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The succession of the Val Marecchia Nappe (Northern Apennines, Italy) in the light of new field and biostratigraphic data

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Abstract This paper challenges the classical idea that the Val Marecchia Nappe, the highest of the north-eastern Apennines, is a nappe that originated from the External Ligurian Domain and consisting of Upper Cretaceous–Middle Eocene rocks, accreted to the Palaeo-Apenninic Chain in the Middle-Late Eocene due to the Ligurian tectonic phase. Its succession comprises a Middle-Late Jurassic ophiolitic substratum and its sedimentary cover of Late Jurassic to Early Miocene age. This succession is quite similar to those of the North-Calabrian and Parasicilide Units of the Southern Apennines and of many Maghrebian and Betic Flysch Domain Units, all originating from the Western Tethys and deformed since the Early Miocene. The Val Marecchia Nappe succession was likely deposited in an oceanic realm that differs from that of the Ligurian Domain and was located in a more external palaeogeographic position with respect to that of the Ligurian Domain. The oceanic realm of the Val Marecchia Nappe constituted the northwards extension of the Maghrebian Flysch Basin-Lucanian Ocean system.

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1 Introduction and previous studies

In the northern sector of the Apenninic Chain it is generally recognized that a north-east-verging nappe stack consisting of oceanic units (Ligurides) thrusted continent-derived-crustal units (Abbate et al. 1970; Elter 1973). This nappe stack is made up of Jurassic-Eocene Internal and External Ligurian oceanic units, originating from the Alpine Tethys Ocean in the west, thrusting, from top to bottom, Sub-Ligurian, Tuscan and Umbro-Marchean continental crustal units, derived from Triassic-Miocene successions deposited on the margin of the easterly adjacent Adria continent (Fig. 1). Among these latter, the Sub-Ligurian units show Cretaceous-Eocene sedimentary successions similar to those of the External Ligurian units, and, therefore, they are considered to have been deposited on the thinned continental crust of the westernmost part of the Adria margin located adjacent to the Ligurian Ocean (see Elter et al. 2003 and Principi 2007 for an overview).

The Val Marecchia Nappe (e.g., Ruggieri 1958, 1970; Veneri 1986; Ricci Lucchi 1987; de Feyter 1991; Conti 1994), widely exposed in the upper Tiber, Savio, Marecchia and Foglia valleys, constitutes the structurally highest nappe within the frontal parts of the Tuscan-Romagnan Apennines (Boccaletti et al. 1987; Conti 1994; Cornamusini et al. 2010; and references therein). This nappe overthrusts both Tuscan and Umbro-Marchean units, including the earlier formed tectonic contact between these units (Fig. 2). Its emplacement was considered as a typical example of gravitational tectonics (Merla 1956; Ruggieri

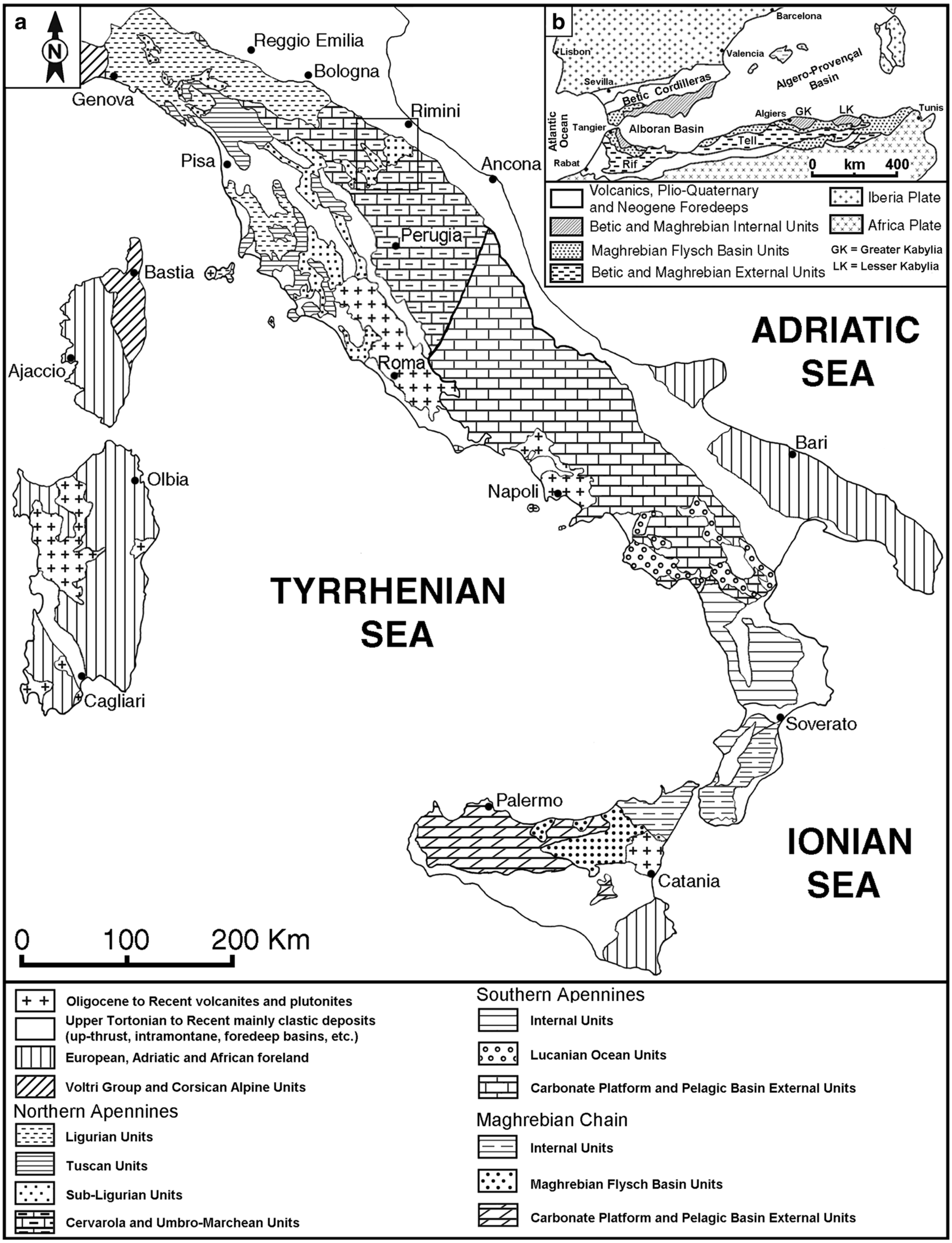

Fig. 1 **a** Simplified tectonic sketch of the Northern Apennines showing the main tectonic units of the Apennine; *box* indicates the area of Fig. 2. **b** Sketch map of the western Mediterranean

1958, 1970). Later, it was attributed to a combination of compression plus sliding (Ricci Lucchi 1987; de Feyter 1991) or exclusively to compressional tectonics (Conti 1994; Cerrina Feroni et al. 2001; Cornamusini et al. 2010; and others).

The lower part of the Val Marecchia Nappe stratigraphic succession is usually considered as made up of several mainly pelitic formations with minor calcareous and siliciclastic turbidite beds, with lateral and vertical transitions between the different formations. These up to

800 m thick formations (Sillano, Villa a Radda, Cercetole, Pugliano, *Argille Varicolori*, etc.), whose age spans from the Aptian to the Ypresian, were grouped into what is referred to as “Complesso Basale” (Basal Complex) in the Italian literature after Abbate and Sagri (1970), a complex that occasionally contains ophiolitic slivers. The formations of the Basal Complex (unit 9 of Fig. 2) are overlain by the Middle-Upper Eocene Monte Morello Fm. (unit 8 of Fig. 2), entirely turbiditic, consisting of limestones, marly limestones and marls, with interbedded minor thin siliciclastic beds and locally ophiolite-derived debrites (Bortolotti 1962, 1964; Abbate and Sagri 1970; Veneri 1986; de Feyter 1991; Vai and Castellarin 1992; Conti 1994; and references).

The paleogeographic location of the basin in which the sediments of the Val Marecchia Nappe were deposited, as well as its tectono-sedimentary evolution, are debated. The most popular interpretation considers the Val Marecchia Nappe as part of the Calvana Supergroup (Abbate and Sagri 1970) or Monte Morello Unit (Boccaletti et al. 1987; Principi 2007). Consequently, it is widely believed that the Val Marecchia Nappe sedimentary succession has been deposited in the easternmost zone of the External Ligurian Domain, close to the western margin of the Adria Plate; it became deformed in the Middle-Late Eocene following the Ligurian tectonic phase, after which it was overlain by the Epiligurian piggy-back basins. In contrast, Vai and Castellarin (1992) and Perrone et al. (1998) questioned this interpretation and considered the Val Marecchia Nappe as originating from the Sub-Ligurian Domain (Fig. 1). According to these authors, stratigraphic succession and tectonic evolution of the Val Marecchia Nappe are different from those of the rest of what is commonly grouped as External Ligurian Units and similar to those of the Sub-Ligurian units. Accordingly, the Val Marecchia Nappe succession would have been deposited on the thinned continental crust of the westernmost part of the Adria margin, east of the External Ligurian Domain, and it would have undergone the same tectonic evolution as that of the Sub-Ligurian Units.

Recently, in the upper Tiber Valley, Plesi et al. (2002) recognized the so-called Monti Rognosi Unit, made up of Middle Jurassic–Lower Cretaceous magmatic and sedimentary rocks (see SW corner of the map of Fig. 2 for location). In this unit, peridotites, gabbro dykes, basalts and ophiolitic breccias are overlain by Upper Jurassic radiolarite (*Diaspri* Fm. *Auct*.), Lower Cretaceous *Calpionella* Limestone and *Palombini* Shale Fms., the latter grading upwards into the Aptian to Eocene Sillano Fm., in turn followed by the Eocene Monte Morello Fm. According to these findings, for the first time, an ophiolitic substratum and an Upper Jurassic-Barremian sedimentary cover was recognized at the base of the Val Marecchia Nappe succession. This alternative interpretation was shared by de Capoa et al. (2003) and Perrone et al. (2008). However, according these authors the stratigraphic succession continues, outside the Monti Rognosi area, with the *Argille Varicolori* Fm. and ends with the Monte Senario Sandstone Fm. The latter testifies for the foredeep evolution of the sedimentary basin.

This paper reports the results of field, litho-biostratigraphic and petrographic analyses carried out on the Val Marecchia Nappe succession, together with a revision of previous data and interpretations. The study has been executed in order to check the tectono-sedimentary evolution of the Val Marecchia Nappe based on the analysis of the entire area, and it makes a comparison with units showing similar features in the Western Mediterranean Alpine chains.

2 Field data

The Val Marecchia Nappe crops out to both sides of the Apenninic watershed, from eastern Tuscany to San Marino, where it dips underneath Pliocene deposits (Fig. 2). The nappe reached its present setting as late as in the Early Pliocene because clays of the *Globorotalia puncticulata* Zone constitute the youngest layers overlain by the nappe. In any case, parts of this same nappe, or olistostromes fed from it, have been recognized off the Adriatic coastline in wells, which drilled Lower Pleistocene deposits.

The map of Fig. 2 allows for reconstructing the movement of the Val Marecchia Nappe in space and time. This nappe structurally overlies a previously thrusted and folded substratum, becoming younger from west to east. This substratum is formed by the Aquitanian-Serravallian terrains of the Cervarola Unit (Pizziolo and Ricci Lucchi 1992; Delle Rose et al. 1994; unit 11 of Fig. 2), and of Langhian-Lower Pliocene deposits of the Umbro-Romagnan-Marchean Units (sandy-marly turbidites, hemipelagites, evaporites and clastics; units 12–14 of Fig. 2).

2.1 The ophiolitic substratum

The ophiolitic substratum of the Val Marecchia Nappe crops out west of Sansepolcro, in the Tiber valley and in the Mt. Rognosi area (unit 10 of Fig. 2). It was first recognized by Plesi et al. (2002) to whom we refer for a detailed description. It is made up mainly of lherzolites with evident compositional layering and foliation and of serpentinized peridotites, originating from ocean-floor metamorphism of spinel lherzolites, intruded by dykes and small bodies of gabbro. Plesi et al. (2002) also pointed out the occurrence of ophicalcites and cumulate sequences consisting of gabbro, dunite, wehrlite and troctolite. Basalts

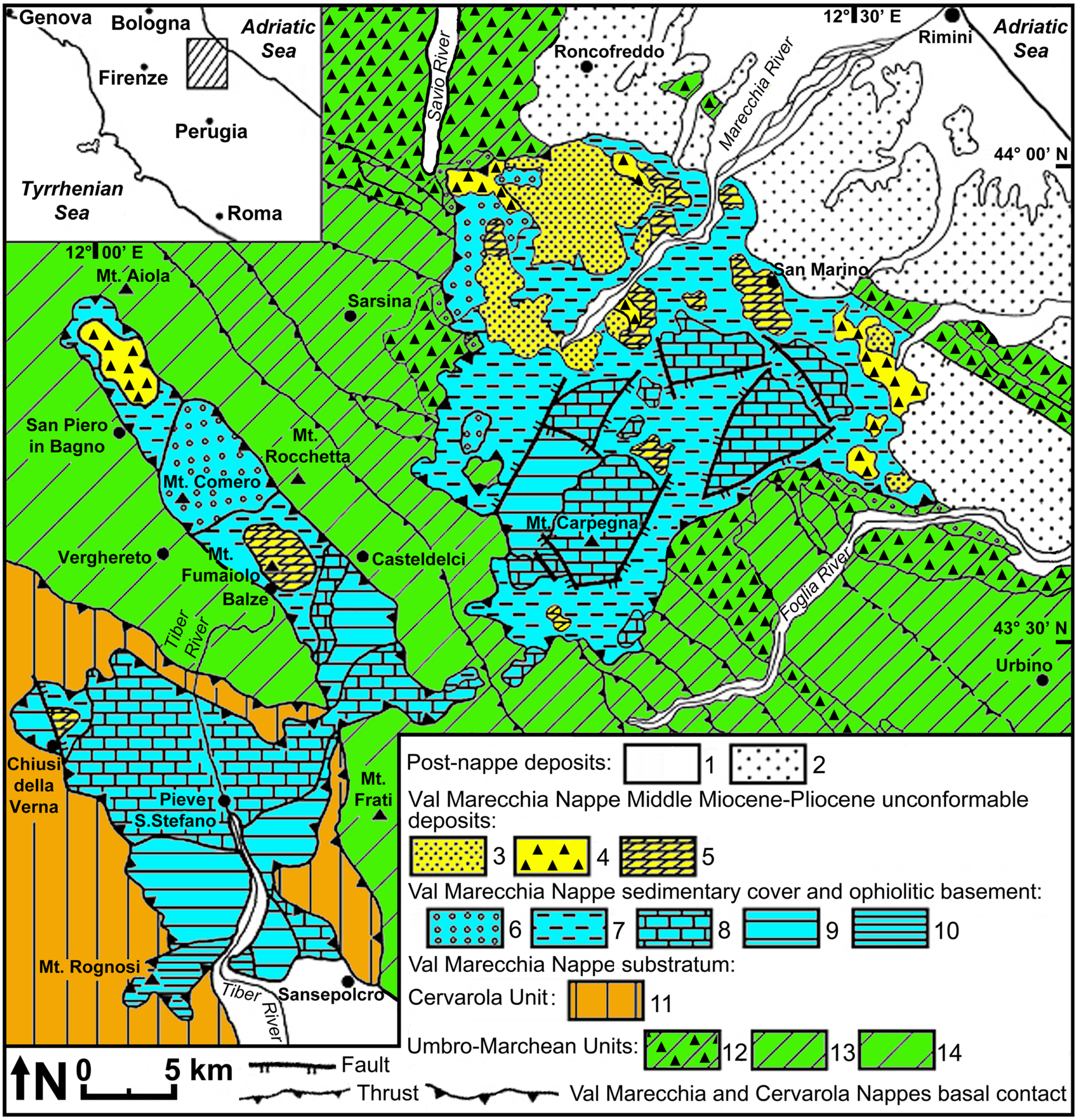

Fig. 2 Schematic geological map of the Val Marecchia Nappe and underlying units after Di Staso et al. (2009) who modified the map of Boccaletti et al. (1987). Post-nappe deposits: *1*. Holocene-Upper Pliocene deposits, *2*. Lower Pliocene deposits. Terrains unconformably resting on the Val Marecchia Nappe: *3*. Lower Pliocene deposits, *4*. Messinian-Upper Tortonian deposits, *5*. Monte Fumaiolo Sandstone and San Marino Limestone Fms. (Serravallian-Langhian). Older units of the Val Marecchia Nappe: *6*. Monte Senario Sandstone and Campaolo Sandstone Fms. (Lower Miocene, taken as a part of the Sub-Ligurides by some authors), *7*. *Argille Varicolori* Fm. (Aquitanian-Upper Oligocene), *8*. Monte Morello Fm. (Oligocene), *9*. "Basal Complex": Sillano, Villa a Radda, Cercetole and Pugliano Fms. (Upper Eocene to Upper Aptian), *10*. *Palombini* Shale, *Calpionella* Limestone, *Diaspri* Fms., ophiolitic slices (Upper Aptian-Middle Jurassic). *11*. Cervarola Unit: Vicchio Marl and Cervarola Sandstone Fms. (Serravallian-Aquitanian). Umbro-Marchean Units: *12*. *Argille a Colombacci* and *Gessoso-solfifera* Fms. (Messinian), *13*. *Ghioli di letto*, *Schlier* and External *Marnoso-Arenacea* Fms. (Lower Messinian-Serravallian), *14*. Internal *Marnoso-arenacea* Fm. (Lower Tortonian-Langhian)

are poorly developed and represented by a few metres of pillow-lavas and pillow-breccias. Polygenic breccias are locally found between serpentinites and the sedimentary cover. They are exclusively made up of magmatic clasts, mainly peridotite and gabbro with scarce basalts, and have been interpreted as Upper Jurassic debris flow deposits related to the opening of the oceanic basin. All these features are quite similar to those characterizing the ophiolitic basement of the Internal Ligurian units (Decandia and Elter 1972; Molli 1996; and others). This suggests that the origin of this basin is related to crustal delamination, i.e. to the activation of listric fault systems, which led the sub-continental mantle to constitute the substratum of the basin.

2.2 The sedimentary cover

Considering the entire area of outcrops of the Val Marecchia Nappe from the Mt. Rognosi area to the Upper Tiber, Savio, Marecchia and Foglia valleys, its sedimentary cover (Fig. 3) is made up from bottom to top of: (1) *Diaspri* Fm., (2) *Calpionella* Limestone Fm., (3) *Palombini* Shale Fm., (4) Sillano Fm., (5) Monte Morello Fm., (6) *Argille Varicolori* Fm., and (7) Monte Senario Sandstone Fm. The lower three units are similar to those of the Internal

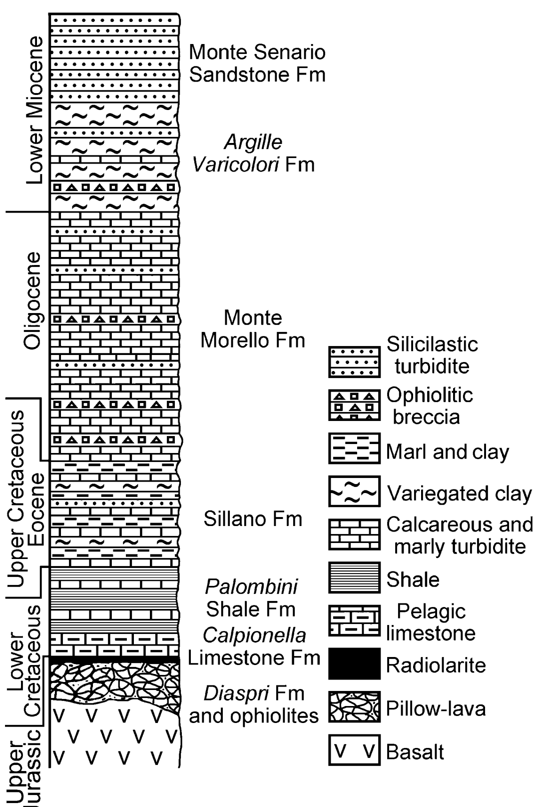

Fig. 3 Schematic stratigraphic column (not to scale) of the Val Marecchia Nappe in the Mt. Rognosi area and upper Tiber, Savio, Marecchia and Foglia valleys

Ligurian successions and are present only in the area where the ophiolitic basement crops out (Plesi et al. 2002). The stratigraphic succession in that area is strongly deformed, overturned and affected by thrusts. Hence, most contacts between formations are tectonic or tectonized.

2.2.1 *Diaspri Formation*

The *Diaspri* Fm., cropping out in the Conventino locality, near 2 km east of Monti Rognosi, is up to 20 m thick and made up of a few dm of red pelites at its base, followed by thin-bedded red radiolarites alternating with minor red pelites. The formation is considered to be of Late Jurassic age (Principi et al. 2004).

2.2.2 *Calpionella Limestone Formation*

This formation consists of a few metres of regularly bedded pelagic calcilutites following the radiolarites in the Conventino area. Its age is commonly considered to be Berriasian to Late Hauterivian.

2.2.3 *Palombini Shale Formation*

The *Palombini* Shale Fm. crops out widely in the Monti Rognosi area and consists of up to 150 m of dm-thick strata of blue-green, frequently silicified, calcilutites (*Palombini*, in the language of Tuscan quarry workers), alternating with fissile dark-grey, brownish or reddish mudstones. Calcilutites are very fine-grained turbidite beds, indicating sporadic supply from a carbonate platform or ramp. The *Palombini* Shale Fm. also rests directly on the ophiolitic substratum but contacts are always badly exposed so that tectonic delamination from the underlying sedimentary units cannot be excluded. Upwards the *Palombini* Shale Fm. grades into the Sillano Fm. Plesi et al. (2002) found a nannofossil association of Biozone CC7 according to Sissingh (1977), indicating an Aptian-Albian age, in agreement with its Late Hauterivian-Late Aptian age recognized in the Internal Ligurian units (Elter and Marroni 1991; Principi et al. 2004).

2.2.4 *Sillano Formation*

The Sillano Fm. is the most widespread stratigraphic unit underlying the Monte Morello Fm., and outside the Monti Rognosi area it constitutes the base of the Val Marecchia Nappe succession (unit 9 of Fig. 2). It grades laterally into other mainly pelitic formations (Villa a Radda and Cercetole Fms.).

The Sillano Fm. consists of 200–500 m thick irregular alternations of grey to brownish mudstones with generally fine-grained calcareous and marly-calcareous turbidite beds

(Fig. 4a). The most frequent successions are those in which mudstones are predominant. However, in some areas, such as SW of Casteldelci, calcareous and marly-calcareous turbidite beds are several tens of metres thick and calcarenite beds, with evident T_{cd} intervals of the Bouma sequence, are also present. Locally, the Sillano Fm. is characterized by greyish clays with small varicoloured lenses very similar to those of the *Argille Varicolori* Fm. This similarity has led many authors to attribute these successions to the *Argille Varicolori* Fm. and to consider the latter as heteropic of the Sillano Fm. However, detailed field analyses allows to distinguish these two formations based on: (a) the absence of some peculiar lithologies of the *Argille Varicolori* Fm., such as barite nodules, sulphur pisolites, clay ironstones, *Tubotomaculum*–like Fe–Mn concretions, "beef" calcite, in the varicoloured layers of the Sillano Fm., (b) the presence of abundant calcareous and marly-calcareous turbidite beds in the Sillano Fm. and (c) the stratigraphic position of the *Argille Varicolori* Fm. above and not below the Monte Morello Fm. (see later). Finally, grey or brownish beds of sandstones, quite similar to those characterizing the Pietraforte Fm., cropping out around Florence (Abbate and Sagri 1970), have been rarely observed in the Sillano Fm. Well-preserved specimens of *Inoceramus* sp. (Fig. 4b) have been found along the Prena stream, near Pennabilli, on the western slope of Mt. Carpegna.

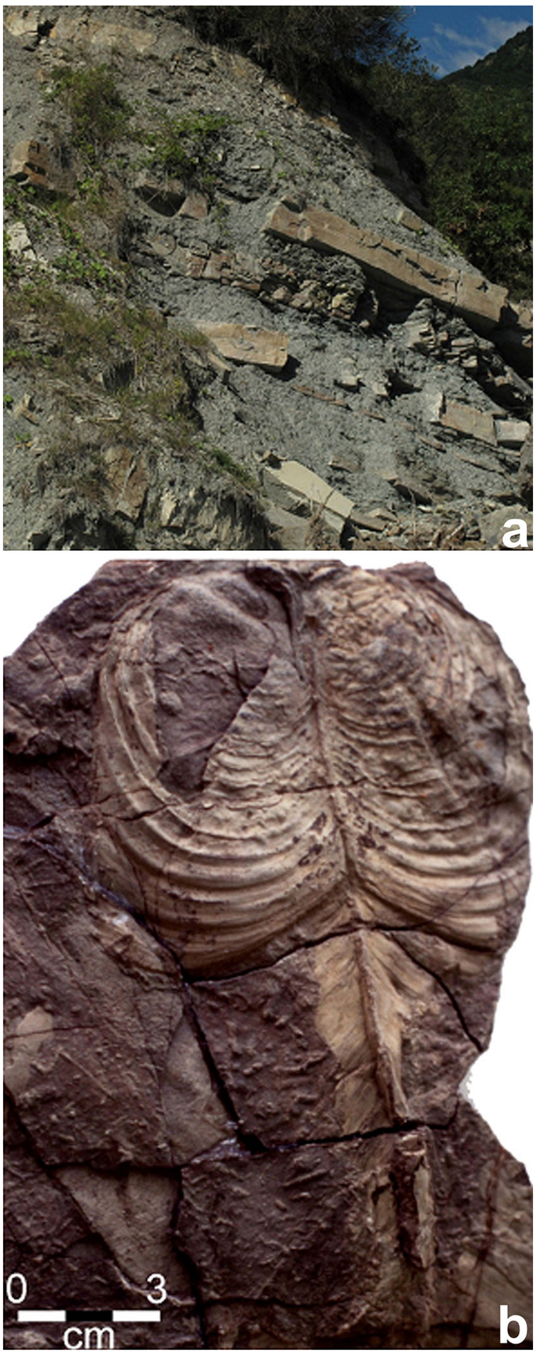

Fig. 4 Sillano Fm.: alternation of clay and limestone at Fosso del Poggio stream (**a**) and *Inoceramus* sp. collected in the lower part of the Prena stream section (**b**)

In both the upper Tiber and Marecchia valleys, the Sillano Fm. passes laterally into other basinal formations, which are characterized by shales and the paucity or absence of carbonate turbidite beds, all upwards grading into the Monte Morello Fm. The Villa a Radda Fm., defined around Radda in Chianti north of Siena, crops out in the valley of the Senatello stream, a left-bank tributary of the Marecchia river. It consists mainly of reddish shales that intercalate a few of greenish fine-grained arenite beds. The lateral passage with the Sillano Fm. is well observable along the road to Balze village. The Cercetole Fm. (Bortolotti 1964) crops out in the upper Tiber valley and is made up of black shales with very rare thin carbonate beds. Finally, in the Senatello valley and around Chiusi della Verna, below the Monte Morello Fm. it is possible to observe a formation of greenish or blackish shales with beds of silicified limestones and fine-grained sandstones, in which at least three cleavage systems occur.

The passage to the Monte Morello Fm. is generally abrupt due to the disappearance of the clayey beds. It is well exposed in the Torrente Messe-Fosso Paolaccio section, at the southwestern corner of Mt. Carpegna, where it is outlined by a 4 m-thick layer of pinkish marls.

2.2.5 Monte Morello Formation

The Monte Morello Fm. (Unit 8 of Fig. 2) is mainly made up of carbonate turbidites (whitish or light grey calcilutites, calcisiltites, marly limestones, marls and bioclastic calcarenites, with a variable content of siliciclastic grains; Fig. 5a) and of minor medium- to fine-grained siliciclastic turbidite beds (Fig. 5c), more frequent in the upper part of the succession. The formation shows a strong variation in thickness from place to place, from 150 up to 700 m, as is usual in turbidite fans.

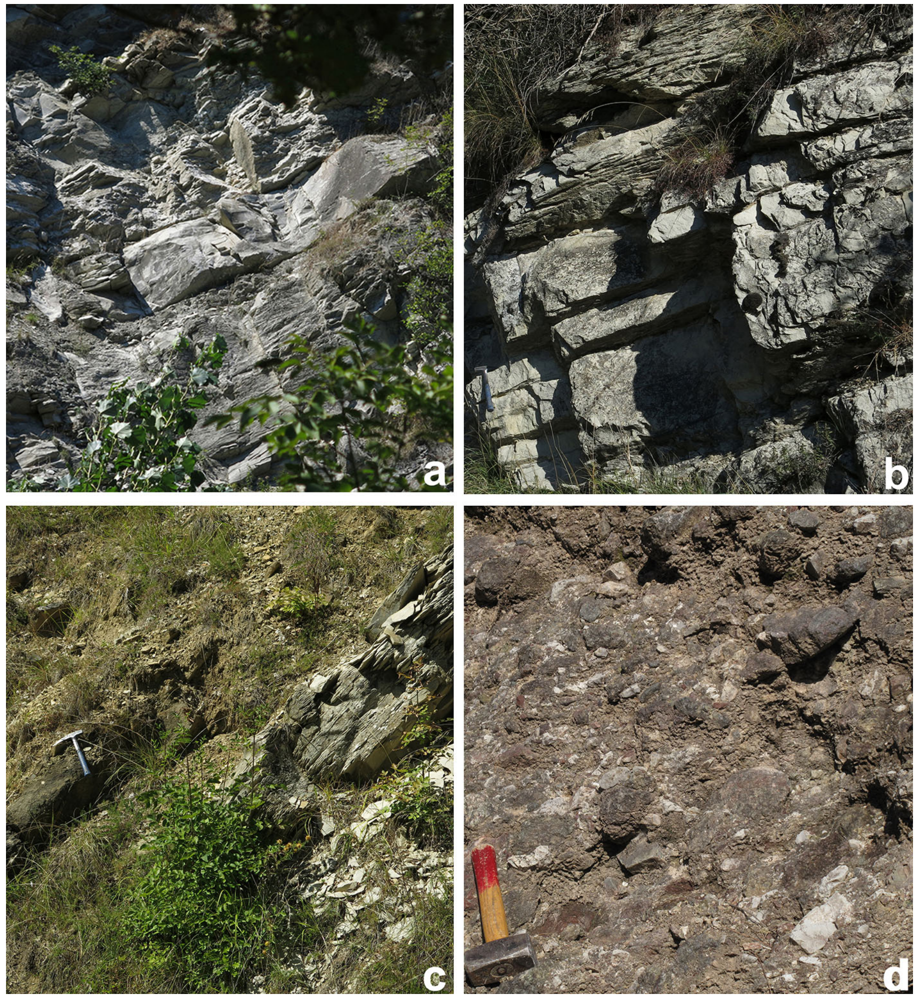

Fig. 5 Monte Morello Fm.: alternation of calcareous and marly turbidites (**a**) and detail of the carbonate turbidite succession (**b**) in the Tiber valley north of Pieve Santo Stefano; siliciclastic arenites interbedded with carbonate turbidites (**c**) and ophiolite-derived debrite (**d**) along the Pieve Santo Stefano-Viamaggio road. Hammer is 25 cm long

Beds of carbonate turbidites are generally 30–40 cm-thick, but beds up to several metres thick also occur. Intervals of the Bouma sequence are frequently visible. Sedimentological features are described by Ponzana (1993), while a detailed petrographic analysis of carbonate and siliciclastic beds is reported by Perrone et al. (2014). The carbonate microfacies types are represented by peloid wackestone, foraminifera-rich packstone and skeletal packstone. Wackestone is the most common and includes rare foraminifera and peloids with dispersed flakes of carbonaceous organic matter. Foraminifera-rich packstone is mainly composed of planktonic foraminifera, minor benthic foraminifera, rare peloids and fragments of neritic fossils. Skeletal packstone comprises variable amounts of macroforaminifera, debris of red algae, echinoids, crinoids and rare bivalves. The fine siliciclastic content of these carbonate turbidites (up to 3 %) consists of quartz, rare feldspar, white mica, metasedimentary and phyllite grains.

Siliciclastic turbidite beds are fine- to medium-grained, moderately to well sorted quartzolithic arenites. They are characterized by abundant quartz, minor lithic fragments, consisting of pelagic limestone, chert, slate, phyllite and fine-grained schist, and low percentages of feldspars ($P/F = 0.80$).

Lenticular bodies or beds of ophiolite-derived sandstones, breccias and olistoliths of peridotite are known in the Monte Morello Fm. in the Tiber valley, east of Pieve Santo Stefano (Bortolotti 1962, 1964; Plesi et al. 2002; Principi et al. 2004; Principi 2007). Similar rocks also occur in the Senatello valley, following the Fosso del Poggio stream upwards. Breccia layers are lenticular debrites, more or less lithified and up to 8–10 m thick, characterized by very coarse gravels to boulders in a sandy or microconglomerate matrix. Breccias are generally polymict and poorly sorted. Both magmatic (mainly peridotite and minor gabbro and basalt) and sedimentary clasts (radiolarite, pelagic calcilutite and minor shale) were fed exclusively from an oceanic crust sequence; fragments supplied from continental crust complexes never have been found. Moreover, lenses of monomict breccias, each consisting exclusively of clasts of peridotite, basalt or *Calpionella* limestone, are also present (Bortolotti 1962).

Sandstone and microbreccia beds are 1 dm-1 m thick, sometimes poorly cemented and clearly graded. They are generally monomict being composed of brownish sub-rounded to highly angular clasts of serpentinite in a fine-grained carbonate matrix. Olistoliths are made of serpentinized peridotite cut by gabbro dykes.

2.2.6 Argille Varicolori Formation

The *Argille Varicolori* Fm., 100–200 m thick, crops out widely in the Marecchia valley and east of the Mt. Carpegna (unit 7 of Fig. 2). It is made up of lead-gray clays, usually variegated due to the presence of greenish or dark reddish to purple/violet irregular lenses or beds (Fig. 6a, b). The *Argille Varicolori* Fm. frequently forms typical badlands, with isolated blocks and pebbles of limestone and sandstone dispersed in the clayey matrix, and it appears as a strongly deformed broken formation. This feature is due to surficial creep; where the soil is deeply eroded, the formation appears to be regularly bedded and little deformed. Moreover, the *Argille Varicolori* Fm. is characterized by the peculiar presence of barite nodules, sulphur pisolites, beds up to some cm thick of clay ironstones (Fig. 6c), Fe–Mn concretions that remind *Tubotomaculum*–like burrows (Mills 1995), and beds, up to 10 cm thick, of fibrous "beef" calcite, the latter interpreted as due to hydraulic fracturing parallel to bedding during diagenesis (de Feyter 1991). These lithologies, more or less abundant but always present, allow to easily distinguish the *Argille Varicolori* Fm. from the varicoloured layers occurring within the Sillano Fm., where they are fully lacking. A few strata of fine-grained sandstone and turbidite limestone are locally present in the clayey succession. However, calcareous and marly-calcareous turbidite beds are very abundant in some areas, such as around Sasso Simone, south of Mt. Carpegna, and in the area south of San Leo, where a succession of medium- to thick beds of graded light calcarenites, calcisiltites and calcilutites, that alternate with very thin layers of greyish, greenish or reddish pelites, is up to 50 m thick. This succession has been considered as a formation heteropic of the *Argille Varicolori* Fm. (Pugliano Fm.; Bortolotti 1964), but field analysis leads to interpret these carbonate rocks as small turbidite fans which locally deposited in the *Argille Varicolori* basin. Finally, rare beds of ophiolite-derived microbreccia, quite similar to those occurring in the Monte Morello Fm. (Fig. 6d), are interbedded in the variegated clays.

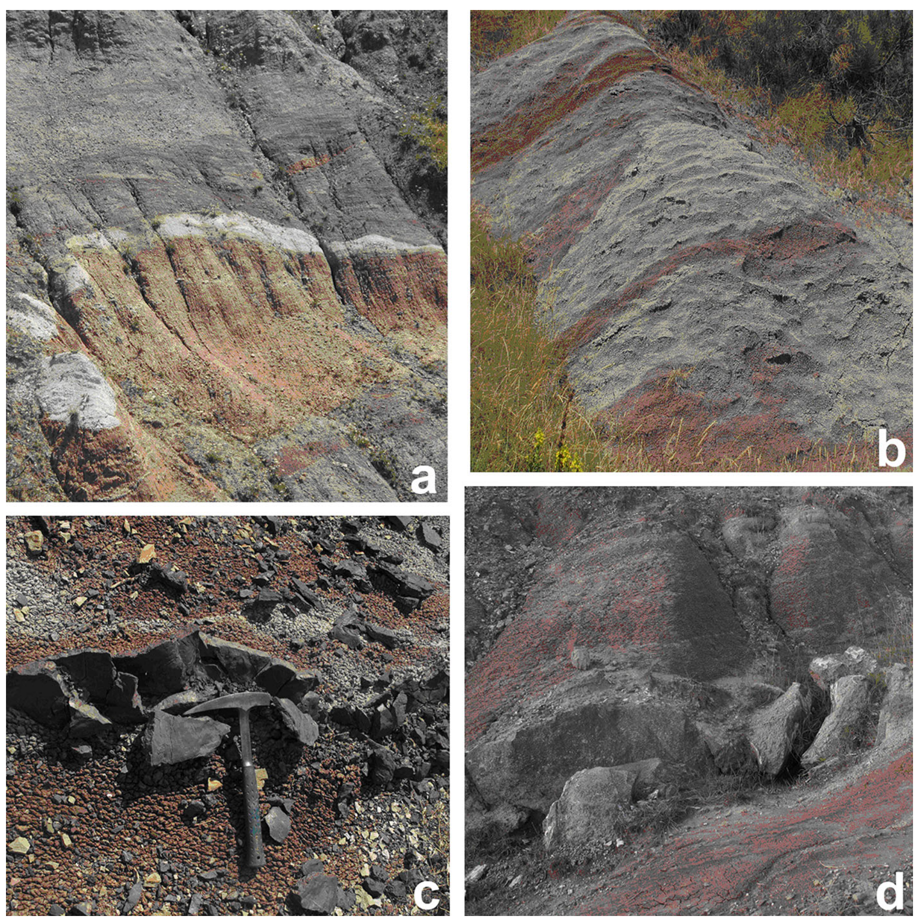

Fig. 6 *Argille Varicolori* Fm.: varicoloured clays South of Sasso Simone (**a**); the white bed is a marly-calcareous turbidite bed) and east of Villagrande (**b**); broken clay ironstone bed South of Sasso Simone (**c**) and ophiolite-derived microbreccia in the Fosso del Petroso stream (**d**)

The *Argille Varicolori* Fm. is generally considered to be a formation belonging to the Basal Complex and to be older than the Monte Morello Fm., and it is mapped as lying under and above it (de Feyter 1991; Conti 1994; Cornamusini et al. 2010; and many others). Where the *Argille Varicolori* Fm. occurs underneath the Monte Morello Fm., the contact between these formations is considered as stratigraphic, while when the *Argille Varicolori* Fm. rests on the Monte Morello Fm. the contact is interpreted as a thrust surface that originated during the transport of the Val Marecchia Nappe towards the Adriatic foreland. In our opinion, the "*Argille Varicolori*" successions occurring underneath the Monte Morello Fm. must be attributed to the Sillano Fm., as is clearly exposed along the western slope of Mt. Carpegna. The passage from the Monte Morello Fm. to the *Argille Varicolori* Fm., however, represents a sharp stratigraphic change in the nature and rate of sedimentation in the basin, whereby turbidite deposits change back pelagic sedimentation. In many localities, beds of the Monte Morello and *Argille Varicolori* successions appear to be fully conformable and show the same attitude above and underneath the presumed tectonic contact, as also mapped by Conti (1994) south-east of Mt. Canale at the southern extremity of Mt. Carpegna massif. This conformable stratigraphic contact with the total absence of tectonic deformation is well observable along the road connecting Senatello and Balze villages. The best exposed passage is visible at the top of Fosso Paolaccio, on the south-western corner of Mt Carpegna, where a recent landslide has highlighted that the beds of Monte Morello and *Argille Varicolori* Fms. appear to be fully conformable and no trace of deformation is present. In some places such stratigraphic contacts appear to be tectonized, as frequently happens when successions characterized by very different mechanical properties are deformed. In any case, tectonic doublings are locally present (de Feyter 1991). In addition, in the area where the Monte Morello Fm. was defined, namely near Florence, the highest part of the formation is characterized by the presence of beds of varicoloured clay and shale, alternating with the whitish limestones and marls (Pescina Shale Fm.; Abbate and Sagri 1970). It is very likely that these varicoloured beds announce a change in sedimentation within the basin and the passage to the *Argille Varicolori* Fm.

2.2.7 Monte Senario Sandstone Formation

The Monte Senario Sandstone Fm. (unit 6 of Fig. 2) has generally been considered as representing an Epiligurian unit, i.e. a formation unconformably resting on Ligurian Units, or alternatively, as belonging to the Sub-Ligurian units (Vai and Castellarin 1992; Conti 1994). It overlies the *Argille Varicolori* Fm. at Mt. Comero in the Savio valley, at Mt. Benedetto-Mt Ercole along the Savio-Marecchia watershed and in a few other outcrops in the Marecchia valley. Some small outcrops also occur on top of the *Argille Varicolori* forming the footwall of the fault marking the eastern side of Mt. Carpegna.

This formation, entirely turbiditic and well known in the Tuscan Apennines, consists of greyish arenaceous and silty-arenaceous beds. In some places, macroforaminifera-bearing calcareous beds are present. Sandstones are middle- to coarse-grained, up to 300 m thick, and frequently show $T_{a\text{–}b\text{–}c}$ intervals of the Bouma sequence. Flute-casts indicate provenance from west. Mineralogical analysis of the arenites (Fig. 7) points to a quartzolithic composition ($Qt47_{12}$ $F23_{5}$ $L30_{7}$), with dominant quartz and lithic fragments and slightly less abundant feldspars, which are mainly represented by plagioclase (P/F = 0,66). Lithic fragments are mostly low- to medium-grade metamorphics (slate, phyllite, chlorite-schist, garnet/epidote-schist; $Lm90_{20}$ $Lv0_{0}$ $Ls10_{20}$). Rare metavolcanics and serpentine-schists are also present. Coarse-grained metamorphic fragments, with the association quartz + plagioclase + epidote/garnet, are common ($Rg11_{3}$ $Rs7_{16}$ $Rm82_{19}$), whilst plutonic rock fragments (granitoids) are subordinate. This quartzolithic composition, dominated by metamorphic detritus, is consistent with a recycled-orogen provenance (Dickinson 1985).

Everywhere, the Monte Senario Sandstone Fm. rests on the *Argille Varicolori* Fm. but at Mt. Comero the contact is not exposed and outcrops are scarce. At Mt Benedetto-Mt. Ercole, on the contrary, the passage is visible and is outlined by the presence of arenite beds in the highest part of

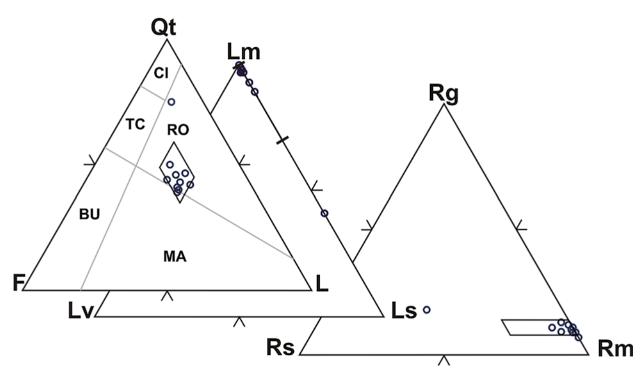

Fig. 7 Ternary plots of the Monte Senario Fm. arenites. Polygons are one standard deviation on either side of the mean. *Qt* total quartz including chert and polycrystalline quartz, *F* Plagioclase and K-feldspar, *L* total lithic fragments, *Lm* metamorphic lithic fragments, *Lv* volcanic lithic fragments, *Ls* sedimentary lithic fragments, *Rg* plutonic rock fragments, *Rs* sedimentary rock fragments, *Rm* metamorphic rock fragments, *CI* Craton Interior, *TC* transitional continental, *BU* basement uplifted, *RO* recycled orogen, *MA* magmatic arc. All provenance fields in QFL diagram after Dickinson (1985)

the *Argille Varicolori* Fm., which is rapidly replaced by turbiditic sediments.

2.3 The formations unconformably resting on the sedimentary cover

Many formations, unconformably lying on the Val Marecchia Nappe cover, reported as a group named Epi-ligurian sedimentary cycles by some authors (Ricci Lucchi 1987; Conti and Fregni 1989; Conti 1994, 2002; and others), have been recognized (units 3, 4 and 5 of Fig. 2). They were deposited in up-thrust basins after successive deformation phases that affected the Val Marecchia Nappe terrains during their eastward transport towards the Adriatic foreland (Conti 1994; among others). These formations are made up of calcareous, clastic and evaporitic strata and are organized in several sedimentary cycles of Langhian to Early Pliocene age, bounded by angular unconformities.

Field studies led us to recognize six sedimentary cycles (Fig. 8), from the oldest to youngest: (a) San Marino Limestone and Monte Fumaiolo Sandstone Fms. (Langhian-Serravallian), (b) Montebello Clay Fm. (Serravallian-Tortonian), (c) Acquaviva and Casa i Gessi Clay Fms. (Upper Tortonian-Lower Messinian), (d) Evaporites (Middle Messinian) (e) Case Monte Sabatino Fm. (Upper Messinian), (f) *Argille Azzurre* Fm. (Lower Pliocene).

The oldest cycle is represented by the Langhian-Serravallian San Marino Limestone and Monte Fumaiolo Sandstone Fms. because other formations, previously considered of Oligocene-Early Miocene age, such as the Poggio Carnaio Sandstone Fm. and the underlying marls ascribed to the Antognola Marl Fm., turned out to be of Tortonian age (D'Errico et al. 2014). It is noteworthy that this cycle rests, from the western to the eastern extremities of the nappe, only on the *Argille Varicolori* Fm. and never has been recognized directly lying on the Monte Morello and Sillano Fms. Only Upper Tortonian and younger cycles lie on formations older than the *Argille Varicolori* Fm.

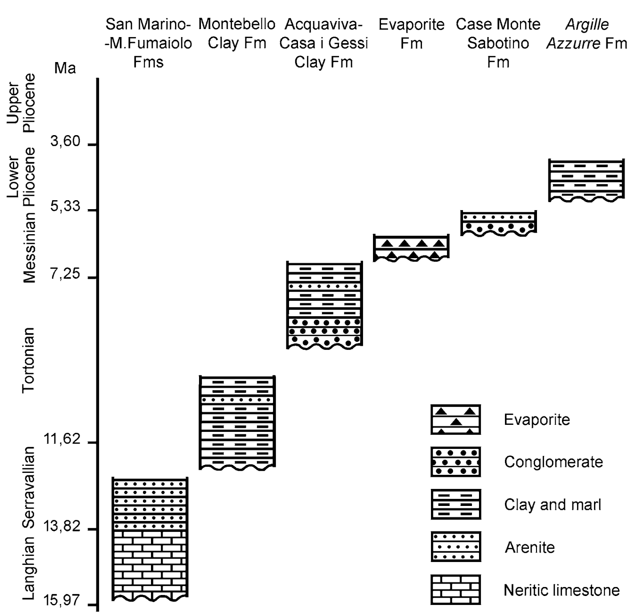

Fig. 8 Simplified stratigraphic columns (not to scale) of the formations unconformably lying on the Val Marecchia Nappe

The San Marino Limestone Fm. is made up of fossil-rich neritic limestones and biocalcarenites up to 150 m thick. Upwards it grades, due to an increasing content of siliciclastic and glauconitic grains, into the sandy marls and sandstones of the Monte Fumaiolo Sandstone Fm. Although we do not have own biostratigraphic data, we agree with a Langhian age of the San Marino Limestone Fm., as proposed by many authors (Ori and Friends 1986; Ricci Lucchi 1987). Lithologically similar successions, unconformable on ocean-derived units, dated as Langhian (Zone N9 of Blow 1969, top Zone NN4 of Martini 1971; de Capoa et al. 2004, 2013), are known all the way from the Betic Cordillera to the Sicilian Maghrebides and Southern Apennines, and also in Tunisia, Malta, Corsica and Provence. These successions are likely related to the Langhian sea-level highstand.

Basic lithological features of the deposits unconformably resting on the Val Marecchia Nappe succession are reported in Fig. 8. For more detailed descriptions the reader is referred to Conti and Fregni (1989) and Conti (1994, 2002).

3 Biostratigraphic data

Biostratigraphic analysis demonstrates the systematic re-working of very abundant Cretaceous to Eocene foraminifers and coccoliths, which co-exist with taxa indicating younger ages. This widespread re-working of taxa has rarely been considered up to now. Our biostratigraphic data on the Sillano, Monte Morello, *Argille Varicolori* and Monte Senario Sandstone Fms. indicate younger ages for all these formations.

Our biostratigraphic study was carried out using coccoliths. Samples were prepared according to Eshet (1996) and nannofossils studied under the light microscope (1250×). Taking into account extensive re-working, scarcity and poor preservation of nannofossils usually occurring in turbidite sediments, a quantitative analysis of the assemblages was not possible. Only the first occurrence of taxa was considered and the ages of the formations were evaluated in terms of their oldest possible age ("no older than…").

3.1 Sillano Formation

On the basis of nannofossil analysis, Plesi et al. (2002) recognized Maastrichtian-Danian associations in the

Sillano Fm. (Biozone CC25 of Sissingh 1977–Biozone NP1 of Martini 1971).

The Sillano Fm. was sampled between Mt. Rognosi and Pieve Santo Stefano in the Tiber valley and along the western versant of Mt. Carpegna in the Marecchia valley, uprising the Prena and Messe streams near Pennabilli. In the Tiber valley, scattered samples were collected, because no well-exposed sections were found. The samples that yielded the oldest ages have provided nannofossil associations (*Biscutum dissimilis*, *Biscutum* sp., *Chiastozygus* sp., *Cribrosphaerella ehrenbergii*, *Eiffellithus turriseiffelii*, *Prediscosphaera columnata*; *Watznaueria barnesae*, *W. biporta*, *Watznaueria* sp.) indicating an age no older than Late Albian (Biozone CC9 of Sissingh 1977). In the same area, many samples are characterized by taxa whose first occurrence is reported in the Late Cretaceous (*Arkhangelskiella cymbiformis*, *Calculites obscurus*, *Ceratolithoides aculeus*, *Eiffellithus eximius*, *Lucianorhabdus cayeuxii*, *Micula concava*, *M. prinsii*, *Quadrum gartneri*; Biozones CC10-26 of Sissingh 1977) or in the Paleocene-Eocene (*Coccolithus eopelagicus*, *Discoaster sublodoensis*, *Pontosphaera multipora*, *Pseudotriquetrorhabdulus inversus*, *Reticulofenestra bisecta*, *R. dictyoda*, *R. hillae*, *R. minuta*, *R. umbilicus*). The youngest sample analyzed resulted in an age that is no older than Late Bartonian (*Micrantholithus altus*, *Reticulofenestra bisecta*, *R. hillae*; Biozone NP17 of Martini 1971).

In the lower part of Prena stream section, characterized by beds of Pietraforte-like sandstones, intercalated with varicoloured marls and pelites, the presence of *Inoceramus* sp. (Fig. 4b) indicates a Late Cretaceous age. Upwards, the youngest sample is no older than Late Bartonian (Biozone NP17 of Martini 1971) because of the presence of *Reticulofenestra bisecta* and *R. hillae*, accompanied by some taxa (*Coronocyclus nitescens*, *Pseudotriquerhabdulus inversus*, *Reticulofenestra coenura*, *R. daviesi*, *R. scrippsae*, *R. umbilicus*, *Zigrhablithus bijugatus*) compatible with the Biozone NP17.

In the Messe stream section, the upper part of the Sillano Fm. is exposed up to the passage into the Monte Morello Fm. and taxa indicating an age no older than Priabonian have been found (*Cyclicargoliyhus floridanus*, *Chiasmolithus oamaruensis*, *Helicosphaera euphratis*) together with *Reticulofenestra gartneri*, *Sphenolithus predistentus* and *S. pseudoradians* (Biozones NP19-20 of Martini 1971).

3.2 Monte Morello Formation

The Monte Morello Fm. has been sampled along the Messe stream up to Fosso Paolaccio, at the south-western corner of Mt. Carpegna. In this section the entire formation crops out between the Sillano Fm., at the base, and the *Argille Varicolori* Fm., at the top. 17 samples resulted barren or provided non-significant taxa. The nannofossil associations recognized in 26 samples are reported in Table 1.

In the lowest part, taxa indicating an age no older than Late Priabonian-Early Rupelian (Biozone NP21 of Martini 1971) are present (*Chiasmolithus oamaroensis*, *Discoaster ornatus*, *Reticulofenestra gartneri*, *Sphenolithus tribulosus*). Upwards, the presence of *Sphenolithus distentus* (Biozones NP22-NP23 of Martini 1971) indicates an age no older than Early Oligocene, whereas in the upper part taxa starting from the Late Oligocene (Biozones NP24-NP25 of Martini 1971) are common (*Coccolithus miopelagicus*, *Cyclicargolithus abisectus*, *Helicosphaera obliqua*, *H. recta*, *Sphenolithus ciperoensis*, *Triquetrorhabdulus carinatus*).

3.3 *Argille Varicolori* Formation

Grey and varicoloured clays of the *Argille Varicolori* Fm. resulted barren or provided a few undeterminable taxa and only samples of calcareous and marly turbidite beds turned out to be useful. As mentioned earlier, carbonate turbidite beds are usually very scarce or absent; however, where they are abundant, such as around Sasso Simone, reworked Cretaceous taxa are more diffuse than Paleogene ones, sometimes almost exclusive, and clearly increase upwards.

The youngest taxa found within the carbonate turbidites of the *Argille Varicolori* Fm. and in the Pugliano Fm. *Auct.* span the Late Oligocene-Aquitanian time interval (*Helicosphaera carteri*, *H. recta*, *Sphenolithus ciperoensis*, *S. conicus*, *S. delphix*, *Triquetrorhabdulus carinatus*, *T. milowii*, *Umbilicosphaera rotula*; Biozones NP25-NN1 of Martini 1971).

3.4 Monte Senario Sandstone Formation

This formation, previously considered to be of Oligocene age, has been sampled on the northern versant of Mt. Benedetto-Mt. Ercole, while in the Mt. Comero area only scattered samples were collected. Many samples were barren or yielded taxa frequently deformed, more or less overgrown or dissolved but, together with abundant reworked Cretaceous and Paleogene specimens, the following nannofossil association has been recognized: *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Coronocyclus nitescens*, *Cyclicargolithus floridanus*, *Discoaster deflandrei*, *Ericsonia cava*, *Helicosphaera carteri*, *H. euphratis*, *Pontosphaera discopora*, *P. japonica*, *P. multipora*, *Reticulofenestra minuta*, *R. minutula*, *R. perplexa*, *Sphenolithus belemnos*, *S. conicus*, *S. delphix*, *Thoracosphaera* sp., *Umbilicosphaera rotula*. Some of these taxa indicate an age no older than Early Miocene, but the most significant datum is the presence of *S. belemnos*,

Table 1 Calcareous nannofossils of the Monte Morello Formation

Calcareous nannofossils	Samples																									
	DS 48	DS 49	DS 51	DS 52	DS 54	DS 55	DS 57	DS 61	DS 62	DS 66	DS 67	DS 70	DS 71	DS 72	DS 74	DS 77	DS 78	DS 79	DS 80	DS 82	DS 83	DS 84	DS 85	DS 87	DS 89	DS 90
Braarudosphaera bigelowii	×	×	×	×	×	×		×				×	×		×	×	×	×	×			×		×	×	
Chiasmolithus oamaroensis	×																									
Coccolithus eopelagicus	×			×	×		×		×		×	×	×				×			×	×	×			×	×
Coccolithus miopelagicus																								×		
Coccolithus pelagicus	×	×		×	×	×		×	×	×	×	×	×	×	×	×		×	×			×	×		×	×
Coronocyclus nitescens	×	×			×		×	×	×	×		×		×	×	×				×	×	×	×	×	×	×
Cyclicargolithus abisectus																				×			×			×
Cyclicargolithus floridanus		×		×		×		×		×	×	×		×			×	×	×				×	×	×	×
Discoaster adamanteus															×						×					×
Discoaster deflandrei	×			×			×	×			×		×				×		×	×	×		×		×	
Discoaster ornatus	×				×						×															
Discoaster spp.	×	×			×		×	×	×	×		×		×	×	×				×	×	×	×	×	×	×
Helicosphaera bramlettei		×							×									×								
Helicosphaera compacta			×				×	×					×						×				×			
Helicosphaera euphratis		×				×			×		×			×		×		×				×	×		×	×
Helicosphaera intermedia	×									×				×						×					×	
Helicosphaera obliqua																						×				
Helicosphaera recta																					×		×		×	×
Helicosphaera reticulata	×																									
Helicosphaera wilco×onii		×				×	×	×					×			×			×							
Lanternithus minutus	×		×	×																						
Pedinocyclus larvalis					×					×			×	×			×				×	×	×		×	
Pyrocyclus hermosus											×			×	×	×				×						
Reticulofenestra bisecta	×			×		×	×			×		×					×			×	×		×			×
Reticulofenestra coenura			×				×		×				×									×				
Reticulofenestra daviesi	×		×																							
Reticulofenestra gartneri	×		×			×				×	×	×		×			×	×	×	×				×		×
Reticulofenestra sp.	×	×	×		×		×	×				×	×	×	×	×	×	×		×	×	×	×		×	×
Sphenolithus ciperoensis																							×	×		×
Sphenolithus distentus							×		×	×	×		×		×	×	×			×		×				
Sphenolithus moriformis	×	×	×	×	×	×	×	×	×	×		×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Sphenolithus predistentus	×	×	×	×		×			×		×															
Sphenolithus pseudoradians	×	×		×			×				×					×			×					×		

Table 1 continued

Calcareous nannofossils	Samples																									
	DS 48	DS 49	DS 51	DS 52	DS 54	DS 55	DS 57	DS 61	DS 62	DS 66	DS 67	DS 70	DS 71	DS 72	DS 74	DS 77	DS 78	DS 79	DS 80	DS 82	DS 83	DS 84	DS 85	DS 87	DS 89	DS 90
Sphenolithus tribulosus	×			×					×		×															
Sphenolithus spp.	×	×		×	×		×	×	×	×		×	×	×		×		×		×	×		×	×	×	
Thoracosphaera spp.	×		×		×			×	×	×	×	×	×	×	×	×		×				×		×		
Triquetrorhabdulus carinatus																			×	×	×		×	×	×	
Zygrhablithus bijugatus		×	×		×	×	×	×			×	×	×	×		×	×	×			×	×				×
Reworked Paleogene taxa	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×	×	×	×	×	×	×	×	×	×	×
Reworked Cretaceous taxa	×	×			×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×

whose first occurrence is reported in the Burdigalian (Biozone NN3 of Martini 1971).

4 Discussion

The field and biostratigraphic data on the Val Marecchia Nappe presented above indicate a different stratigraphic succession and younger ages than what has been previously reported in literature (Ruggieri 1970; Conti and Fregni 1989; Conti 1994; Principi 2007; and references therein). The most important new datum concerns the stratigraphic position of the *Argille Varicolori* Fm., which is not a Cretaceous formation of the Basal Complex, as considered in all previous studies, but a formation that conformably follows the Monte Morello Fm., although layers strongly reminding the *Argille Varicolori* Fm. are present also in the underlying Sillano Fm. Nannofossils in the *Argille Varicolori* Fm. indicate a Late Oligocene-Early Miocene age in agreement with the Oligocene age of the underlying Monte Morello Fm. and a stratigraphical position above, and not under, that formation. On the other hand, the presence of the oldest unconformable formation (San Marino Limestone Fm.) everywhere above the *Argille Varicolori* Fm., and never above older formations, cannot be explained if the *Argille Varicolori* Fm. is considered part of the Basal Complex. A general deepening of the Val Marecchia Nappe succession toward east is evident (Fig. 2) and the systematic passage from oldest to youngest formations from west to east, such that the *Argille Varicolori* Fm. crops out almost exclusively in the eastern area, due to its high position in the stratigraphic succession. Similarly, field and biostratigraphic data suggest that the Monte Senario Sandstone Fm. constitutes the youngest stratigraphic unit of the Val Marecchia Nappe, testifying for the foredeep evolution of the basin.

All this shows that the sediments of the Val Marecchia Nappe were deposited in an oceanic basin. Moreover, the sediments point towards a continuous Tethyan-derived sequence that consists of Jurassic ophiolites and a sedimentary cover that reached the Early Miocene. Its tectono-sedimentary evolution can be synthesized as follows:

- Middle Jurassic opening of an oceanic basin, which led to the deposition of pelagic sediments directly onto subcontinental mantle peridotites that became exhumed at the ocean floor (Molli 1996; Marroni et al. 2001);
- Ocean-floor spreading up to the Jurassic-Cretaceous boundary;
- Cretaceous to Late Eocene remnant oceanic basin, with pelagic sedimentation (clays and marls with episodic siliciclastic and carbonate turbidites);

- Oligocene sharp change to calciturbidite sedimentation and re-activation of paleofaults, which led to the emplacement of submarine landslides and turbidites;
- Late Oligocene-Aquitanian almost complete de-activation of the calciturbidite systems and restoration of pelagic sedimentation;
- Burdigalian evolution towards a foredeep with siliciclastic turbidite sedimentation;
- Late Burdigalian-Early Langhian first phase of deformation;
- Langhian-Serravallian sedimentation of the San Marino and Monte Fumaiolo Fms., forming the oldest unconformable deposits resting on the Val Marecchia Nappe;
- Subsequent Middle Miocene to Early Pliocene tectonic phases and transport of the Val Marecchia Nappe further towards the Adriatic foreland; from west to east the nappe overthrusts successively younger rocks of the Cervarola and Umbro-Marchean substratum, at the same time that unconformable sediments were deposited in up-thrust basins.

In the following we point out some very peculiar features of the Val Marecchia Nappe tectono-sedimentary evolution. Ophiolitic substratum and Upper Jurassic-Lower Cretaceous sedimentary cover are very similar to what is found in the Internal Ligurian Units (Vara Supergroup; Abbate and Sagri 1970; Decandia and Elter 1972; Principi et al. 2004). However, it appears difficult to assign the Val Marecchia Nappe to either the Internal or the External Ligurian Unit in view of the Late Cretaceous-Eocene age of their sedimentary successions and mainly their much older age of deformation. The Ligurides underwent mid-Eocene "Alpine" W directed tectonics ("Ligurian phase" of Elter et al. 1966; "Ligurian phase 1" of Marroni et al. 2001), overstepped by Latest Eocene and younger Epiligurian basins, followed by "Apenninic" top-E thrusting ("Ligurian phase 2" of Marroni et al. 2001). This entire tectonic evolution is clearly older than the onset of deformation in the Val Marecchia Nappe, which is constrained to near the Burdigalian-Langhian boundary. These differences strengthen the hypothesis that the sedimentary succession of the Val Marecchia Nappe took place in an oceanic realm other than that in which the sediments of both the Internal and External Ligurian units were deposited.

The sharp change in the nature and rate of sedimentation testified by the Oligocene Monte Morello Fm. has been interpreted as an event related to the strong Oligocene sea-level fall (Perrone et al. 2008, 2014). This interpretation is supported by the regional extent of similar and coeval deposits that are found beyond the Northern Apennines, namely in the Southern Apennines, in the entire Maghrebian Chain and in the Betic Cordillera (de Capoa et al. 2013, 2014).

The faunal assemblages of skeletal packestones, together with the textural features of peloid wackestones and foraminifera-rich packstones, indicate that the turbidites of the Monte Morello Fm. have been fed by a low to moderate energy shallow-water carbonate environment, i.e. open platform or ramp characterized by moderate water energy (Hayton et al. 1995), which provided calcareous mud, silt and sand together with planktonic foraminifera and neritic bioclasts (red algae, echinoids, crinoids). Neritic bioclasts are typical of Heterozoan associations (Nelson 1988; Hayton et al. 1995; James 1997; Flügel 2004), implying shelves located in temperate-cool water non-tropical environment. In addition, skeletal allochems are well preserved and occur as single fragments and never as a part of limestone clasts. Therefore, they are interpreted as originating from a source area, likely internal to the basin or located very close to it, where non-diagenized calcareous sediments were present. It is well known that in temperate-cool water shelves, due to the relatively low temperature of the seawater, destructive diagenetic processes do not lead to cementation of calcareous sediments (Nicolaides and Wallace 1997). On the other hand, Heterozoan associations and temperate-cool water carbonate shelves are known since the Cretaceous in Southern Apennines and Sardinia (Carannante et al. 1988, 1995, 1997) and in the Oligocene–Miocene successions of the African foreland (Malta and Hyblean Plateau; Knoreich and Mutti 2003). It follows from this that the Cretaceous to Eocene calcareous sediments remained as being not yet diagenized in the Western Mediterranean Domains. These deposits, due to the Oligocene lowstand, emerged and likely were easily re-mobilized and re-sedimented as turbiditic beds (Perrone et al. 2008, 2014). Hence, in deep basins contiguous to carbonate shelves the Oligocene sea-level fall triggered strongly fed turbidite systems, which substituted the previous pelagic sedimentation. The Aquitanian sea-level rise caused the almost complete de-activation of the calciturbidite systems and the restoration of the previous pelagic sedimentation, which became dominant again (*Argille Varicolori* Fm.). Consequently, the lack of Uppermost Cretaceous-Oligocene sediments in carbonate platforms located on stable margin, like in the Southern Apennines, and the abundance in contiguous basins of Oligocene turbidites, mainly made up of Cretaceous-Eocene calcareous mud, silt and fossils, may be reasonably explained. Finally, the distribution of reworked Cretaceous and Palogene taxa in the carbonate turbidites of both the Monte Morello and *Argille Varicolori* Fms., and the fact that Cretaceous taxa clearly increase upwards, becoming almost exclusive in the *Argille Varicolori* Fm., while at the same time the Eocene taxa decrease, seem to indicate a peculiar unroofing leading to the erosion from top to bottom of the Cretaceous-Eocene successions.

The presence of quartz and mica grains in calcareous beds and even of siliciclastic beds indicates a prevalent supply from epimetamorphic basement and its sedimentary cover. This testifies that the turbidite systems of the Monte Morello Fm. were not fed by intra-oceanic platforms but rather by peri-continental platforms or ramps, located on a continental margin made up of epimetamorphic formations and granitoids. This continental margin has to be looked for west of the Val Marecchia Nappe oceanic basin because: (i) all studies (Ponzana 1993; and references therein) indicate a western provenance of the turbiditic supply, (ii) the Dinaric platform, located east of the basin on the Adriatic margin, was too far away for feeding the thick sedimentary succession of the Monte Morello Fm. and (iii) turbidite sediments comparable with those of the Monte Morello Fm. are quite absent in the Oligocene successions deposited west of the Dinaric platform (Centamore and Micarelli 1991), i.e. between that platform and the basin in which the Val Marecchia Nappe succession deposited. On the other hand, a carbonate platform (Bagnolo Platform) has been drilled under Messinian-Quaternary sediments in the Po Plain north of Reggio Emilia (Bosellini et al. 1981) and, moreover, the presence of shallow water carbonate environments in the North-Apenninic domains is testified by the widespread and thick Helmintoid Flyschs of External Ligurian Units and by abundant neritic clasts in many Sub-Ligurian and Tuscan successions. The problems related with the origin of the shallow water carbonate supply, however, have been rarely considered and neglected also in recent palaeogeographic and paleotectonic reconstructions of the Northern Apennines.

The continental crustal block, which hosted the carbonate platforms that fed the oceanic basins of Northern Apennines, is identifiable in the Mesomediterranean Microplate of Guerrera et al. (1993), successively recognized by many authors, partly under the name ALCAPEKA (Bonardi et al. 2001; Michard et al. 2002; Handy et al. 2010; and others). This microplate originated following the Pangea break-up and separated a northern Tethyan realm from a south-eastern realm. The northern realm comprises the Piedmontese, Ligurian and Nevado-Filabride oceanic belts, whose successions were deformed in the Cretaceous-Late Eocene time span while the southeastern realm consists of the Maghrebian Flysch Basin and the Lucanian Ocean, whose successions were deformed in the Early Miocene (see Fig. 9 of Guerrera et al. 1993).

As regards the ophiolite-derived clastic rocks occurring in the Monte Morello and *Argille Varicolori* Fms., that were previously considered as extra-basinal deposits fed by the previously stacked Internal Ligurian Units, forming the inner (western) flank of the Val Marecchia Nappe basin (Principi 2007; and references therein), they cannot to be

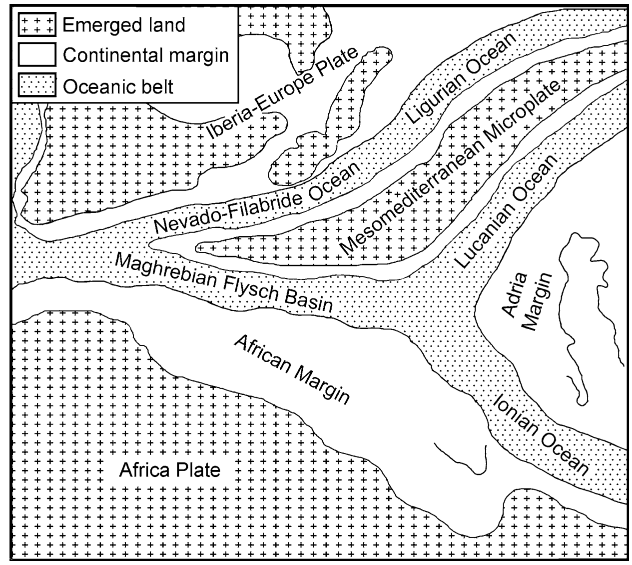

Fig. 9 Late Jurassic-Early Cretaceous paleogeography of the Central-Western Mediterranean region, after Dercourt et al. (1986) and Guerrera et al. (1993), modified

related to the carbonate and siliciclastic input of the Val Marecchia Nappe. Actually, these sandstones, debrites and olistoliths were fed exclusively from oceanic crust; continental clasts have never been found in them (Perrone et al. 2014). This indicates that their provenance is totally different from that of the carbonate and siliciclastic turbidites with which they are interlayered. Indeed, the presence of extra-basinal ophiolite-derived debrites and olistoliths in a foreland basin characterized by fine-grained and pelitic deposits, such as those characterizing the Monte Morello and *Argille Varicolori* Fms., is difficult to reconcile with an extrabasinal provenance. Perrone et al. (2014) have interpreted these ophiolite-derived clastic bodies as intrabasinal deposits, resulting from tectonic instability in some areas of the oceanic basin, which would have led to the reactivation and/or inversion of older normal/transform faults and caused submarine landslides and minor turbidites.

As previously mentioned, successions with a sedimentary and tectonic evolution similar to that of the Val Marecchia Nappe, i.e. oceanic sequences consisting of Upper Jurassic ophiolitic rocks and a sedimentary cover made up of Tithonian-Aquitanian foreland and Burdigalian foredeep deposits, have been recognized in other parts of the central-western Mediterranean Alpine belts (Fig. 10; Perrone et al. 2008; de Capoa et al. 2013; and references therein), i.e. in the Lucanian Oceanic Units of the Southern Apennines (Bonardi et al. 1988, 2001) and further west in the Flysch Basin Units of the Maghrebian Chain (Bouillin et al. 1977; Durand Delga et al. 2000; and others). Therefore, the basin in which the Val Marecchia Nappe succession was deposited very likely represents the

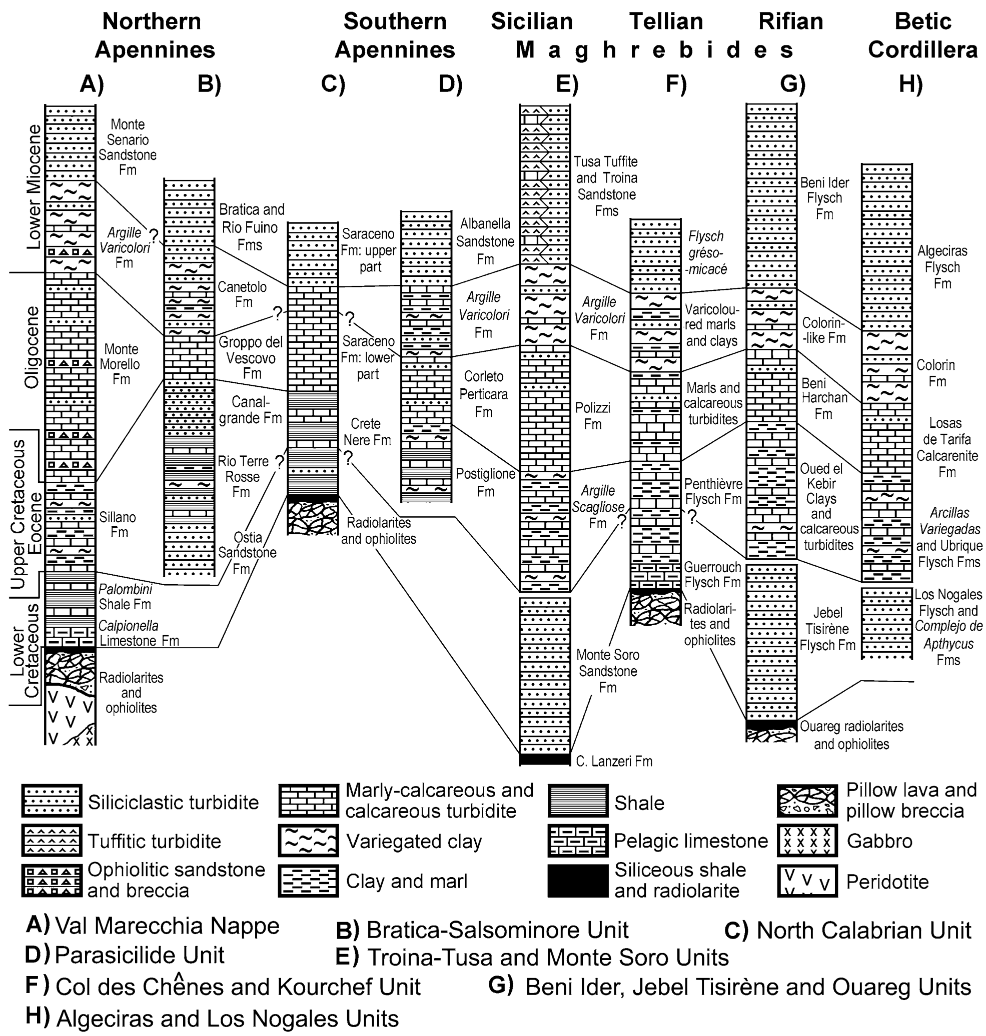

Fig. 10 Stratigraphic columns (not to scale) of the units originating from the Lucanian Ocean and the Maghrebian Flysch Basin. Northern Apennines: **A** Val Marecchia Nappe (this paper); **B** Bratica-Salsominore Unit (according to Cerrina Feroni et al. 2004; ages modified). Southern Apennines: **C** North-Calabrian Unit (according to Bonardi et al. 2001 and Perrone et al. 2008); **D** Parasicilide Unit (according to Ciarcia et al. 2009; modified). Sicilian Maghrebides: **E** Troina-Tusa and Monte Soro Units composite section (according to Perrone et al. 2008). Tellian Maghrebides: **F** Col des Chênes and Kourchef Units composite section (according to Perrone et al. 2008). Rifian Maghrebides: **G** Beni Ider, Jebel Tisirène and Ouareg Units composite section (according to Perrone et al. 2008). Betic Cordillera: **H** Algeciras and Los Nogales Units composite section (according to Perrone et al. 2008)

northwards extension of the Lucanian oceanic realm into the North-Apenninic domains. In both these areas deformation did not start before the Late Burdigalian. This Lucanian basin constituted an oceanic branch that is external with respect to the Ligurian oceanic basin and separated from it by the Mesomediterranean Microplate, as was suggested for the Maghrebian Chain and in the Southern Apennines by Guerrera et al. (1993, 2005) and Bonardi et al. (2001).

On the other hand, when interpreting the Val Marecchia Nappe as a part of the Sub-Ligurian Domain some problems arise because the latter is considered to be at least partly an oceanic belt, and because of its paleogeographic location. Evidently, as already pointed out by Vai and Castellarin (1992) and Perrone et al. (1998, 2008), development and age of the stratigraphic succession of the Val Marecchia Nappe are very similar to those of the Sub-Ligurian units. For example, the Groppo di Vescovo Limestone Fm., which characterizes the Sub-Ligurian Units in the Emilian Apennines and which consists of carbonate turbidites, revealed the same Oligocene age of the Monte Morello Fm. (de Capoa et al. 2014). However, differences do remain about the Burdigalian age of the Monte Senario Sandstone Fm., capping the Val Marecchia Nappe succession, and the Oligocene age attributed by most authors to the turbidite deposits topping the Sub-Ligurian Units (Ponte Bratica, Petrignacola, Val d'Aveto Sandstone Fms., and others) and consequently about the deformation age of the Val Marecchia Nappe and of the Sub-Ligurian Units. Actually, the age of the Ponte Bratica, Petrignacola and Val d'Aveto Sandstone Fms. has been the object of heated discussions starting from the sixties of the past century when Boni et al. (1968) and Bellinzona et al. (1968) attributed to these formations an Early Miocene age. This age has been rejected by the great majority of researchers, who considered these formations of Early Oligocene age (see Elter et al. 1997, 1999 and references therein), although an Early Miocene age for the above formations capping the Sub-Ligurian Units has been several times re-proposed also in recent times (Aiello 1975;

Vannucci and Wezel 1978; Montanari and Rossi 1982; Montanari et al. 2004). In particular, Vai and Castellarin (1992) pointed out that the first important unconformity in both the Val Marecchia Nappe and Sub-Ligurian units is located at the base of the Langhian San Marino Limestone and Bismantova Fms., and Cerrina Feroni et al. (2004) recognized at the top of Sub-Ligurian units cropping out in the Bobbio tectonic window ages reaching the Early Aquitanian and the Aquitanian–Burdigalian boundary. In detail, Cerrina Feroni et al. (2004) found nannofossils indicating the MNN1c-MNN1d (Early Aquitanian) and the MNN2a (Aquitanian–Burdigalian boundary) Zones of Fornaciari and Rio (1996), respectively, in the silicilastic turbidites topping the Bratica and the Salsominore Units. Finally, also in the Coli-Marra Unit, considered as the most external unit, nannofossils referable to the Zone MNN2a have been recognized. These recent results are very important because they indicate a tectono-stratigraphic evolution for some Sub-Ligurian units that is very similar to that of the Val Marecchia Nappe. This makes it very likely that these Sub-Ligurian Units and the Val Marecchia Nappe originated from the same paleogeographic domain (de Capoa et al. 2014; Perrone et al. 2014). In this regard, however, we underline that the age of the oldest unconformable deposits is Langhian both in the Val Marecchia Nappe (San Marino Limestone Fm.; Ori and Friends 1986; Ricci Lucchi 1987) and in the Sub-Ligurian Units (Bismantova Limestone Fm.; Vai and Castellarin 1992). In any case, it has to be verified if all units up to now attributed to the Sub-Ligurian Domain were deposited in an oceanic belt that underwent deformation in the Early Miocene. Further studies are required, aimed at a precise dating of the formations at the top of both the Sub-Ligurian units and the Val Marecchia Nappe succession, as well as the oldest unconformable deposits lying on them.

The Late Burdigalian-Early Langhian deformation of the Val Marecchia Nappe—and likely also that of some Sub-Ligurian Units—is younger than the Aquitanian deformation of the Tuscan Domain (Tuscan Metamorphic and Falda Toscana Units), whose successions end with Upper Oligocene-Aquitanian turbidite deposits (Pseudomacigno and Macigno Fms., respectively; Boccaletti et al. 1980; Pandeli et al. 1994). Taking into account the geometry and the eastward vergence of the nappe stack, the Late Burdigalian-Early Langhian age of deformation of the Val Marecchia Nappe implies that one needs to locate this oceanic basin in an external (eastern) position with respect to the Tuscan Domain, i.e. between the Tuscan Domain and the Cervarola basin, the latter having been deformed in the Serravallian. In this case, the Tuscan Domain would need to be located on the Mesomediterranean Microplate. We point out that, in seismic profiles of the Emilian Apennines, Zanzucchi (1988; see Figs. 2, 3, 4) recognized, oceanic units above and under the Tuscan Units and hypothesized that part of the Tuscan units derive from a promontory of Adriatic continental crust within the oceanic area, which locally separated two Ligurian belts. In addition, a position of the Tuscan Domain on a continental margin different from the Adriatic margin has been already hypothesized by French researchers working in Kabylias (Coutelle and Duée 1984; Coutelle 1987) and by Perrone et al. (2008). According to this hypothesis, back-thrusts of Sub-Ligurian Units onto the Tuscan Units have to be admitted. Similar back-thrusts, allowing units from both the Maghrebian Flysch Basin and the Lucanian Ocean to overthrust units originating from the Mesomediterranean Microplate, are well known in the entire Maghrebian Chain, from Rif to Southern Calabria, and in Southern Apennines (Bouillin 1977; Bouillin et al. 1977; Durand Delga, 1980; Guerrera et al. 1993; Bonardi et al. 2005; de Capoa et al. 2013; and references therein).

5 Conclusions

1. Field and biostratigraphic studies carried out in the area in and around the Val Marecchia Nappe allowed recognizing a succession consisting, from bottom to top, of:
   - Middle-Upper Jurassic ophiolites (serpentinized peridotite, basalt and breccias);
   - Upper Jurassic radiolarites and Lower Cretaceous pelagic limestones;
   - Lower Cretaceous-Upper Eocene shales and clays with interlayered calcareous and quartzolithic turbidite beds;
   - Oligocene calcareous, marly-calcareous and marly turbidites with interlayered minor siliciclastic beds and locally ophiolitic sandstones, debrites and olistoliths;
   - Upper Chattian-Aquitanian varicoloured clays and Burdigalian quartzolithic turbidites.
2. The Val Marecchia Nappe succession was deposited in an oceanic realm, which formed during the Jurassic and persisted as a remnant oceanic basin, characterized by pelagic and fine-grained calcareous turbidite deposits, up to the Early Miocene. In the Burdigalian, the basin evolved towards siliciclastic foredeep sedimentation immediately before its closure and the inclusion of its successions in the Apenninic accretionary wedge.
3. The Oligocene eustatic fall caused the emersion and erosion of Heterozoan peri-continental calcareous platforms or ramps close to the Val Marecchia Nappe

basin and induced the deposition of thick carbonate turbidites in this basin, thus interrupting the pelagic sedimentation (Monte Morello Fm.). At the same time tectonic instability locally occurred within the basin, as testified by ophiolite-derived breccias and olistoliths originating from intrabasinal highs.

4. The Aquitanian sea-level rise de-activated the carbonate turbidite systems and caused the restoration of the pelagic sedimentary regime (*Argille Varicolori* Fm.).
5. During the Burdigalian, a drastic environmental and compositional change from pelagic to siliciclastic sedimentation is reflected by the deposition of the turbidite succession of the Monte Senario Sandstone Fm., testifying for the foredeep evolution of the Val Marecchia Nappe basin. The quartzolithic composition of arenites, testifying for a recycled-orogen provenance, is the result of unroofing/erosion of low- to medium-grade metamorphic and subordinately plutonic terrains that constituted the Internal Units of the Apenninic Chain.
6. The age and tectono-sedimentary evolution of the Val Marecchia Nappe succession is incompatible with its attribution to the Ligurian oceanic basin. However, the evolution of this succession fits well with its deposition in an oceanic realm other than the Ligurian oceanic basin. This oceanic basin was located in a more external (eastern) position than the Ligurian basin and separated from it by a continental crust block, the Mesomediterranean Microplate. At a western-central Mediterranean scale, the tectono-sedimentary evolution of the Val Marecchia Nappe is quite similar to that of the units that originated from the Maghrebian Flysch Basin and from the southern Apenninic Lucanian Ocean, of which the Val Marecchia Nappe basin represents the northward continuation;
7. The tectono-sedimentary evolution of the Val Marecchia Nappe is similar to that of the Sub-Ligurian Units, and likely both sedimentary sequences were deposited in the same domain. Therefore, the hypothesis that at least a part of the successions of the Sub-Ligurian Domain was deposited in an oceanic basin located east of both the Ligurian and Tuscan Domains becomes more likely.

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