sequence mainly consists of carbonatic, siliceous, and arenaceous rocks that, since the Middle Ages, have been used as building material. In particular, the sandstone of the Macigno Fm (late Oligocene-Early Miocene) was a stone material used for the construction of military, civil, and religious buildings in the Filettole area (Aquino *et al.*, 2020; **fig. 1**). The first geological and paleontological studies, and the first geological maps of Monti d'Oltre Serchio have been

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published by Ugolini (1905) e Fucini (1921; 1925). In the sixties Giannini & Nardi (1965) published the geological map of north-western Monti Pisani and Monti d'Oltre Serchio with a detailed description of lithologies. An updated geological map of the Monti d'Oltre Serchio is reported in the Geological Sheet 261 Lucca (Servizio Geologico d'Italia, 2017), and Geological Sheet 273 Pisa (Servizio Geologico d'Italia, 2010) 1:50.000 scale.

This work describes the educational lithological collection of the Tuscan Nappe outcropping in the Monti d'Oltre Serchio, housed at the Department of Earth Sciences (DST), University of Pisa. Through detailed lithological descriptions and photographic documentation, this study aims to improve the educational resources of the (DST) and to complement the previous work by Musumeci & Ciomei (2021) regarding the collection of metamorphic rocks from the Monti Pisani.

In the following sections, after a geological outline of the Monti d'Oltre Serchio, the lithological features of the geological formation will be described according to the stratigraphic order from the Late Triassic to the Early Miocene.

Northern Apennines

The structure of the Northern Apennine chain consists of eastward verging continental crust (Tuscan Domain) and oceanic crust (Ligurian Domain) tectonic units (fig. 2). The nappe structure results from early Eocene-Oligocene subduction of Ligurian oceanic crust followed by Oligocene-Miocene continental collision (e.g., Boccaletti *et al.*, 1971; Boccaletti *et al.*, 1999; Carmignani *et al.*, 2004; Molli, 2008). After the main phase of continental collision, the orogenic belt has undergone significant post-orogenic extension. From Middle-Late Miocene slab rollback and back-arc retreat of the subducting Adriatic plate induced crustal thinning and the development of extensional fault systems (e.g. Sani *et al.*, 2009).

From bottom to the top, tectonic units are: (i) Tuscan Metamorphic Complex outcropping along an arcuate structure (Middle Tuscan Ridge, fig. 2) from Apuan Alps at north to Argentario promontory at south; (ii) non-metamorphic to very low metamorphic grade Tuscan Nappe sequence (Baldacci *et al.*,

1967; Cerrina Feroni *et al.*, 1983; Carosi *et al.*, 2003) and (iii) non-metamorphic Ligurian Unit sequence (Bortolotti *et al.*, 2001). Tectonic units are covered by the sedimentary deposits of Neogene succession deposited in shallow marine basins (Bossio *et al.*, 1993).

The lithological sequence of the Tuscan Metamorphic Complex and Tuscan Nappe consists of Middle-Upper Triassic to Lower Miocene deposits that record the evolution of the Adria passive margin from continental to deep marine basin during Mesozoic-Cenozoic times (e.g., Baldacci *et al.*, 1967; Kalin *et al.*, 1979; Fazzuoli *et al.*, 1994; Ciarapica and Passeri, 1994). The Tuscan Metamorphic Complex experienced deep subduction (HP/LT metamorphism; e.g., Théye *et al.*, 1997; Molli *et al.*, 2000; Brogi and Giorgetti, 2012; Bianco *et al.*, 2019) and exhumation at a shallow crustal level. Differently, the Tuscan Nappe sequence represents a cover unit, detached from its original basement along a detachment zone (tectonized Norian anidrites and dolostone), overthrust above metamorphic unit and deformed at shallow crustal level under anchizone metamorphic conditions (Cerrina Feroni *et al.*, 1983; Carosi *et al.*, 2003).

Monti d'Oltre Serchio geological outline

The Monti d'Oltre Serchio massif (figs 3, 4) consists of Tuscan Nappe sedimentary sequence (Giannini 1950; Giannini & Nardi 1965), that (i) tectonically overlies the Tuscan Metamorphic Complex (Santa Maria del Giudice Unit) in the westernmost portion of Monti Pisani Massif (figs 2, 3), and (ii) is in turn tectonically covered by Ligurian Unit at west of Filettole village (fig. 3). The Upper Triassic to Lower Miocene sequence consists of syn and post-rift marine deposits along the Adria continental margin. The syn-rift cycle (Middle Triassic-Early Jurassic) starts with shallow water lagoonal and carbonate deposits (Calcare Cavernoso Fm.), followed by the shallow water carbonate platform (Calcare a *Rhaetavicula contorta* Fm.; Calcare Massiccio Fm.). The Early Jurassic-Late Jurassic fault activity and subsidence of the continental margin led to the drowning of the carbonate platform with deposition of emi-pelagic and pelagic carbonate sediments (Rosso Ammonitico Fm., Calcare selcifero di Limano Fm., Calcare e Marne a *Posidonia* Fm., Calcare

selcifero della Val di Lima Fm.). Post-rift cycle starts with the deposition of siliceous deposits in pelagic environment (Diaspri Fm.), followed by the Lower Cretaceous pelagic limestone (Maiolica Fm.), Upper Cretaceous-upper Eocene terrigenous and carbonatic deposits (Scaglia Toscana Fm.), and upper Oligocene-Lower Miocene foredeep turbiditic deposits (Macigno Fm.).

Giannini & Nardi (1965), in their comprehensive and detailed study of Monti Pisani and Monti d'Oltre Serchio, divided the Tuscan Nappe sequence into two subunits. A lower subunit that comprises Middle Triassic-upper Eocene formations, which is tectonically overlain through a low angle fault by the upper subunit represented by the Upper Jurassic to Lower Miocene deposits (Diaspri Fm., Maiolica Fm., Scaglia Toscana Fm., and Macigno Fm.). The contact between the two subunits is exposed at north and east of Mt. Niquila (figs 3, 4), where the Macigno Fm. discordantly lies above Upper Jurassic to upper Eocene deposits of the lower unit (Diaspri Fm., Maiolica Fm., and Scaglia Toscana Fm.) and in the Mt. Maggiore area (figs 3, 4) with the Diaspri Fm. and Maiolica Fm.

that lie in tectonic contact above the Upper Triassic deposits (Calcare Cavernoso Fm.). The lower subunit is also characterized by some variation in thickness of sedimentary formations as in the Mt. Legnaio, where the Diaspri Fm. shows a strong reduction in thickness (fig. 3). At the map scale the structure of Monti d'Oltre Serchio corresponds to a N-S striking monoclinical structure (fig. 4), steeply to moderately dipping toward west, that at north-west of Filettole is in turn tectonically overlain by a synform of pelites belonging to the Ligurian Unit. East of the Serchio River, on the northwestern side of the Monti Pisani massif, the tectonic contact between the Tuscan Nappe sequence and the underlying Santa Maria del Giudice Unit, is marked by the vacuolar limestone and dolomitic limestone of the Calcare Cavernoso Fm., a tectonic breccia that marks the base of the Tuscan Nappe in the Northern Apennines (e.g., Baldacci *et al.*, 1967; Gandin *et al.*, 2000). The main deformation corresponds to the development of a map-scale NS-striking anticline, gently plunging toward the north, cored by Triassic formations of the Tuscan Nappe lower unit (Giannini & Nardi 1965). In the northern



Fig. 1 - Monti Pisani and Monti d'Oltre Serchio massifs (from Google Earth).

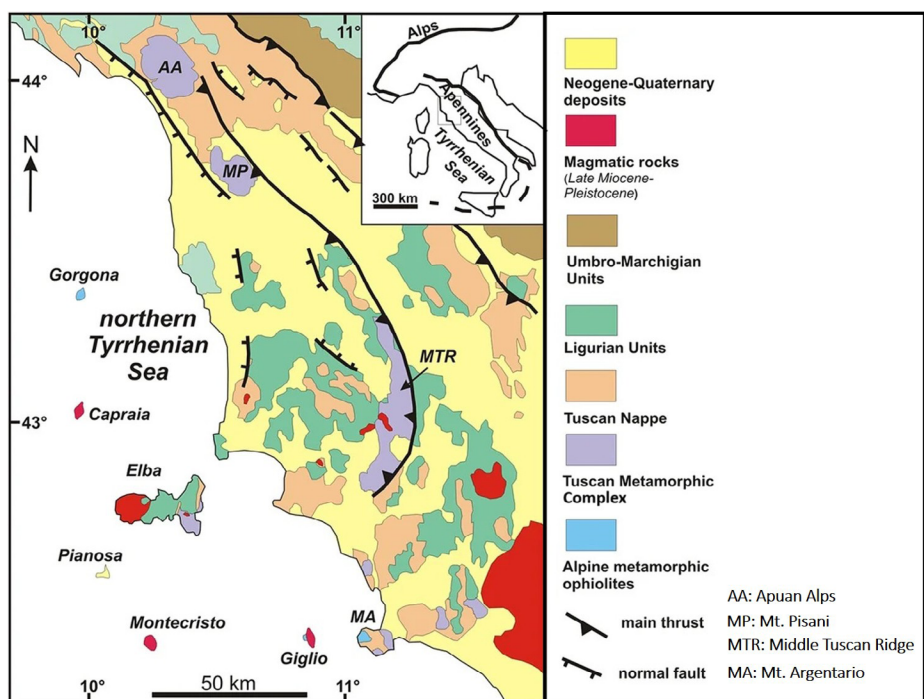


Fig. 2 - Tectonic sketch map of northern Appennine (slightly modified after Massa *et al.*, 2017).

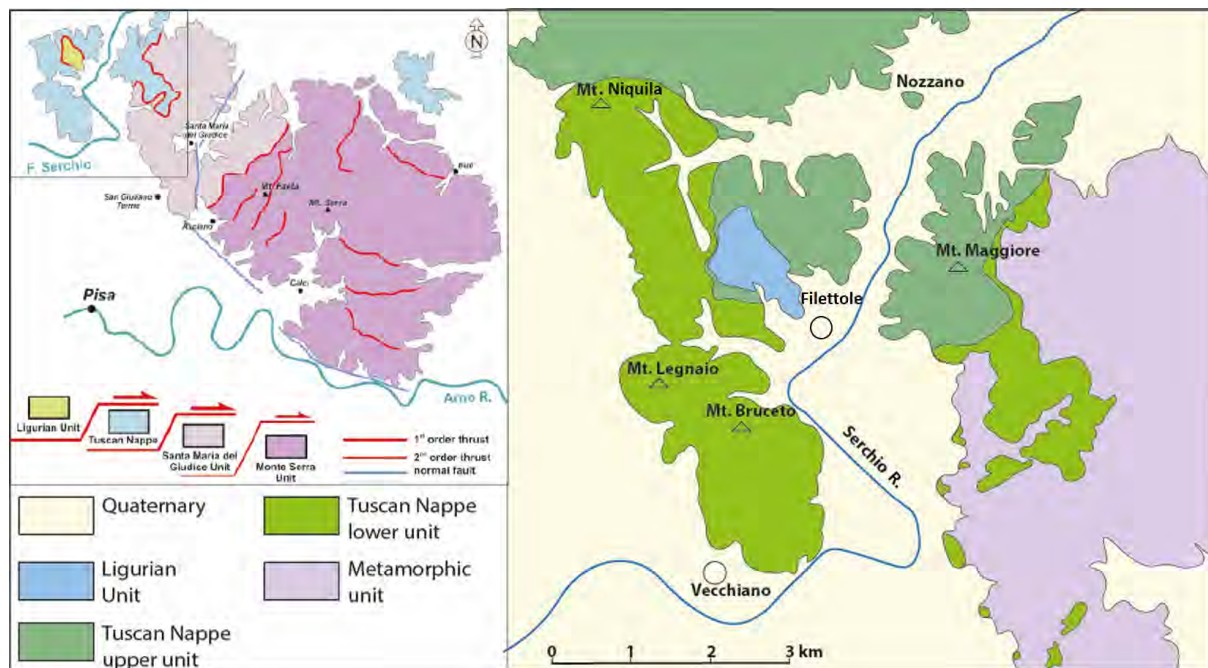


Fig. 3 - Tectonic sketch map of Monti Pisani and Monti d'Oltre Serchio massifs (slightly modified after Giannini & Nardi, 1965).

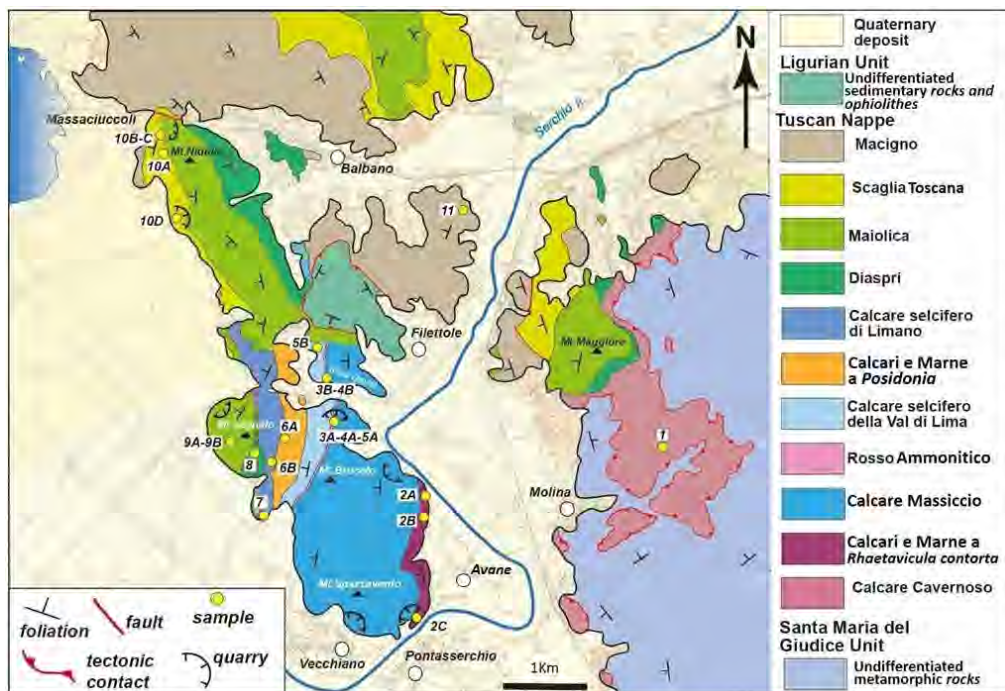


Fig. 4 - Geological map of Monti d'Oltre Serchio, the location of described samples is also reported (slightly modified after Giannini & Nardi, 1965).

area, the anticline structure is unconformably overlain by tectonic contacts at the base of the Tuscan Nappe upper unit (see Giannini & Nardi 1965, geological map). At the mesoscale, deformation is mainly highlighted by upright folds with subvertical axial planes (Giannini & Nardi, 1965), well recognizable in the Maiolica and Scaglia Toscana formations exposed in abandoned quarries (e.g., in the Monte Legnaio quarry; fig. 3). Syn-sedimentary deformation structures can be observed in the Calcare selcifero della Val di Lima Fm. exposed in the abandoned quarry north of Mt. Bruceto, where metre-scale submarine slumping structures are preserved (sample 5A, figs 3, 4).

Educational collection

A complete collection of rock samples representative of the lithostratigraphic sequence of the Falda Toscana in the Monti d'Oltre Serchio area was set up. The samples are identified with the label MSO, which is the acronym of Monti d'Oltre Serchio. Sample position is reported in the geological map (fig. 4), in the lithostratigraphic column (fig. 5),

and in tab. 1. The samples position is also reported in the supplementary material (S1), where they are illustrated and described. Moreover, in supplementary material (S2), the microphotographs of selected sample microfacies are shown. Samples were collected in well-exposed and accessible outcrops, most of them located along roads and/or tracks. In the following paragraphs, a synthetic description of the compositional and textural features of the Tuscan Nappe formations in the Monti d'Oltre Serchio is reported.

For an extensive description of the lithotypes and geological map refer to: Giannini & Nardi (1965), Servizio Geologico d'Italia (2010), Carosi *et al.* (2010), Servizio Geologico d'Italia (2017), and Cerina Feroni *et al.* (2017). For the nomenclature and acronyms of the formations, refer to Geological map at scale 1:50.000: F.261-Lucca, and F.273-Pisa.

This educational collection is stored, visible, and available for studies at the Department of Earth Sciences of the University of Pisa. The description and photographic documentation of the lithology can be consulted in the attached Supplementary material (S1 and S2).

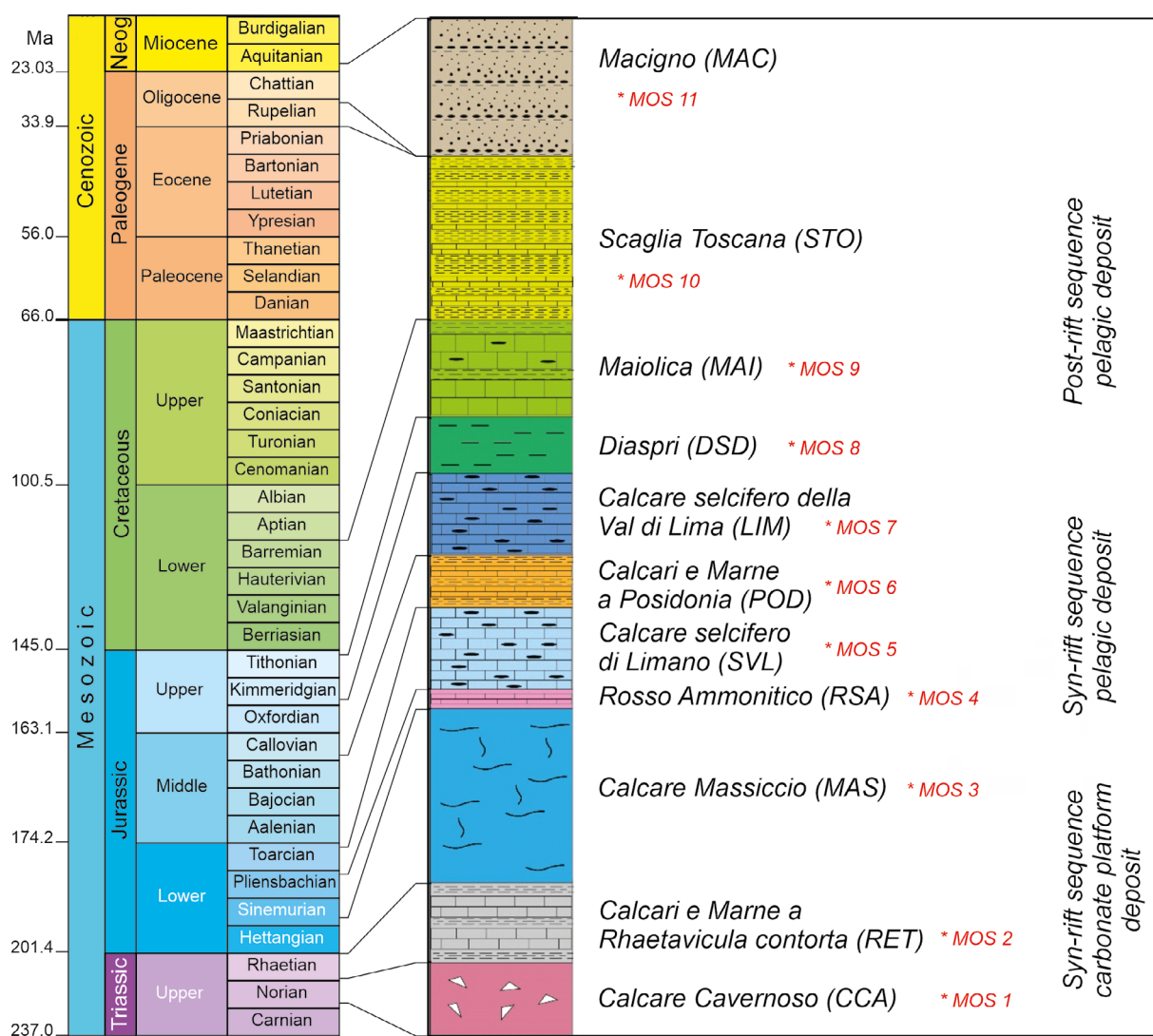


Fig. 5 - Monti d'Oltre Serchio Tuscan Nappe lithostratigraphic sequence, not to scale. The described samples (*MOS) are also reported. The hiatus between the STO and MAC units corresponds to the lower Oligocene Marne di Rio Benabbiana Fm (cf. Marne di Rovaggio Fm.; see the 1:50,000 scale Geological map, Sheet 261 – Lucca).

TUSCAN NAPPE SEQUENCE

SYN-RIFT SEQUENCE

CALCARE CAVERNOSO FM. (CCA) (Norian p.p. – Rhaetian p.p.)

Calcare Cavernoso Fm. crops out only in the Mt. Maggiore area (northwestern Monti Pisani massif; **fig. 4**). This formation consists of dolomitic limestone and polygenic breccia with clasts of dolostone and dolomitic limestone that tectonically overlay the Santa Maria del Giudice Unit. The vacuolar texture that is the distinctive feature of *Calcare Cavernoso Fm.* is due to the dissolution the gypsum

during diagenesis, and later tectonic deformation. These rocks of Norian-Rhaetian age represent the record of carbonate platform-margin sedimentation in a sub- to supra-tidal environment, sample MOS 1 (**figs 4, 5; tab. 1; S1**).

CALCARI E MARNE A RHAETAVICULA CONTORTA (RET) (Rhaetian)

This formation is made up of dark grey limestone and marly limestone that crop out along the eastern side of Mt. Spazzavento at north of Vecchiano village and west of Avane (**fig. 4**). Giannini & Nardi (1965) distinguished two carbonate facies. A lower

Tab. 1 - List of samples with gps coordinates.

Sample	Lithology	Formation	Coordinates (Latitude, Longitude)
MOS 1	carbonatic breccia	Calcare Cavernoso	43°47'58.18"N, 10°26'05.72"E
MOS2A	fine-grained limestone	Calcari e Marne a <i>Rhaetavicula contorta</i>	43°47'42.60"N, 10°24'10.80"E
MOS 2B	grey limestone and marls	Calcari e Marne a <i>Rhaetavicula contorta</i>	43°47'46.10"N, 10°24'13.59"E
MOS 2C	massive dark grey limestone	Calcari e Marne a <i>Rhaetavicula contorta</i>	43°47'46.10"N, 10°24'13.59"E
MOS 3A	massive grey limestone	Calcare Massiccio	43°48'09.61"N, 10°23'22.27"E
MOS 3B	fine-grained grey limestone	Calcare Massiccio	43°48'31.00"N, 10°23'21.00"E
MOS 4A	dark red nodular limestone	Rosso Ammonitico	43°48'10.10"N, 10°23'22.04"E
MOS 4B	pink nodular limestone	Rosso Ammonitico	43°48'31.10"N, 10°23'20.72"E
MOS 5A	fine-grained grey limestone	Calcare Selcifero di Limano	43°48'09.60"N, 10°23'20.64"E
MOS 5B	fine-grained cherty limestone	Calcare Selcifero di Limano	43°48'34.00"N, 10°23'16.00"E
MOS 5C	marly limestone (interbed layer)	Calcare Selcifero di Limano	43°48'34.00"N, 10°23'16.00"E
MOS 6	marly limestone	Calcari e Marne a Posidonia	43°47'57.82"N, 10°22'56.76"E
MOS 7A	cherty limestone	Calcare Selcifero della Val di Lima	43°47'48.87"N, 10°22'49.85"E
MOS 7B	medium-grained cherty limestone	Calcare Selcifero della Val di Lima	43°47'41.23"N, 10°22'49.74"E
MOS 8	pinkish-red radiolarites	Diaspri	43°48'04.28"N, 10°22'44.85"E
MOS 9A	light grey limestone	Maiolica	43°48'05.15"N, 10°22'41.13"E
MOS 9B	stratified limestone with chert lists	Maiolica	43°48'07.78"N, 10°22'38.61"E
MOS 10A	greenish-grey clayey shale	Scaglia Toscana	43°50'00.50"N, 10°21'55.15"E
MOS 10B	grey calcarenite	Scaglia Toscana	43°50'04.02"N, 10°21'53.85"E
MOS 10C	grey calcarenite with chert list	Scaglia Toscana	43°50'04.02"N, 10°21'53.85"E
MOS 10D	marly limestone	Scaglia Toscana	43°49'32.27"N, 10°22'02.88"E
MOS 11	medium to coarse-grained sandstone	Macigno	43°49'34.11"N, 10°24'28.03"E

facies ("Calcari e marne ad *Avicula contorta*" Auct.) that consists of metre thick levels of stratified limestone and marly limestone alternate with centimetre-thick marl layers, often showing yellowish alteration. The upper facies ("Calcari grigio scuri" Auct.) is made up of poorly stratified metre-thick dark grey limestone. This facies is characterized by the diffuse occurrence of fracture networks filled by white to yellowish calcite veins. These rocks represent the record of lagoon sedimentary environment, sample MOS 2 (figs 4, 5; tab. 1; S1).

CALCARE MASSICCIO (MAS) (Hettangian – Sinemurian p.p.)

Poorly stratified light grey to whitish massive limestone that crops out along the ridge between Mt. Spazzavento at south and Sassi Grossi at the north (fig. 4). The uppermost portion of the formation is characterised by pink colour at the contact with overlying *Rosso Ammonitico Fm.* that indicates a transitional boundary between the two formations. An Hettangian-Sinemurian age has been attribut-

ed to this formation based on fossiliferous content (Giannini & Nardi, 1965; Cerrina Feroni *et al.*, 2017 and reference therein). Massive limestone is affected by carsism with development of dolines filled by residual red soils (Marinelli, 1955). Moreover, Pliocene sedimentary breccias with marine fossils filling karst caves are indicative of a Pliocene sedimentary environment proximal to a marine basin (Bianucci & Landini, 2005).

The *Calcare Massiccio Fm.* represents the record of a carbonate platform margin sedimentary environment, sample MOS 3 (figs 4, 5; tab. 1; S1 and S2a).

ROSSO AMMONITICO (RSA) (Sinemurian p.p. – Pliensbachian p.p.)

Well-stratified pinkish to dark red limestone and marly limestone with a characteristic nodular texture. This formation in the Monti di Oltre Serchio is characterized by a reduced thickness (nearly 20 meters) and transitional stratigraphic contact with *Calcare Massiccio Fm.* at the base and *Calcare selcifero di Limano Fm.* at the top. In particular, the contact

with *Calcare Massiccio Fm.* is characterised by pink limestone, which is well recognizable at the Sassi Grossi locality. Fossiliferous content mainly consists of ammonites (Arietites; Cerrina Feroni *et al.*, 2017 and reference therein). The *Rosso Ammonitico Fm.* represents the record of deep slope pelagic sedimentary environment, sample MOS 4 (figs 4, 5; tab. 1; S1; S2b, c, d)

CALCARE SELCIFERO DI LIMANO (LIM) (Pliensbachian p.p. – Toarcian p.p.)

Well-stratified greyish limestone with thin (centimetre-thick) chert layers and nodules. The sedimentary bedding is evidenced by alternance of decimetre-thick limestone layers and thin yellowish silty clay levels. This stratigraphic sequence is well recognizable in the abandoned quarry at the base of the Sassi Grossi hill western slope (43°48'34.00"N, 10°23'16.00"E). The transition from the *Rosso Ammonitico Fm.* is generally marked by a sharp contact, although sometimes it can be gradual with a passage through alternations as recognizable in the abandoned quarry at north of Mt. Bruceto (43°48'09.60"N, 10°23'20.64"E).

This geological formation is characteristic of a deep slope pelagic sedimentary environment, sample MOS 5 (figs 4, 5; tab. 1; S1; S2e, f)

CALCARI E MARNE A POSIDONIA (POD) (Toarcian p.p. – Callovian p.p.)

Well-stratified alternance of fossiliferous reddish marls, pinkish marly limestone, and grey limestone. Fine laminated marls and marly limestone are the dominant lithology of the formation. This sequence can be observed along the dirty road on the southern slope of Mt. Bastione. The formation is characterized by the occurrence of fossils belonging to the genus *Posidonia*. The sediments represent a sedimentary environment from deep marine to basinal slope, sample MOS 6 (figs 4, 5; tab. 1; S1)

CALCARE SELCIFERO DELLA VAL DI LIMA (SVL) (Callovian p.p. – Kimmeridgian p.p.)

Dark grey medium-grained (calcarene) to fine-grained (calcilutite) limestone, light in color when altered, with abundant sedimentary bedding-parallel dark chert lists and/or nodules. The stratigraphic sequence is well exposed along the road on the southern slope of Mt. Bastione (43°47'41.23"N,

10°22'49.74"E). The *Calcare Selcifero della Val di Lima* represents turbiditic resedimentation of calcarenites in a pelagic environment, sample MOS 7 (figs 4, 5; tab. 1; S1; S2g).

POST-RIFT SEQUENCE

DIASPRI (DSD) (Kimmeridgian p.p. – Tithonian p.p.)
Well-stratified siliceous rocks with remains of siliceous shell organism (radiolarites; Cerrina Feroni *et al.*, 2017 and reference therein). Sedimentary bedding made up of decimetre to centimetre-thick layers, pink to reddish in colour, with thin clay and/or marly intercalations. These rocks settled in a deep pelagic sedimentary environment, below the CCD, sample MOS 8 (figs 4, 5; tab. 1; S1).

MAIOLICA (MAI) (Tithonian p.p. – Barremian)

This formation exposed on the western side of Monti d'Oltre Serchio, crops out continuously from Mt. Legnaio in the south to Monte Niquila in the north. It consists of white to light grey cherty, very fine-grained limestone (calcilutite) with some intercalation of thin marl layers. Sedimentary bedding ranges from centimetres to decimetres in thickness. The lowermost portion of the *Maiolica Fm.*, well exposed in the abandoned quarry north of Mt. Legnaio, close to the contact with the *Diaspri Fm.* consists of metre thick calcilutite strata. A continuous section of *Maiolica Fm.* crops out along the dirt road south of Mt. Legnaio. In this section, the lower portion consists of well-stratified light grey calcilutite with rare chert lists and regular decimetre-thick sedimentary bedding. In the upper portion of the sequence, dark grey limestones are intercalated with diffuse chert lists that are more regular in thickness and thin marl layers. The *Maiolica Fm.* is deposited in a sedimentary environment represented by a deep pelagic basinal plain, sample MOS 9 (figs 4, 5; tab. 1; S1).

SCAGLIA TOSCANA (STO) (Aptian – Priabonian)

The *Scaglia Toscana Fm.* is exposed in NS striking band along the western side of Monti d'Oltre Serchio and in the Ripafratta area to the east of Serchio River. This formation is made up of varicoloured clay at the base, followed upward by calcilutites and calcarenites. It can be observed in the abandoned quarry at La Casetta locality along the Via Pietra a Padule (43°49'32.27"N, 10°22'2.88"E) and along the road at west of Mt. Niquila.

In the quarry, a decimetre thick alternation of varicoloured and marly limestone crops out, followed upwards by a metre thick calcarenitic limestone. The same sequence is exposed in road at west of Mt. Niquila, where calcarenites are the dominant lithology. They consist of fine to medium-grained grey calcarenites with centimetre to decimetre thick strata alternating with fine-grained calcilutites similar to the *Maiolica* limestone. Locally, chert lists are intercalated within the calcarenites. The *Scaglia Toscana Fm.* settled in a deep basinal plain, sample MOS 10 (figs 4, 5; tab. 1; S1; S2h)

MACIGNO (MAC) (Chattian – Aquitanian p.p.)

This formation is widely exposed on the northern and eastern side of Monti d'Oltre Serchio and in a small outcrop in the Ripafratta area on the north-western side of Monti Pisani. The *Macigno Fm.* consists of decimetre to metre-thick turbiditic sandstone with intercalated decimetre-thick dark pelites, and it is in tectonic contact with the underlying formation of Tuscan Nappe. In the northernmost Monti d'Oltre Serchio, south of Massaciuccoli, the *Macigno Fm.* lies discordantly above the underlying formations up to the *Calcari Selciferi di Limano Fm.* close to the Balbano village (Servizio Geologico d'Italia, 2017). This formation of hectometre thickness at the map scale is poorly exposed in the area, and graded turbiditic sandstone intercalated with dark mudstone can be well observed in an abandoned quarry in the north-eastern side of Monti d'Oltre Serchio, south of the Nozzano railway station. The *Macigno Fm.* deposited in a sedimentary environment represented by the Northern Apennine foredeep, sample MOS 11 (figs 4, 5; tab. 1; S1; S2i)

Conclusions

This work illustrates and describes the lithological characteristics of the Tuscan Nappe rocks outcropping in the Monti d'Oltre Serchio, which form part of the DST UNIPI educational rock collection. Detailed descriptions and images of the lithology at meso and microscopic scales are provided in the supplementary material (S1 and S2). The geological and stratigraphic data provide context for the samples within the local geology of the Monti d'Oltre

Serchio, and the broader framework of the Northern Apennines' tectono-stratigraphic evolution. This approach provides students with a comprehensive geological-stratigraphic overview that extends beyond the simple identification of individual rock samples.

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Conflict of interest statement

The authors declare that they have no conflict of interest, known competing financial interests, or personal relationships that could have appeared to influence the work reported in this paper.

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