Geological Field Trips and Maps

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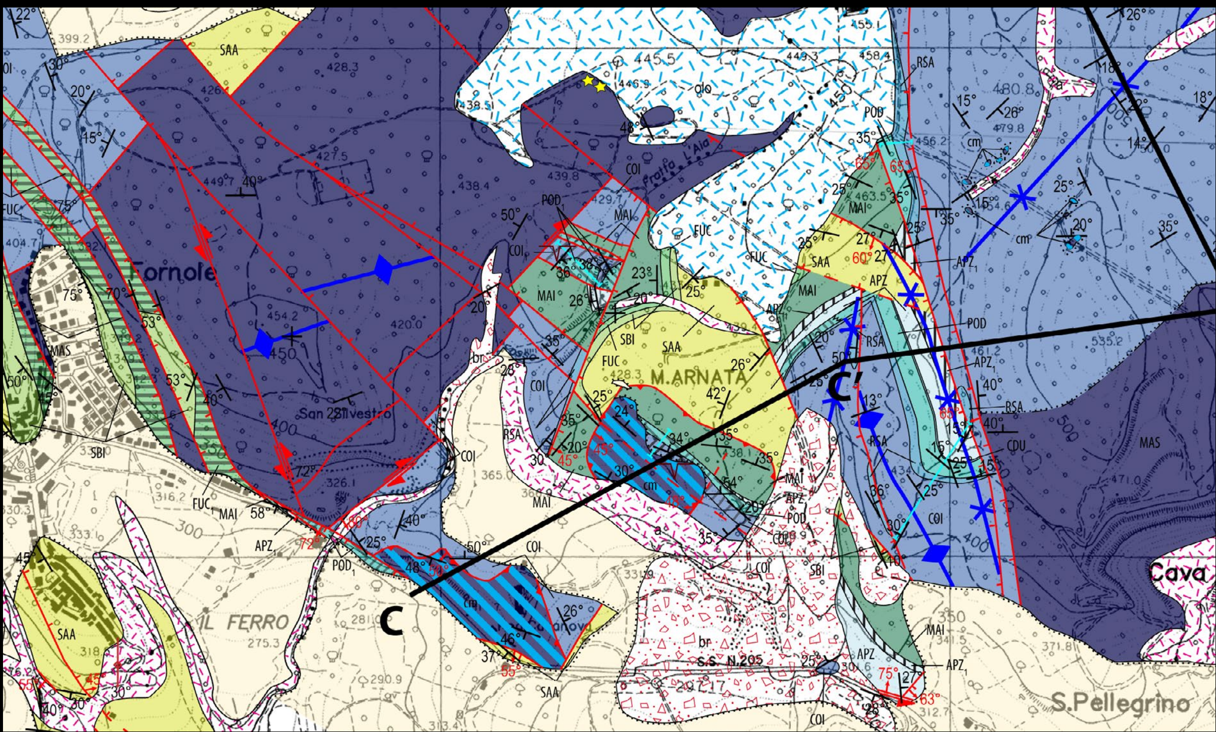

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Geological map of the central part of Narni-Amelia Ridge (Central Apennines, Italy)

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Cover page Figure A
Panoramic view of the Nera Gorge near Stifone, about 3 km SW of Narni.

Cover page Figure B
Part of the geological map concerning the Fornole-Mt. Arnata area.

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Abstract

These explanatory notes are companion of a 1:12,500 geological map and present new stratigraphic and structural data gathered from the under-investigated Narni-Amelia Ridge (Central Apennines, Italy). Here Meso-Cenozoic rocks of the Umbria-Marche-Sabina sedimentary succession crop out, deeply influenced in its tectonic-stratigraphic evolution by the Early Jurassic Tethyan rifting. Geological mapping was accompanied by facies analysis and by a dense network of stratigraphic/sedimentologic logs.

Several Jurassic structural highs flanked by deeper-water basins were identified through palaeoescarpments analysis and allowed to reconstruct the Mesozoic palaeogeography of the study area.

Unexpected fine-grained calcarenites made up of neritic material were found embedded in the upper Pliensbachian-Bajocian deposits (sedimented after the drowning of the Calcare Massiccio carbonate platform), providing new data for restoring the Jurassic palaeogeography of the Central Apennines.

Evidence of an Early Cretaceous extensional phase, which is well-documented in the southernmost part of the Narni Ridge, was also recognised in the study area. Here the Marne a Fucoidi (Aptian-Albian) rest unconformably on the Hettangian shallow-water carbonates of the Calcare Massiccio, as a result of rejuvenation and erosion of the Early Jurassic margin of the Amelia intra-basinal high.

Keywords: Narni-Amelia Ridge; Umbria-Marche-Sabina sedimentary succession; syn-sedimentary tectonics; Jurassic; pelagic carbonate platform-basin systems; Cretaceous escarpments; Apenninic orogeny; Pliocene normal faulting.

Introduction

The Narni-Amelia Ridge (Umbria-Sabina pre-Apennine, Central Italy) represents the most internal and highest unit of the Central Apennines (Fig. 1). Here, Meso-Cenozoic rocks of the well-known Umbria-Marche-Sabina (UMS) sedimentary succession (e.g. Centamore et al., 1971; Farinacci et al., 1981 Galluzzo and Santantonio, 2002) crop out. Part of this succession records the earliest Jurassic rifting phase related to the opening of the Western Tethys Ocean (e.g. Bertotti et al., 1993; Santantonio and Carminati, 2011). In particular, during Hettangian-Sinemurian times, normal faulting dismembered the vast "Calcare Massiccio" carbonate platform and caused a palaeogeographic differentiation in several neritic and pelagic domains (at the footwall and at the hangingwall of the Jurassic master-faults, respectively) (e.g. Cantelli et al., 1978; Chiocchini et al., 2008). The future UMS region was a pelagic domain characterised by a complex morpho-structural patchwork of displaced blocks organised in structural highs and lows (Farinacci, 1967, 1970; Colacicchi et al., 1970; Centamore et al., 1971; Passeri, 1971; Farinacci et al., 1981; Bice and Stewart, 1990; Santantonio, 1993, 1994; Galluzzo and Santantonio, 2002; Santantonio and Carminati, 2011; Fabbi and Santantonio, 2012; Donatelli and Tramontana, 2014; Cipriani, 2016; Cipriani et al., 2016a; Paparella et al., 2017; Cipriani et al., 2019a). As a consequence of the rifting, there was the drowning (*sensu* Schlager, 1981) of the Calcare Massiccio benthic factory and the development of two main sedimentary environments: pelagic carbonate platforms (PCPs *sensu* Santantonio, 1993, 1994) on the horst blocks, and basins around them. Tectonic subsidence led to the sudden drowning of the benthic factories in the hangingwalls, as testified by the "calcare massiccio C lithofacies" (*sensu* Petti et al., 2007; "drowning succession of the hangingwall-block rift basins" in Marino and Santantonio, 2010), and forced the sedimentation to pelagic and turbiditic. By contrast, on the horst-blocks shallow-water carbonate production persisted up to the early Pliensbachian (Morettini et al., 2002; Passeri and Venturi, 2005), even though with a combined contribution of the planktonic carbonate factory. The resulting transitional facies is represented by the "calcare massiccio B member" (*sensu* Petti et al., 2007; "Calcare Massiccio B" in Centamore et al., 1971; "footwall-blocks drowning succession" in Marino and Santantonio, 2010). The definitive demise of the benthic carbonate factory on the structural highs was a synchronous event at a regional scale and was not due to tectonic subsidence but to palaeoceanographic perturbations (Marino and Santantonio, 2010; Masetti et al., 2016). Following this drowning, the whole UMS domain became a pure pelagic domain. The complex depositional architecture inherited by the Early Jurassic rift is highlighted by facies and geometrical variations of the Jurassic-Lower Cretaceous post-rift deposits. The Sinemurian to Tithonian basin-fill succession is represented by the Corniola, Rosso Ammonitico/Marne del Monte Serrone, "Calcari e Marne a *Posidonia*", "Calcari Diasprigni" and "Calcari ad aptici e *Saccocoma*" formations. These units rest in angular unconformity on the pre-rift, horst-block Calcare Massiccio exposed along the submarine palaeoescarpments (e.g. Santantonio et al., 1996; Romano et al., 2019). Basin-margin successions bear detrital material in the form of Calcare Massiccio olistoliths/megabreccias. These calciclastics derived from the submarine erosion of the high-angle PCP margins (i.e. inactive Hettangian rift fault-scarps – Galluzzo and Santantonio, 2002). The lower Pliensbachian to Tithonian (locally Berriasian) condensed PCP-top succession constitutes the Bugarone Group (Cecca et al., 1990; Deiana et al., 2009; Damiani et al., 2011; originally a formation-rank unit - Jacobacci et al., 1974). Notably, the stratigraphic interval covered by the Calcari Diasprigni (radiolarian

cherts) in basinal successions is encompassed by a circa 20 My hiatus on all PCPs of the Apennines (Cecca et al., 1990). Thin veneers of condensed facies (Bugarone Group) can be also unconformably found on the Calcare Massiccio along the flanks of PCPs. These small patches of fossil-rich pelagites are preserved in morphological irregularities of the palaeoescarpment (i.e. collapse niches of detached blocks/olistoliths) in the form of epi-escarpment deposits (Galluzzo and Santantonio, 2002).
From the Cretaceous to the Miocene the whole UMS Domain was characterised by an overall homogeneous pelagic and hemipelagic sedimentation, even though syn-sedimentary tectonics caused local "anomalies" in the Cretaceous to Neogene stratigraphic record (Decandia, 1982; Corda and Mariotti, 1986; Tavarnelli, 1996; Marchegiani et al. 1999; Fabbi et al., 2016; Cipriani and Bottini, 2019a). From the Miocene the orogenic deformations, related to the subduction of the Adriatic lithosphere beneath the Apenninic wedge (Scrocca et al., 2003), affected the UMS sedimentary succession and the progressive roll-back towards north-east of the subducting plate caused the coeval opening of the back-arc basin (Tyrrhenian sea) in the most internal sectors (see Doglioni, 1991 for the geodynamic model of Central Italy).
All the above-described features (i.e. the passage from rifting to drifting to convergent/collisional, and to back-arc extensional conditions) were recognised in the

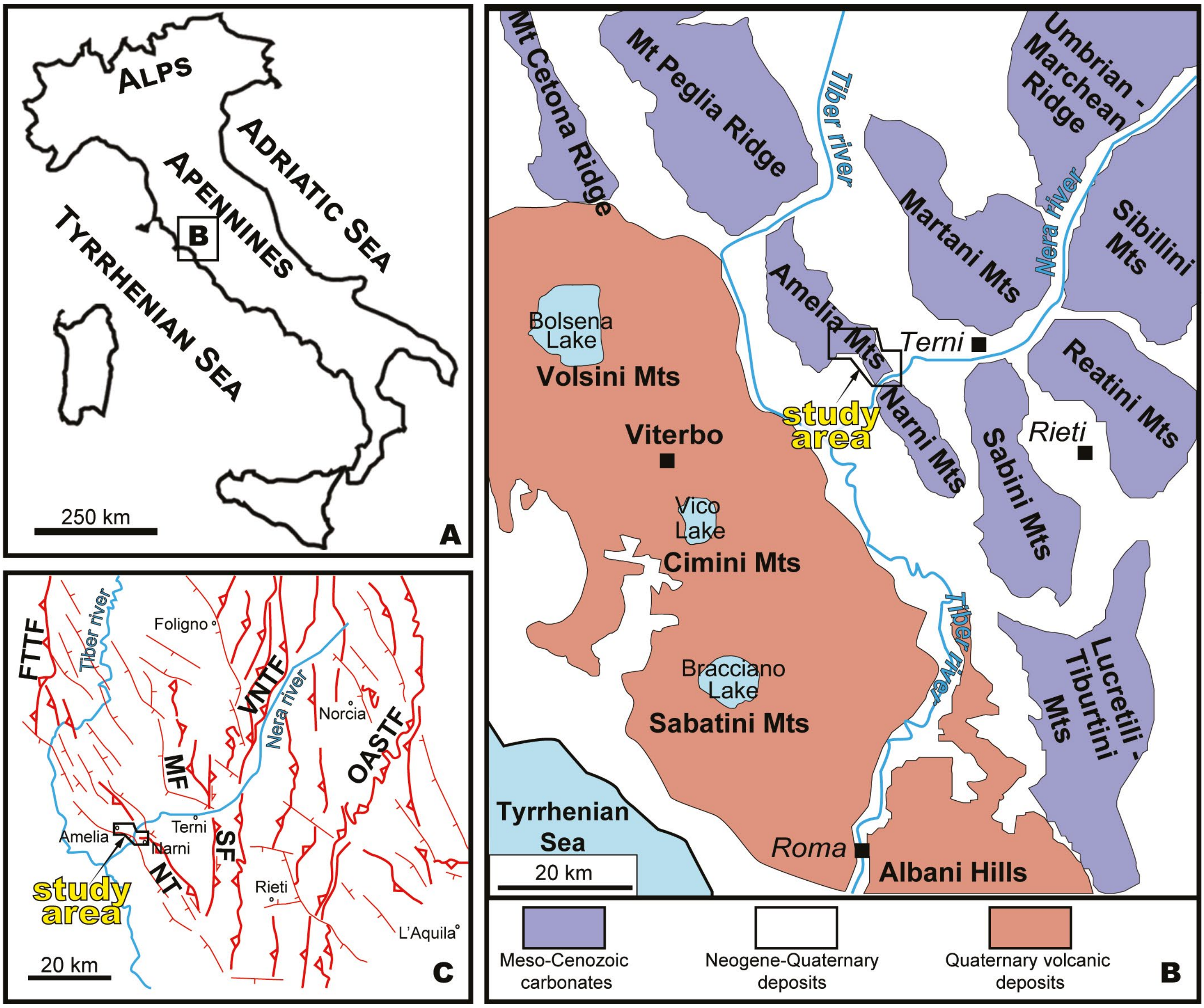

Fig. 1 - A-B) Regional overview of the study area (modified from Cipriani, 2016). C) Simplified structural scheme of the Central Apennines. *FTTF*: Falterona-Trasimeno Thrust Fault; *NT*: Narni Thrust; *MF*: Martana Fault; *SF*: Sabina Fault; *VNTF*: Val Nerina Thrust Fault; *OASTF*: Olevano-Antrodoco-Sibillini Thrust Fault (modified from Bigi et al., 2000).

Narni-Amelia Mts, a somewhat under-investigated area in the region. The official cartographic data about the whole Narni-Amelia area are the Sheets 130 "Orvieto", 137 "Viterbo" and 138 "Terni" of the Geological Map of Italy on the 1:100,000 scale (Servizio Geologico d'Italia, 1969, 1970a, b) and relative explanatory notes (Jacobacci et al., 1970; Bertini et al., 1971; Chiocchini et al., 1975), while is not included in the new Cartographic Project (CARG Project) of the Italian Geological Survey on the 1:50,000 scale to date. Other cartographic data are from Lotti (1926), Conforto and Parboni (1964), Fazzini (1968), Chiocchini et al. (1993), Pierantoni (1994), Calamita et al. (1996), Storti and Salvini (1996), Bigi et al. (1998), Boncio et al. (2000), Cipriani (2016, 2017).

This work presents a new, detailed, geological map of the central part of the Narni-Amelia Ridge as a result of a geothematic cartographic project performed at 1:10,000 scale (locally at 1:5,000 scale). The main lithostratigraphic features of the mapped units will be described in these explanatory notes, as well as the main structural elements, providing a new field-based dataset about the stratigraphy and the geostructural setting of the study area.

During the field-work, previously unreported Meso-Cenozoic outcrops were identified in the Amelia area. The study area is dominated by Mesozoic rocks and during the fieldwork the attention was focused on them. Detailed geological mapping, facies analyses and measurement of stratigraphic sections allowed to identify several PCP-basin systems (*sensu* Cipriani and Santantonio, 2016; Cipriani, 2017), albeit if displaced by Neogene-Quaternary, orogenic and post-orogenic, deformations.

Methods and Techniques

The purpose of this paper is to provide new Mesozoic stratigraphic elements from the UMS Domain as a result of geothematic mapping. Fieldwork was performed on the 1:10,000 scale C.T.R. (Carta Tecnica Regionale) of the Umbria Region (available online at http://www.umbriageo.regione.umbria.it/pagine/cartografia-tecnica-regionale-a-grande-e-media-sca), sections n°: 346010 "Amelia"; 346020 "Capitone"; 346060 "Fornole"; 346070 "Narni". The map is presented at 1:12,500 scale, for a total area of about 45 km^2. Spatial reference of the Cartesian grid follows the Gauss Boaga Projection (Est Zone). Altimetric curves represent 10 m intervals, while main contour lines are 50 m spaced out. A simplified structural scheme of the mapped area accompanies the geographic localisation, as well as seven geological sections and a scheme of the stratigraphic relationships between the mapped units.

The geological map has been redrawn from a hand-drawn map using the vector graphics software Adobe Illustrator CC.

Methodologies used during the field activity were the classical ones of geological mapping (cartography, facies and biostratigraphic analysis, stratigraphic sections measurement, outcrop visualisation and description, sampling), associated with the identification of peculiar diagenetic, sedimentological and stratigraphic features (see Galluzzo and Santantonio, 2002; Fabbi, 2015 and Cipriani, 2016 for further details) that allowed to better define the Mesozoic palaeogeography of the study area. Microfacies description was performed on 30 thin sections using an Olympus CH-2 binocular microscope placed in the Micropalaeontology Laboratory of Earth Sciences Department, "Sapienza" University of Rome. Microfacies and textural descriptions were made following Dunham (1962) and Embry and Klovan (1971) classifications for carbonate rocks.

The mapped lithostratigraphic units are in agreement with the Catalogue of the Italian geological formations (Cita et al., 2007) (Fig. 2). Differences with the classical stratigraphy of the UMS region regard the Middle and Upper Jurassic deposits, that, according to Petti and Falorni (2007) should be labelled as Calcari Diasprigni, based on the distinctive abundance of chert, and subdivided in two members: the "selciferous member" and the "calcari a *Saccocoma* e Aptici member" (Cita et al., 2007). By contrast, Galluzzo and Santantonio (2002) and Cipriani (2016) subdivided the Calcari Diasprigni (*sensu* Petti and Falorni, 2007) into three different formations ("Calcari e Marne a *Posidonia*" *p.p.*, "Calcari Diasprigni" *s.s.* and "Calcari ad aptici e *Saccocoma*" formations) on the base of the lithogenetic role played by the faunal components ("pelagic bivalves", radiolarians, crinoids and cephalopods, respectively). Since the identification of these fossils is more practical and objective on the field with respect to the evaluation of the chert content, the last subdivision has been adopted during the survey of the here presented map. Moreover, the majority of Jurassic basinal units (Corniola, Rosso Ammonitico, "Calcari e Marne a *Posidonia*" and "Calcari ad aptici e *Saccocoma*" formations), with the exception of the "Calcari Diasprigni" *s.s.*, laterally pass to condensed-like lithofacies. The latter lithotypes were distinguished in the field and mapped as informal members of their formation-rank parents. Last exception to the classical stratigraphy of the UMS succession is represented by the *"Rocchette"* member (*sensu* Cipriani, 2016). This lithosome encompasses the sixth lithofacies of the Marne a Fucoidi *sensu* Coccioni et al. (1987) and the W1 and W2 members of the Scaglia Bianca (Coccioni et al., 1992 in Coccioni and Premoli Silva, 2015), and can be correlate with the "upper member" of the Marne

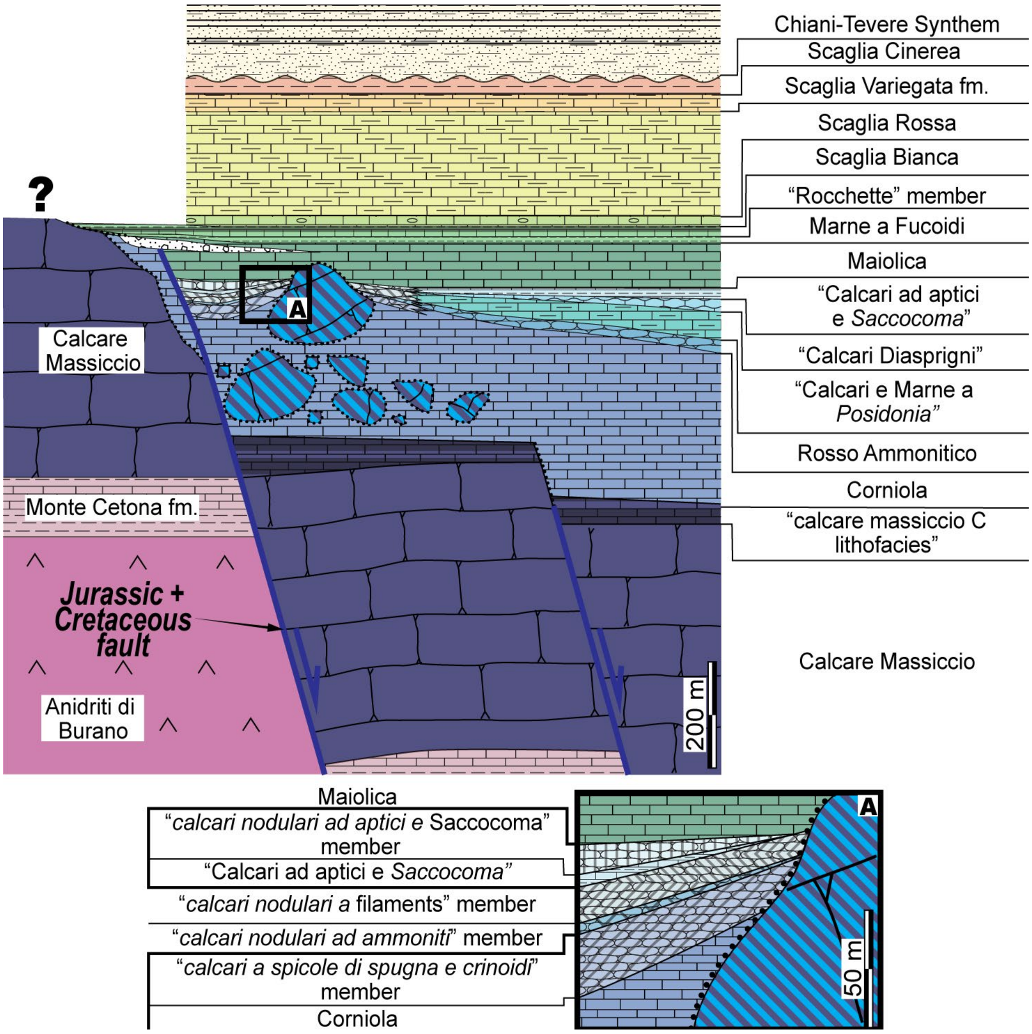

Fig. 2 - Stratigraphic setting and sedimentary succession of the study area.

a Fucoidi *sensu* Jacobacci et al. (1974), Centamore et al. (1975, 1979) and Centamore and Micarelli (1991). Comparable facies were also described in the contiguous western Sabini Mts by Galluzzo and Santantonio (2002). This unit was differentiated from the Marne a Fucoidi being i) easily identifiable in the field and ii) mappable, being tens of meters in thickness. Pleistocene-Holocene deposits were distinguished in synthems, being unconformity-bounded stratigraphic units. The main, basal, unconformity has a regional outcome and represents the lower boundary of the Tiber Basin Supersynthem. Other major unconformities bound synthems as part of the Tiber Basin Supersynthem.

Field data

Lithostratigraphy

The litho-biostratigraphic features of the mapped units (from older to younger) will be described below. Abbreviations are the same used for the official cartography of the Italian Geological Survey (except for the Monte Cetona and the "Calcari ad aptici e *Saccocoma*" formations) and correspond with the contractions reported on the geological map. Abbreviations for the informal members and of the *"Rocchette"* member are the same of the parent formations followed by a subscript number, in accordance with Galluzzo et al. (2009).

Pre-rifting succession

Monte Cetona formation (*sensu* Ciarapica et al., 1986) **(FZM)**: equivalent of the calcari e marne a *Rhaetavicula contorta* (e.g. Barchi and Marroni, 2007), the Monte Cetona formation (hereafter, fm.) represents the older unit outcropping in the Narni-Amelia Ridge. Lithologically it contains: i) well- to thickly-bedded (up to 1 m) dolostones and dolomitic limestones, grey in colour; ii) well-bedded (up to 15 cm) limestones and marly limestones, brown and orange in colour; iii) thinly-bedded (up to 5 cm) dark marls and shaly marls embedding laminated and graded oolitic calcarenites (Fig. 3A); iv) alternations of well-bedded (up to 15 cm) hazelnut to grey limestones, locally (thinly-bedded)

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marly limestones, and dark shaly marls. Algal mounds (up to 5 m-thick) are also present. Litho-bioclastic packstones/grainstones, sometimes wackestones, are the main recognised textures; locally megalodontid-rich facies and bivalve coquinas form bivalve floatstones (Fig. 3B). Skeletal content is characterised by bivalves (*Rhaetavicula contorta*, *Conchodon* sp., *Cardita* sp., *Nucula* sp., *Modiolus* sp.), gastropods (Ceritidae), benthic foraminifers (*Triasina hantkeni, Frondicularia* sp., *Aulotortus* sp., *Gandinella* sp., Nodosariidae),

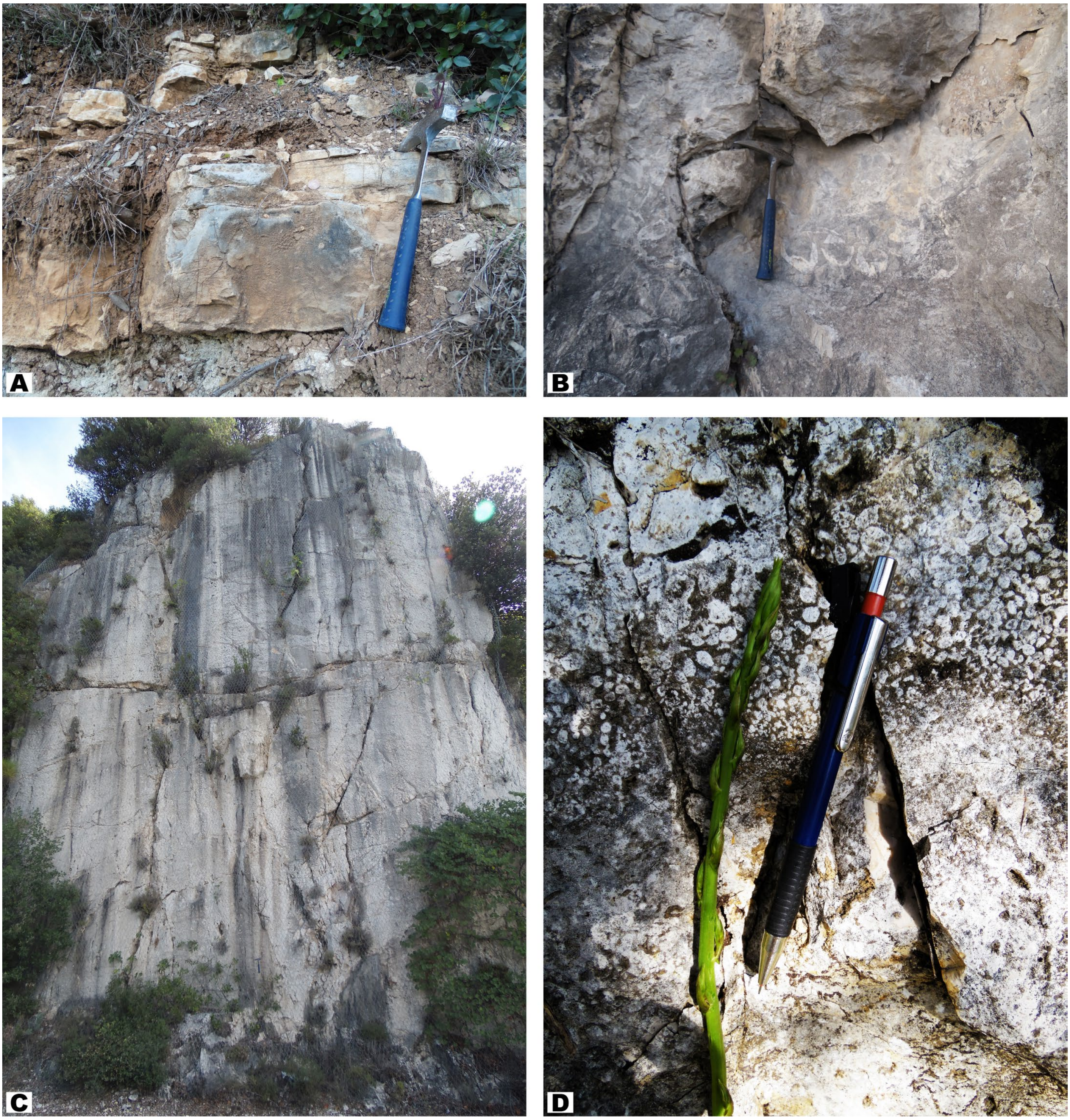

Fig. 3 - A) Graded and laminated, ooidal, calcarenitic level embedded in marly facies of the Monte Cetona fm. Locality: Capitone. B) Megalodontid-rich dolostones at the top of the Monte Cetona fm. Locality: Poggio, few km S of the study area. C) Metric beds of the Calcare Massiccio. Locality: Narni. D) Peritidal facies of the Calcare Massiccio showing (from up to down): whitish mudstones bearing rizoliths, oncoidal rudstone and peloidal grainstone. Locality: Narni.

ostracods, *Bactrillium* sp., *microproblematicum* (*Thaumatoporella parvovesiculifera*), dasycladacaean algae (?*Gyroporella* sp.). Non-skeletal components are mainly coated grains (ooids, peloids, oncoids). Calcareous lithoclasts (extraclasts) are also present.
The lower stratigraphic boundary of the unit is not exposed, while the passage to the overlying Calcare Massiccio is well-exposed at St Pellegrino, Capitone and Foce. The stratigraphic boundary between the Monte Cetona and Calcare Massiccio formations is marked by the passage from dark dolomitised facies to whitish, grain-supported deposits, and coincides with the uppermost occurrence of *Conchodon*-rich facies.
In the study area, the formation is more than 110 m-thick. Passeri and Pialli (1973) described 110 m of the Upper Triassic lithotypes for the Poggio area (Ponte Arverino section, 8 km S of Narni). At a regional scale, the thickness of this unit is variable. In the Rapolano area (northernmost part of the Tuscany Domain - Lazzarotto et al., 2010) the Monte Cetona fm. reaches 330 m; in the Mt Civitello 1 well log (available online here: http://www.videpi.com/deposito/pozzi/profili/pdf/monte_civitello_001.pdf), drilled by AGIP at the end of the 1980s in the Gubbio area, the Monte Cetona fm. is 150 m-thick; at Mt Cetona (type-locality of the unit) the exposed thickness of the formation is 110 m (Ciarapica et al., 1986; Stefani and Trombetta, 1989; Cirilli et al., 1994); at Mt Malbe (Perugia Massif) this unit is about 80 m-thick and rests directly on the Calcare Cavernoso, while the top is not exposed (Barchi and Marroni, 2007); in the Martani Mts the unit crops out for a total thickness of 120 m (the lower boundary is not exposed). In this work, 120 m is the thickness assumed for the formation and used in the geological sections.
The age is Rhaetian *p.p.*, due to the occurrence of *Triasina hantkeni* and of *Rhaetavicula contorta*.
Calcare Massiccio (MAS): massive or poorly-bedded, white to hazelnut, limestones and locally dolomitised limestones (Fig. 3C). Shallowing upwards peritidal cycles, usually asymmetric, characterise the whole unit. Palaeosoils and reddened levels rich in pisoids are associated with palaeokarst breccias, stromatolitic, fenestral, gastropods-rich, peloidal and oncolitic facies (Fig. 3D). Litho-bioclastic grainstones/rudstones, microbial bindstones/cementstones and mudstones are the main observed textures of this formation. Recognised fossils are gastropods (*Narnica* sp. – Conti and Monari, 1994), bivalves, echinoderms, ostracods, benthic foraminifers (*Trocholina* sp., *Siphovalvulina* sp., valvulinids), calcareous algae (*Palaeodasycladus mediterraneus*, *Cayeuxia* sp., *Rivularia* sp., Solenoparaceae, Dasicladaceae, Cyanophyceae), microplobematica (*Thaumatoporella parvovesiculifera*, *Lithocodium aggregatum*, *Bacinella* sp., *Tubiphytes* sp.). The Calcare Massiccio crops out extensively in the study area; spectacular exposures are located at Narni, at Fornole-Mt Arnata, at Foce and near Amelia. The passage to the overlying units (i.e. "calcare massiccio C lithofacies" and "calcare massiccio B member" *sensu* Petti et al., 2007 in basinal and PCP-top successions, respectively) was not observed in the study are, and so the total thickness of the Calcare Massiccio cannot be evaluated. A thickness of more than 450 m has been estimated through the geological sections. The Calcare Massiccio presents lateral stratigraphic contacts with Jurassic and Lower Cretaceous pelagic units. These unconformable relationships are marked by the occurrence of crusts and nodules of chert. The Calcare Massiccio is an otherwise chert-free unit and the presence of chert is a diagenetic feature, described as silicification of the Calcare Massiccio (Santantonio et al., 1996), related to the stratigraphic contact with the cherty pelagites onlapping it. Silicified Calcare Massiccio outcrops at Podere Casanova — and at Podere Capalto – ~1 km NNE of Amelia.
The age of the formation is ?Rhaetian *p.p.*/Hettangian-Sinemurian *p.p.*

Syn- and post-rifting succession

Corniola (COI): well-bedded (10-40 cm) limestones and marly limestones, light grey to brown in colour and rich in dark chert (Fig. 4A, B). As the Calcare Massiccio, this unit is widespread in the area and the best outcrops may be observed at Tisciano, Mt Arnata and along the S.P. Amerina near Fornaci locality. This unit testifies to the drowning of the Calcare Massiccio carbonate factory in the hangingwall basins, overlying the "calcare massiccio C lithofacies" (not exposed in the study area, but outcropping few km southwards in the Mt Cosce Ridge – Cipriani, 2016), and is characterised by a typically pelagic background sedimentation (mudstones and wackestones with radiolarians, siliceous sponge spicules and ammonites). Furthermore, this unit records the younger demise of the shallow-water carbonate production on the structural highs. The Sinemurian to lower Pliensbachian part of the Corniola is dominated by calciturbidites showing Calcare Massiccio *s.s.*- and calcare massiccio B-type compositions (*sensu* Fabbi and Santantonio, 2012), resedimented in the spicules and radiolarians-rich micrites (Fig. 4C). Turbidites are often graded, thickly bedded, and bear peloids, benthic foraminifers, fragments of algae, molluscs and echinoderms. The disappearance of calciturbidites in the post-lower Pliensbachian deposits coincides with the drowning of the horst-block benthic factories. Often breccias and megabreccias made of Calcare Massiccio clasts are associated with resedimented loose benthic material. Sometimes blocks are hundreds of metres across, forming large-scale, silicified Calcare Massiccio

Fig. 4 - A) Thick beds of the Corniola, bearing breccia bodies and calcarenites, and chert as well. Locality: Palombara, 2 km E of Amelia. B) Thinly-bedded Corniola bearing white chert beds. Locality: Fosso Fratta L'Aia. C) Graded bio-lithoclastic gravity-flow deposit embedded in the Corniola, displaying a sharp erosional base. Locality: Palombara. D) Red, nodular and ammonitiferous, facies (Pliensbachian "Ammonitico Rosso"-type deposits) outcropping at Fosso del Molinaccio near the top of the Corniola. E) Crinoids and brachiopods-rich deposits of the "*calcari a spicole di spugna e crinoidi*" informal member. Differential erosion highlights the partial pelagic infilling of brachiopod shells in respect of the geopetal one.

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olistoliths ("cm" in the geological map). Spectacular are the examples of Mt Arnata (about 2 km ENE of Fornole), L'Aspreta and Mt St Salvatore (0,5 km SE of Amelia). Calciclastic-rich facies form two thirds of the Corniola total thickness.

Near the top of the formation, a 5 to 8 m-thick red marly-nodular lithosome with red chert occurs. The ammonite assemblage (mainly *Fuciniceras* and *Protogrammoceras*), such as the occurrence of *Fuciniceras lavinianum*, allow to refer this lithosome to the base of the upper Pliensbachian (*Fuciniceras lavinianum* Biozone, lower Domerian *sensu* Faraoni et al., 2002) (Fig. 4D). This "Ammonitico Rosso"-type facies is spectacularly exposed at Fosso del Molinaccio. The highest part of the Corniola is characterised by thin alternations of yellow/grey/greenish marls and hazelnut limestones. Near Foce the upper part of the formation is pervasively dolomitised, forming characteristic "zebra-rock" type deposits.

Intra-litho-bioclastic rudstones/grainstones to floatstones/wackestones and spiculitic and radiolarians mudstones/wackestones are the main observed textures.

The palaeontological content is made up of radiolarians, siliceous sponge spicules, crinoidal fragments, benthic foraminifers (ophtalmidiids, lagenids, nodosariids), small gastropods, thin-shelled bivalves (*Diotis* sp.), brachiopods, ammonites.

The base of the unit is never exposed, while the stratigraphic boundary with the overlying Rosso Ammonitico is sharp and marked by the sudden passage from yellowish cherty limestones to red marls and shales. Laterally, the Corniola rests directly on the horst-block Calcare Massiccio through an unconformity surface. The thickness of the formation is variable and could exceed 400 m. The age is Sinemurian *p.p.*-Toarcian *p.p.*

***"calcari a spicole di spugna e crinoidi"* informal member (COI$_1$)**: well-bedded (10-30 cm), brownish to orange, micritic limestones without chert. This unit is extremely fossiliferous and is characterised by abundant crinoid fragments, brachiopods (mainly Terebratulidae and Rhynchonellidae), ammonites, benthic foraminifers (*Agerina martana*, *Trocholina conica*, *Involutina* sp., *Spirillina liasica*, lagenids, nodosariids), radiolarians, siliceous sponge spicules, Demospongiae, small gastropods and thin-shelled bivalves (*Diotis* sp.) (Fig. 4E). Gravity-deposits in the form of graded calcarenites dominated by crinoid fragments (encrinites) are abundant. Incipiently nodular facies were also identified at different stratigraphic levels. Bio-intraclastic floatstones/packstones and wackestones are the main observed textures. The *"calcari a spicole di spugna e crinoidi"* informal member follows megaclastic and turbiditic facies of the Corniola, and laterally passes to the uppermost facies of the formation. This member laterally rests in angular unconformity on the Calcare Massiccio and has been found as sedimentary dykes infill fractures. As for its formation-rank parent, the passage to the overlying younger unit is sharp and marked by a mineralised hard-ground. The unit is up to 20 m thick and crops out at Podere Casanova-Fosso Fratta L'Aia (about 1 km E of Fornole) and at L'Aspreta (1,5 km NE of Amelia). No biostratigraphic constraints were identified during the fieldwork, but lacking evidence for shallow-water neritic material (e.g. coated grains), this lithofacies postdates the drowning of the Calcare Massiccio carbonate platform on the top of structural highs. As a result, this member is not older than the early Pliensbachian and arrives to the earliest Toarcian.

Rosso Ammonitico (RSA): grey-greenish marls and shales bearing a black shale interval (Early Toarcian Oceanic Anoxic Event - Jenkyns, 1985) passing upwards to burrowed red and green nodular marls and marly limestones alternated with shales (Fig. 5A). The fossils are dominated by ammonites (Hildoceratidae, Dactylioceratidae, Phymatoceratidae, Hammatoceratidae, Phylloceratidae, Lytoceratidae) and thin-shelled bivalves (*Bositra buchii* and *Lentilla humilis* - Conti and Monari, 1992), but radiolarians, gastropods, *Atractites* sp., benthic foraminifers (*Lenticulina* sp.), rare crinoids and brachiopods have also been found. Ichnofossils are abundant (*Thalassinoides* and *Chondrites*). Near Amelia, along the S.P. Amerina, clasts of Calcare Massiccio and Corniola formations are embedded in the Rosso Ammonitico marls, forming a peculiar polygenic breccia (Cipriani et al., 2019b). Intra-litho-bioclastic floatstones and packstones/wackestones are the main observed textures.

Chert is missing throughout the unit and the stratigraphic boundary with the younger "Calcari e Marne a *Posidonia*" was placed on the field and in the map at the first occurrence of chert.

Best outcrops of this unit are located at Scalelle di Sopra (0,5 km W of Cigliano), at Fosso del Molinaccio (~0,5 km NW of St Pellegrino quarry), at Il Granaro (1 km ESE of Foce), at Le Rote (1,5 km WNW of Foce) and at Amelia, along the S.P. Amerina. The total thickness of the formation ranges from 8 (Le Rote) to 17 m (Fosso del Molinaccio). Ammonites assemblage suggests a Toarcian *p.p.* age for this lithostratigraphic unit.

***"calcari nodulari ad ammoniti"* informal member (RSA$_1$)**: well-bedded nodular limestones and marly limestones (Fig. 5B), brown to orange in colour, passing upwards to red marly limestones and, subordinately, limestones. Sub-centimetric interbeds of red shales are also present. At their tops, the beds often display

Fig. 5 – A) Marly and nodular facies of the Rosso Ammonitico. Locality: Podere Casaglia, near Foce. B) Nodular marly limestone and limestone of the *"calcari nodulari ad ammoniti"* informal member exposed at Podere Casanova. C) Laminated and graded posidoniid-rich resediment, associated with yellowish chert, embedded in the "Calcari e Marne a *Posidonia*". Locality: Scalelle di Sopra. D) Nodular limestones at the top of the *"calcari nodulari a* Posidonia" informal member. Note the sharp boundary between the thick nodular limestones of the *"calcari nodulari a* Posidonia" informal member and the very thinly-bedded, cherty and calcarenitic, facies of the "Calcari ad aptici e *Saccocoma*". Locality: Podere Capalto. E) "Pinch and swell" geometry of the "Calcari Diasprigni" *s.s.* beds. Locality: Narni. F) Thin calcarenitic beds of the "Calcari ad aptici e *Saccocoma*". Locality: Podere Capalto. G) Detail of the cross-bedded calcarenites resedimented in the "Calcari ad aptici e *Saccocoma*". Locality: Fosso Fratta L'Aia. H) Incipiently nodular facies of the *"calcari nodulari ad aptici e* Saccocoma" informal member, bearing decimeter-sized ammonites. Locality. Ceccanibbio.

oxidised (FeMn) crusts, referable to hard-grounds. The fossiliferous content is comparable with the Rosso Ammonitico, and the main microfacies are intra-bioclastic wackestones/floatstones.

The passage to the above unit is marked by the abrupt reduction in shale content and in nodules. This member is well-exposed at L'Aspreta, where is up to 8 m thick, while at Podere Casanova is 0,6 m thick. The "*calcari nodulari ad ammoniti*" informal member laterally replaces the Rosso Ammonitico and, as a result, is Toarcian *p.p.* in age.

"Calcari e Marne a *Posidonia*" (POD) *sensu* Galluzzo and Santantonio (2002): this unit is characterised by two main lithofacies: i) the lower one, made up of alternations of yellow-greenish limestones and purple/red-green marls, sometimes nodular and ammonitiferous; ii) the upper one, made up of chert-rich green and yellowish limestones with green shales (Fig. 5C). Bed thickness ranges between 5 and 20 cm. In the easternmost outcrops of the "Calcari e Marne a *Posidonia*", near Foce, ooidal calcarenites embedded in the cherty facies were found.

The faunal assemblage is essentially made up of thin-shelled posidoniid bivalves (*Bositra buchii* and *Lentilla humilis* - Conti and Monari, 1992), coupled with radiolarians, foraminifers (*Lenticulina* sp. and rare *Globuligerina oxfordiana*), echinoid fragments and rare ammonoids. The textures are mainly bioclastic wackestones/mudstones, with occasional laminated packstones with iso-oriented posidoniids and ooidal grainstones/packstones. The stratigraphic boundary with the overlying unit is placed at the disappearance of thin-shelled bivalves.

The lithotypes of the "Calcari e Marne a *Posidonia*" are well-exposed along the eastern slopes of Mt St Pellegrino (Cigliano), at Fosso del Molinaccio, at Foce and at Le Rote. The thickness of the unit is variable but does not exceed 30 m. The age is Toarcian *p.p.*-?Bajocian *p.p.*

"*calcari nodulari a* Posidonia" informal member (POD$_1$): well-bedded (10-40 cm) chert-free limestones, locally incipiently nodular and/or dolomitised, reddish/orange/hazelnut in colour. Graded and laminated deposits made up of iso-oriented posidoniids associated with pebbly mudstones were identified. Fossiliferous content is abundant and dominated by thin-shelled bivalves, ammonites, crinoid fragments, small gastropods, radiolarians, ostracods and foraminifers. Thick-shelled *Globuligerina oxfordiana* occurs in the uppermost (Bajocian) facies of this unit (Giovagnoli and Schiavinotto, 1987). Bio-intraclastic floatstones and wackestones, locally packstones, are the main observed textures.

This unit is well-exposed at Mt St Pellegrino-Scalelle di Sopra (Cigliano), at Podere Casanova, at Fosso del Molinaccio, at Fosso Fratta L'Aia, at Le Rote and at L'Aspreta. In particular, at Fosso Fratta L'Aia the "*calcari nodulari a* Posidonia" informal member rests in angular unconformity on the "*calcari a spicole di spugna e crinoidi*" through a NNE-trending erosional surface. At Scalelle di Sopra this unit replaces upwards the "Calcari e Marne a *Posidonia*". The stratigraphic boundary with the above unit ("Calcari Diasprigni" *s.s.*) is sharp and marked by the disappearance of macro- and microfossils, and by the occurrence of cherty facies. At L'Aspreta, the "Calcari ad aptici e *Saccocoma*" (Fig. 5D) rests directly on the "*calcari nodulari a* Posidonia" informal member, while at Podere Casanova the Maiolica onlaps this unit. The thickness is variable and ranging between 10 and 20 m, while the age is Toarcian *p.p.*-early Bajocian.

"Calcari Diasprigni" (CDU) *sensu* Galluzzo and Santantonio (2002): polychrome radiolarian cherts and subordinately cherty limestones, with thin (1-2 cm) interbeds of green shales. The up to 10 cm thick-beds are tabular or alternatively show "pinch and swell" geometries (Fig. 5E). No macrofossils are generally observed in this unit and the faunal assemblage is dominated by radiolarians. Bioclastic mudstones/wackestones are the main observed textures. Lithologically the passage to the above unit is gradual and marked by the increase in calcareous content; on the field and in the map the stratigraphic boundary has been placed with the first occurrence of the crinoid *Saccocoma*.

This unit crops out at Scalelle di Sopra, at Fosso del Molinaccio, at Macchie di Ciabella (0,5 km NW of Foce), at L'Aspreta and at Ceccanibbio (0,5 km SE of Amelia). The thickness ranges from 0 (therefore locally is absent) to 25 m and the age is ?Bajocian *p.p.*/Bathonian-early Kimmeridgian (Bartolini et al., 1996).

"Calcari ad aptici e *Saccocoma*" (APZ) *sensu* Galluzzo and Santantonio (2002): thinly bedded (10-20 cm), yellow, red and greenish limestones and burrowed marly limestones associated with green, blue and, locally, red chert in nodules or discontinuous beds (Fig. 5F). Interbeds of green shales are present. Locally, up to 1 m-thick incipiently nodular facies embedded in the cherty limestones were identified. Calcareous nodules are 5-7 cm in diameter and are often associated with ammonites. Fragments of the crinoid *Saccocoma* (*S. tenellum* and *S. vernioryi* - Manni and Nicosia, 1984, 1994), sometimes forming laminated and graded sands, aptychi (*Laevaptychus* sp., *Lamellaptychus* sp. - Farinacci et al., 1976), ammonites (simoceratids, phylloceratids), belemnites, brachiopods, undeterminable bioclasts, radiolarians, calcisphaerulids and calpionellids (at the top of the unit) are common. Bioclastic wackestones/packstones, sometimes bio-intraclastic floatstones are the main observed textures.

This formation outcrops at: Scalelle di Sopra; Fosso del Molinaccio; at Fosso Fratta L'Aia, where cross-bedded and laminated *Saccocoma*-made calcarenites were identified (Fig. 5G); at L'Aspreta, where a very-thin (1 cm), lens-shaped, ooidal grainstone was identified. As for the ooidal facies in the "Calcari e Marne a *Posidonia*", the occurrence of this calciturbiditic deposits was unexpected. The stratigraphic passage to the following unit is marked by the occurrence of Maiolica-type facies (white cherty limestones). The thickness is variable and ranging between 6 and 30 m, while the age is early Kimmeridgian-late early Tithonian.

"calcari nodulari ad aptici e **Saccocoma" informal member (APZ$_1$)**: nodular or incipiently nodular limestones and marly limestones, orange to reddish in colour and free of chert (Fig. 5H). Beds are thick (up to 60 cm) and display pressure-solution structures, as well as oxidised crusts. In the study area, these lithotypes partially or completely replace the "Calcari ad aptici e *Saccocoma*" facies. Faunal assemblage is dominated by cephalopods (ammonites – even though badly preserved -, belemnites, rhyncolites, aptychi) and crinoids (*S. tenellum* and *S. vernioryi*), associated with gastropods, brachiopods, foraminifers (thin-shelled *Globuligerina oxfordiana sensu* Giovagnoli and Schiavinotto, 1987), radiolarians, calcisphaerulids, undeterminable bioclasts, chitinoidellids and calpionellids (at the top of the unit). Ammonite phragmocones and brachiopods often present geopetal infillings, while the aragonitic shells are replaced by calcite coupled with glauconites. Bio-intraclastic floatstones/wackestones are the main observed textures. The stratigraphic boundary with the overlying Maiolica is placed with i) the disappearance of the nodular aspect, ii) the disappearance of *Saccocoma*, iii) the occurrence of chert and iv) the switch from orange bioclastic wackestones to white mudstones. This member crops out at Scalelle di Sopra, at Fosso del Molinaccio, at Fosso Fratta L'Aia, at L'Aspreta and at Ceccanibbio, and is from 2 to 25 m-thick. The age is late early Kimmeridgian-late Tithonian.

Maiolica (MAI): white to yellowish limestones with light grey to dark chert. Beds are thin (10-40 cm) and display stylolitic boundaries (Fig. 6A). Locally, MAI is dolomitised, displaying ankerite and dolomite crystals. Soft sediment deformations and lensoid lithoclastic breccias embedded in tabular strata were also found. The latter breccias are polygenic and characterised by clasts of the Jurassic and Lower Cretaceous units of the UMS sedimentary succession; in particular, elements referable to the Calcare Massiccio, to the Jurassic basinal and PCP-top deposits and to the Maiolica (with and without calpionellids) were observed embedded in a Maiolica-type matrix (Barremian in age - see Cipriani and Bottini, 2019a, 2019b for further details).

The palaeontological content of the Maiolica is characterised by calpionellids (in the lower part of the unit), dinoflagellate cysts, radiolarians, aptychi, crinoids, ammonites and planktonic foraminifers (at the top of the formation). Textures are bioclastic mudstones, rarely wackestones, and litho-bioclastic floatstones. This formation crops out along the southern and eastern slopes of Mt St Pellegrino (Scalelle di Sopra and Madonna del Lecino), in the Fosso Fratta L'Aia-Podere Casanova-Fosso del Molinaccio area, near Foce (Macchie di Ciambella and Casa Picchi localities), at L'Aspreta and at Ceccanibbio. Ammonite-rich facies forming coquina-like deposits with geopetal structures in their phragmocones were identified at L'Aspreta. Neptunian dykes made of Maiolica-type facies and cross-cutting the Calcare Massiccio occur near Fornole.

The passage to the younger Marne a Fucoidi is sharp and marked by the sudden occurrence of marls and shales. At Podere Casanova this formation laterally rests in angular unconformity on the MAS and on the POD$_1$. At L'Aspreta, the Maiolica bears lithoclastic breccias and onlaps the POD$_1$ and the APZ$_1$ through a high-angle erosional surface. The thickness of the unit is up to 66 m, while the age is late Tithonian-early Aptian *p.p.*

Marne a Fucoidi (FUC): polychrome shales passing upwards to thinly-bedded marls and marly limestones (Fig. 6B). A prominent black-shale horizon, indicating anoxic or dysoxic conditions, represents the OAE1a ("Selli Level" - Coccioni et al., 1987) and is associated with centimetric organic matter-rich horizons at different stratigraphic levels. The faunal association is dominated by planktonic foraminifers (hedbergellids, ticinellids, globigerinelloidids) and radiolarians; burrows (*Chondrites*, *Zoophycos*) are also common. The occurrence of chert nodules marks the boundary between the Marne a Fucoidi and the Scaglia Bianca formations (Petti, 2007). In the study area, however, the occurrence of chert is associated with a peculiar marl/limestone alternation. This alternation allows to define an informal lithofacies, easily recognisable on field, called *"Rocchette"* member (Cipriani, 2016). This member characterises the upper part of the Marne a Fucoidi.

Due to its rheology, the Marne a Fucoidi rarely is well-exposed. The best outcrops of this formation are at Madonna del Lecino, at Macchie di Ciambella, at L'Aspreta and at Ceccanibbio. The thickness of the unit is variable and reaches at maximum 15 m. The age is early Aptian *p.p.*-Albian *p.p.*

"Rocchette" **member (FUC$_1$)**: transitional interval between the Marne a Fucoidi and the Scaglia Bianca formations (Fig. 6C). Lithologically the member is represented by cyclic alternations of thin-bedded (up

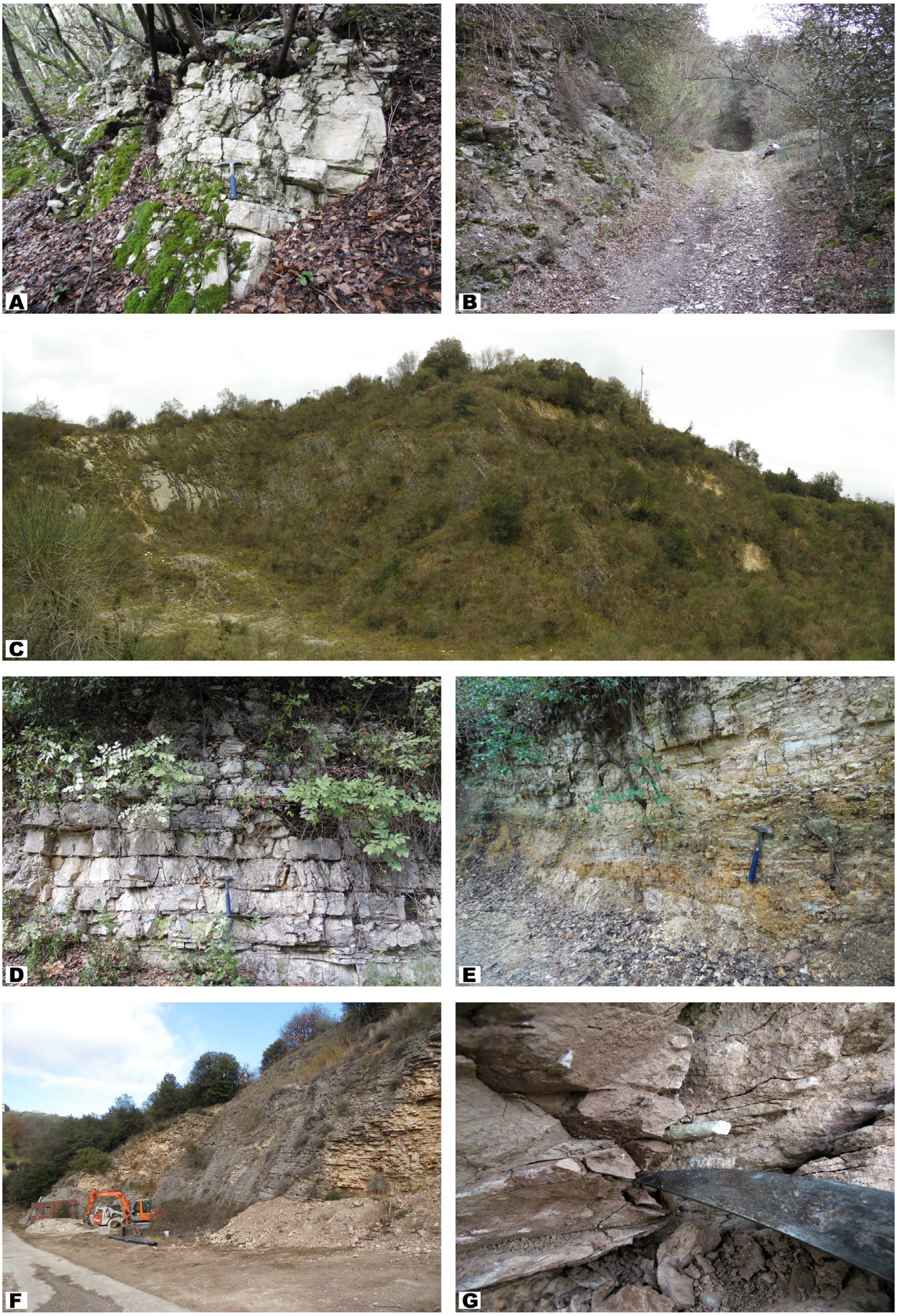

Fig. 6 – A) Well-bedded Maiolica exposed at Madonna del Lecino. B) Marly and, subordinately, marly limestones of the Marne a Fucoidi. Locality: L'Aspreta. C) Panoramic view of an abandoned quarry near Fornole, where the passage between the *"Rocchette"* member (left) and the Scaglia Bianca (right) is spectacularly exposed. Quarry front: about 30 m. D) Well-bedded limestones, bearing chert, of the Scaglia Bianca. Locality: Madonna del Lecino. E) Particular of the "Bonarelli Level" at the top of the Scaglia Bianca, exposed at Madonna del Lecino. Orange colours are due to oxidation of the organic matter-rich shales. F) Scaglia Rossa exposed in an anthropogenic cut near Fornole. Excavator size: about 3,5 m. G) *Chondrites* in the marls of the Scaglia Variegata at St Casciano.

to 15 cm) limestones, whitish in colour, and grey-green shales and marls (2-10 cm). Pink, brown, sometimes violet and dark chert is characteristic. The shales/ marls content decreases up-section and the definite disappearance of marly interbeds marks the passage to the above Scaglia Bianca. The fossiliferous content is characterised by planktonic foraminifers (*Biticinella breggiensis, Pseudothalmanninella ticinensis, Ticinella* spp., *Parathalmanninella apenninica*, *Planomalina buxtorfi*, *Thalmanninella globotruncanoides*, globigerinelloidids, hedbergellids, heterohelicids – *B. breggiensis, Ps. ticinensis, Pa. apenninica* and *Th. globotruncanoides* Zones *sensu* Premoli Silva and Sliter, 1999; Coccioni and Premoli Silva, 2015) and radiolarians; ichnofossils are abundant (*Thalassinoides, Chondrites, Planolites*). Locally, very thin (0,2-2 cm) graded and laminated calcarenites made of iso-oriented planktonic foraminifers were identified. Bioclastic mudstones and wackestones are the main textures, but grainstones/packstones occur.

At Madonna del Lecino, Fornole and L'Aspreta this unit is spectacularly exposed; other outcrops are near Capitone and at Macchie di Ciambella. At Podere Capalto (0,5 km NE of Amelia) this unit rests in angular unconformity on the Calcare Massiccio (Cipriani and Bottini, 2019b). This outcrop is the only one of the whole UMS domain, to date.

The thickness is about 25 m, while the planktonic foraminifer biostratigraphy allows to refer this unit to the upper Albian-Cenomanian *p.p.* interval.

Scaglia Bianca (SBI): white or pale limestones with grey/brown/black chert (Fig. 6D). This unit is well-bedded (10-20 cm) and its upper part is characterised by a 60 cm-thick, organic matter-rich, level made of black shales and chert. This level correlates with the "Bonarelli Event", an oceanic anoxic event (OAE2 – e.g. Premoli Silva et al., 1999) (Fig. 6E). About 1,5 m above the black shales, pink-red chert occurs marking the passage to the younger Scaglia Rossa. The textures are mudstones and wackestone with planktonic foraminifers (thalmanninellids and rotaliporids) and radiolarians.

This formation crops out spectacularly at Madonna del Lecino, Fornole and L'Aspreta and is 20 m-thick. The age is Cenomanian *p.p.*-earliest Turonian.

Scaglia Rossa (SAA): well-bedded (10-15 cm) limestones and marly limestones, yellowish/pink/red in colour, associated with pink/red chert in beds or nodules (Fig. 6F). Tabular strata are sometimes interrupted by soft-sediment deformations. Shallow water-derived, graded, calciturbidites were found. The lithoclasts and the loose shallow-water grains (*Orbitoides media*, *Siderolites* sp., *Cuneolina* sp., miliolids, fragments of rudists, gastropods, echinoderms, algae) were sourced from a productive carbonate platform (e.g. Latium-Abruzzi Platform) and were embedded in pelagic sediments dominated by planktonic foraminifers (marginotruncanids, dicarinellids, globigerinelloidids, hedbergellids, globotruncanids, morozovellids, globorotalids, acarinids), radiolarians, calcisphaerulids and rare brachiopods. The switch from "globotruncanids" to "globorotalids" allows to identify the terminal Cretaceous biotic crisis and the Cretaceous/Palaeogene boundary, easily recognisable also on field. The passage to the above unit is transitional and is marked by: i) the increase of terrigenous content, ii) the occurrence of grey-greenish colours and iii) the decrease of chert content.

This formation is well-exposed in the Narni-Madonna del Lecino area, at Fornole, at Ceccanibbio and at L'Aspreta. The thickness is more than 250 m, and the age is early Turonian-middle Eocene *p.p.*

Scaglia Variegata formation (VAS): thin (up to 10 cm) alternations of polychrome marls and marly limestones, with scarce pink chert. The siliciclastic component increases up-section to become predominant in respect to the calcareous one. Lithologically, the stratigraphic boundary with the younger Scaglia Cinerea is conventionally placed with the disappearance of the reddish colours. The palaeontological content includes planktonic foraminifers (*Globigerinatheka* spp., *Turborotalia* spp.) and radiolarians; fossil traces also occur (*Chondrites*) (Fig. 6G). Texturally are bioclastic wackestones/mudstones. This formation outcrops at St Casciano (*circa* 0,5 km W of Narni), is about 30 m thick and is middle-late Eocene in age.

Scaglia Cinerea (SCC): grey/greenish/brown shaly marls, marls and subordinate marly limestones in thin beds (Fig. 7A). Chert is missing. Due to Neogene tectonics and erosion, the stratigraphic passage to the overlying unit (Bisciaro) lacks. The fossils are, mainly, planktonic foraminifers (globigerinids) and ichnofossils (*Zoophycos, Chondrites*). This formation outcrops at St Casciano, is Oligocene in age and is more than 40 m thick. In the borehole 2A (Chiocchini et al., 1993) the Scaglia Cinerea was drilled for 141m.

Post-orogenic Unconformity-Bounded Stratigraphic Units

Tiber Basin Supersynthem

The Tiber Basin Supersynthem encompasses the Pleistocene continental deposits mapped in the study area unconformably resting on the pre-Pliocene bedrock. Three synthems were identified: the Chiani-Tevere, the Nera river and the Rio Grande river synthems. The main and oldest unconformity surface separates the Chiani-Tevere Synthem from the Meso-

Fig. 7 – A) Grey marls of the Scaglia Cinerea cropping out at St Casciano. B) Shales and loams bearing abundant invertebrate fauna (mainly gastropods and bivalves) of the Chiani-Tevere Synthem. Locality: cemetery of Amelia. C) Pleistocene sandy and loamy travertines (Chiani-Tevere Synthem) outcropping at Le Spiasce (1 km E of Amelia). D) Fluvial conglomerates bearing heterometric and sub-rounded pebbles/cobbles, associated with reddened palaeosoils. Locality: Fosso Fratta L'Aia. E) Clinobedded and poorly-cemented slope breccias. Locality. Le Rote.

Cenozoic bedrock. The latter surface displays a complex morphology made of low- to high-angle onlap surfaces on which rest the Pleistocene deposits. The Quaternary unconformity is locally marked by boring traces made by lithophagus molluscs, sponges and polychaetes, suggesting shallow-marine and coastal environments. According to Mancini et al. (2004), this unconformity corresponds to the first erosive event associated with the exhumation of the pre-Apennine in the latest Miocene-earliest Pliocene.
The Chiani-Tevere Synthem is bounded upwards by deeply-incised unconformity surfaces, covered by the fluvial deposits of the Nera River and Rio Grande River synthems. These surfaces are referable to cut and fill cycles and are Pleistocene-Holocene in age.
Chiani-Tevere Synthem (CHT): the deposits of this synthem surround the Meso-Cenozoic nucleus of the Narni-Amelia Ridge and are represented by Plio-Pleistocene marine to continental deposits in the southern part of the ridge (see Cipriani, 2016) and by Pleistocene continental deposits moving northwards (for further details, see Mancini et al., 2004). In the study area, a siliciclastic succession bearing calcareous beds was identified and mapped. Massive yellow-brown silty/shaly sands passing upwards to lead-grey shales rich in organic matter are the main facies (Fig. 7B). Cross-bedded, lens-shaped, conglomerates also occur. Embedded in the terrigenous rocks are stratified phytohermal travertines and sandy/loamy travertines, bearing molluscs (*Melanopsis affinis*, *Viviparus bellucci*, *Emmericia umbra, Planorbis* spp.). These travertinous beds are up to 20 m-thick (Fig. 7C). The faunal assemblage of the sandy and shaly facies is oligotypic and is dominated by brackish water taxa, mainly gastropods (*Melanopsis affinis, Bittium deshayesi, Potamides tricinctus, Thericium vulgatum, Trucalariopsis trunculus*) and bivalves (*Cerastoderma edule, Ostrea edulis*).
These deposits directly rest in angular unconformity on the Meso-Cenozoic carbonate bedrock or pass laterally to coarse-grained, cemented and polygenic, breccias draping the carbonatic ridge. The latter megaclastic deposits are made of calcareous clasts of the UMS succession and are the result of rock-falls from steep cliffs, forming rocky shore palaeobreccias. Based on the lithostratigraphic features, these lithotypes are comparable with the "*argille sabbiose del Chiani-Tevere*" *sensu* Ambrosetti et al. (1987) and the Chiani-Tevere fm. of Mancini et al. (2004).
The deposits of the Chiani-Tevere Synthem are more than 200 m thick in the study area and are early Pleistocene in age (Mancini et al., 2004).
Rio Grande River Synthem (RIO): these deposits characterise the upper left corner of the geological map, near Amelia and L'Aspreta. This synthem groups:

i) sandy/silty/shaly river-bed deposits. Locally, carbonatic cobbles and pebbles form imbricated conglomerates (RIO_1). These deposits are Holocene in age;
ii) Holocene lacustrine silty/shaly deposits (RIO_2);
iii) terraced deposits made of lens-shaped conglomerates incising flood-plain shales and sands (RIO_3). The age is Pleistocene *p.p.*-Holocene.

Nera River Synthem (NER): deposits referable to this synthem characterise the Narni area, in the lower right corner of the geological map. In this synthem are grouped in-channel deposits (NER_1), alluvial deposits (NER_2) and talus breccias covering the cliffs of the Nera Gorge (NER_3). In particular:

i) NER_1 are in-channel silty-to-coarse sands with pebble-rich lenses that incise
ii) terraced, fine-grained (sands, loams and shales) deposits of flood plain with imbricated cobbles in erosional lenses (NER_2) (Fig. 7D). Interdigitate with the terraced deposits are
iii) heterometric, massive rudites with poorly rounded to angular carbonate clasts and red sandy-clayey matrix, cemented by freshwater carbonates. These coarse-grained deposits form thick talus at the toes of the Nera gorge rocky cliffs resulting from abundant rock-fall events and rest directly on the Meso-Cenozoic rocks of the Narni-Amelia Ridge (NER_3).

The thickness of this synthem deposits ranges from 0 to 30 m, while the age is Pleistocene *p.p.*-Holocene.
Eluvium-colluvium and "*terre rosse*" (olo): loams, sands and lateritic soils embedding clasts of the parent bedrock. These deposits rest through erosional surfaces on the carbonate bedrock and are up to few metres thick. The age is Pleistocene-Holocene.
Slope breccia (br): weakly-cemented and massively-bedded, heterometric, talus deposits with red sandy-clayey matrix. These deposits rest through erosional surfaces on the carbonate bedrock and are up to few metres thick. The age is Pleistocene-Holocene.
Scree (a): unconsolidated or very-poorly cemented breccias and conglomerates, made of carbonate clasts in reddish sandy and silty matrix (Fig. 7E). These deposits are clinobedded, rest trough erosional surfaces on older deposits and reach up to 20 m of thickness. The age is Holocene.

Tectonics

At least four main tectonic events were identified in the study area, according with regional studies: i) the Hettangian rift-related extensions (*sensu* Santantonio and Carminati, 2011); ii) the Barremian post-rift extensional phase (*sensu* Cipriani and Bottini, 2019a, b); iii) the Miocene orogenetic phase and; iv) the Pliocene post-orogenic normal faulting (*sensu* Ambrosetti et al., 1987). Moreover, strike-slip faults were mapped.

Even though there is no direct evidence for Mesozoic palaeofaults (both, Hettangian and Barremian), in this part of the Narni-Amelia Chain the effects of the Western Tethys rifting are clear. The presence of Jurassic basinal units of the UMS succession onlapping the Calcare Massiccio as pre-rift bedrock exposed along submarine fault-related escarpments allows to identify several PCPs (Mt St Pellegrino, Mt Arnata-Fornole, Le Rote and Amelia PCPs) surrounded by deeper water basins bearing Calcare Massiccio-made megaclastic deposits (Narni, Foce and L'Aspreta basins). Stratigraphic and sedimentological evidence for late Early Cretaceous synsedimentary tectonics is the angular unconformity between Lower Jurassic deposits (i.e. Calcare Massiccio and Corniola formations) and uppermost Lower Cretaceous facies (Maiolica and Marne a Fucoidi formations), mapped at Podere Capalto (Amelia) and L'Aspreta. Other supporting data for synsedimentary tectonics are the occurrences of lithoclastic and polygenic breccias embedded in the Maiolica (L'Aspreta and Podere Casaglia) and of slumps as well (Madonna del Lecino). According to Cipriani and Bottini (2019a, 2019b), this extensional tectonic phase rejuvenated the evened-out Jurassic rift architecture, affecting the margins of buried PCPs. Tracts of Jurassic escarpments were exhumated and backstepped by gravity-driven collapses, causing the accumulation of mass-transport deposits at their base. The exposed parts of the Cretaceous escarpments were, then, onlapped by younger post-Barremian deposits.

Contrarily, the Miocene deformations could be easily observed. Two main tectonic units bounded by a regional compressive shear zone, the Narni thrust (*sensu* Calamita et al., 1996), were identified. These tectonic units are highlighted in the structural scheme of the geological map.

The upper tectonic unit ("Hangingwall Block of the Narni Thrust" in the structural scheme of the geological map) characterises the Narni-Madonna del Lecino area, albeit if displaced by younger Pliocene normal faults. Here, the Calcare Massiccio overthrusts an overturned Jurassic and Cretaceous pelagic succession (Fig. 8A). The main thrust is associated with several splays that displace the overturned limb of the footwall syncline (St Casciano syncline). These minor faults form duplex structures that overthrust the normal limb of the syncline. In the Narni-St Casciano area the hangingwall-block Calcare Massiccio overthrusts the normal flank of the footwall syncline as well. This down-section propagation of the hangingwall block suggests an out-of-sequence reactivation of the Narni thrust, as also noted by Calamita et al. (1996) and Boncio et al. (2000). Another notable feature is the variation in dip direction of the NW-trending thrust fault. In its western outcrops the compressive lineament dips towards SW by about 30°, while at Narni is ENE-dipping by about 20°. The St Casciano footwall syncline (and the associated mesoscale folds affecting the thinly-bedded Cretaceous-Oligocene pelagites) presents an ENE-dipping axial plane. That is a notable feature, the vergence towards WSW being opposite to the transport direction (towards NE) of the Narni thrust (and of the whole Apenninic fold-and-thrust belt).

The lower tectonic unit ("Footwall Block of the Narni Thrust" in the structural scheme of the geological map) includes part of the Narni Mts and the whole studied Amelia Mts, and is bounded downwards by a buried thrust fault. The Meso-Cenozoic rocks of this unit are folded and, locally, displaced by small thrusts. One of these compressive shear zones was mapped at Mt St Pellegrino, where a plane dipping towards W by 43° overthrusts the "Calcari e Marne a *Posidonia*" on the "*calcari nodulari ad aptici e* Saccocoma" informal member (Fig. 8B).

South of Amelia a N-dipping compressive structure causes the juxtaposition of the Calcare Massiccio on the Corniola, describing a S-verging footwall syncline (Fig. 8C). Oblique slickenslides (pitch angles of 45°) suggest a dextral polarity of the transpressive fault.

Intriguing is the case of Podere Casanova, where a Calcare Massiccio olistolith and the onlapping condensed-like succession overthrust Upper Cretaceous pelagic units. This shear zone is NE-verging and is bounded NW-wards and SE-wards by two opposite lateral ramps (SE- and W-dipping, respectively).

Strike slip-dominated faults, both NE- (anti-apenninic) and NW- or NNW-trending (apenninic), were mapped. The main anti-apenninic transcurrent fault is the about 3 km-long Fornole-Mt Arnata discontinuity. This sub-vertical shear zone shows right-lateral cinematic and causes the tectonic contact between the Calcare Massiccio and the Corniola. Locally, this lineament is displaced by younger, Pliocene, normal faults.

NW-SE-trending strike-slip faults occur at Capitone and at Macchie di Ciambella. In both the cases, these structures form negative flower structures and cause the contact between Cretaceous pelagic deposits and Upper Triassic-Lower Jurassic ones. These relationships were interpreted as due to transtensive strike-slip duplexes *sensu* Woodcock and Fisher (1986).

The Narni-Amelia Ridge represents the eastern boundary of the Paglia-Tevere Graben (related to the opening of the Tyrrhenian Sea as back-arc basin – e.g. Doglioni, 1991) and the western boundary of the Terni Basin (a Quaternary intermountain basin

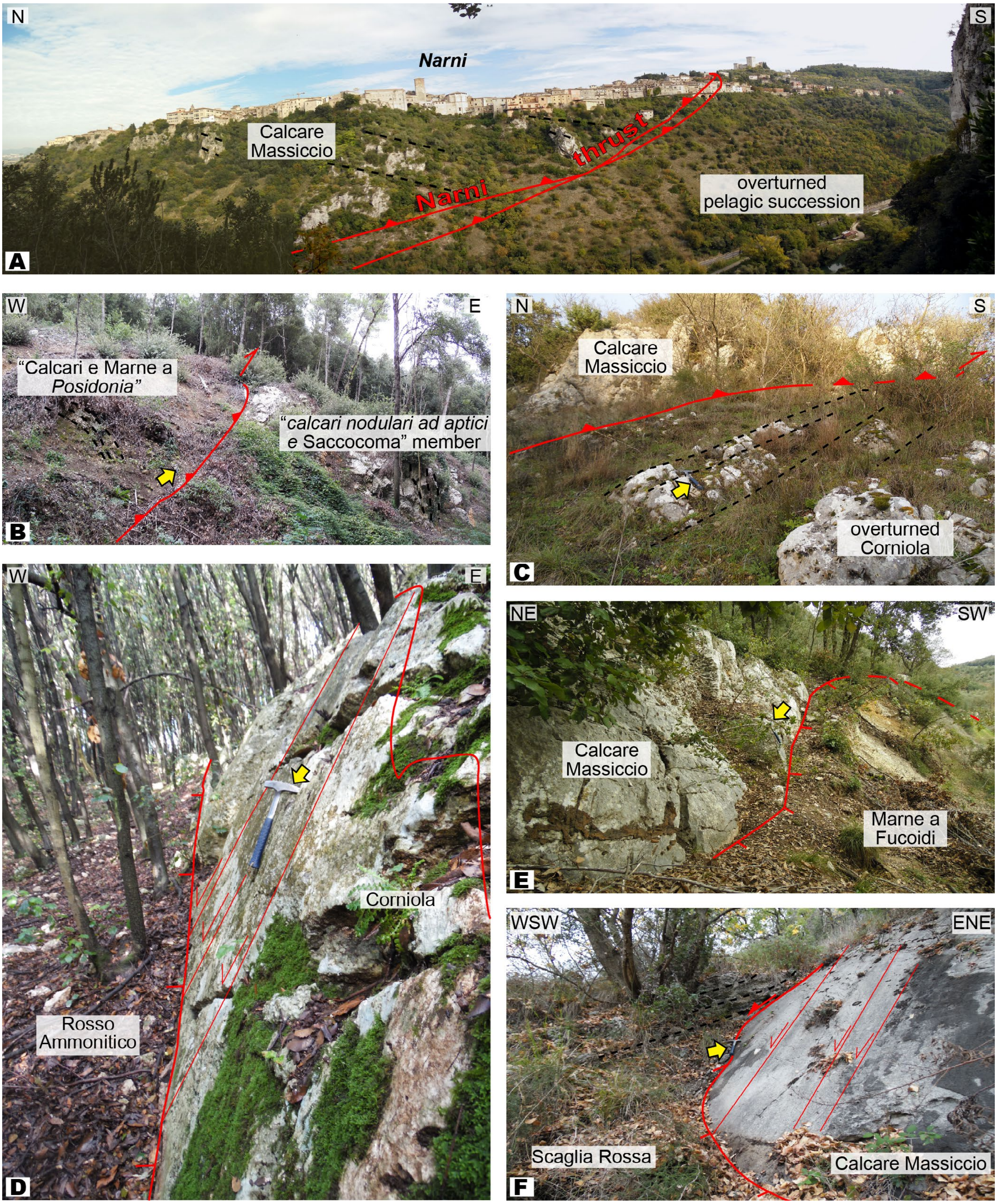

Fig. 8 – A) Panoramic view of the Narni thrust, spectacularly exposed in the Nera Gorge. This picture represents a length of approximately 1 km. B) "Calcari e Marne a *Posidonia*" over-thrusting the *"calcari nodulari ad aptici e* Saccocoma" informal member at Scalelle di Sopra. C) Outcrop view of the Amelia ramp, which causes the juxtaposition of the Calcare Massiccio on the overturned Corniola beds. D) Mt St Pellegrino – Foce fault outcropping at Fosso del Molinaccio and displacing the Rosso Ammonitico on the calciclastic facies of the Corniola. E) Eastern boundary of the Amelia - Macchie fault system, characterised by a SW-dipping normal faults which downthrows the Marne a Fucoidi on the Calcare Massiccio. Locality: Fornaci di Fornole. F) Scaglia Rossa displaced on the Calcare Massiccio at Podere Casanova. Arrowed hammer for scale.

– e.g. Cattuto et al., 2002). As a result, this chain is pervasively dissected by Plio-Pleistocene normal faults (e.g. Ambrosetti et al., 1978; 1987). These NNW- and NW-trending conjugated structures form extensional systems, the mains of which are evidenced in the structural scheme of the geological map.

The St Casciano – Capitone fault system is the easternmost. This system is made of high-angle ENE-dipping normal faults displacing the Narni thrust and its footwall syncline.

Characteristic is the Mt St Pellegrino – Foce fault (Fig. 8D), which displays notable dip azimuth variations (from S- to W-dipping), as well as "apparent" along-strike amount of displacement changes. In fact, this W- to N-trending structure locally downthrows the Jurassic-Cretaceous pelagic units on the Calcare Massiccio, locally displaces the Calcare Massiccio.

Moving towards W, a complex system of synthetic and antithetic faults characterises the Madonna del Lecino-Fornole – L'Aspreta system. As the Mt St Pellegrino-Mt Arnata fault, this NW- to NNW-trending system shows along-strike variations in displaced units, mainly down-throwing the Cretaceous pelagic units on the Corniola and the Calcare Massiccio (Fig. 8E, F).

The Amelia – Macchie fault system is the westernmost of the study area and is characterised by two main NW-trending antithetic faults. Even though these lineaments are almost buried by the Pleistocene deposits of the Chiani-Tevere Synthem and by the Holocene fluvio-lacustrine deposits of the Rio Grande Synthem, the hangingwall block outcrops in the Fosso delle Streghe (0,5 km E of Ceccanibbio). Here, the Cretaceous deposits of the Marne a Fucoidi plus Scaglia *s.l.* are juxtaposed with the Jurassic ones.

Discussion and Conclusions

New cartographic, stratigraphic and structural elements from an under-investigated sector of the Apenninic Chain are here provided. Field-work was mainly focused on the Mesozoic rocks and was aimed at reconstructing the Jurassic rift-related palaeotectonic setting. A better definition of the Jurassic-Cretaceous palaeogeography allows to constraint the Meso-Cenozoic tectonic and stratigraphic evolution of the whole study area, it being influenced by rifting heterogeneities. The effects of the Hettangian rifting in the Narni-Amelia Ridge are clear (see also Cipriani, 2016) and marked by facies and thickness variations of the Jurassic rocks. Lacking PCP-top condensed successions due to Mio-Pliocene tectonics and Quaternary erosion, the basin-margins analysis allowed to define the complex Jurassic palaeogeography made of several PCPs flanked by deeper basins (Cipriani and Santantonio, 2016; Cipriani, 2017). The Jurassic onlap successions display anomalous facies and thickness in respect to the classical basinal units. Pinch-out towards the basin margins causes thinning from 600 m (pure basinal succession – e.g. Cecca et al., 1990) to about 200 m of the Lower Jurassic to Lower Cretaceous pelagic deposits. The already thin onlap successions bear huge Calcare Massiccio olistoliths (up to 200 m in diameter) detached from the submarine margins of structural highs (e.g. Galluzzo and Santantonio, 2002). Due to their volumes, these boulders acted as morphological highs in basinal settings, inducing geometrical and facies variations in pelagic deposits. The latter are comparable at all with those of PCP settings and are represented by the condensed-like facies mapped in the study area (Cipriani and Santantonio, 2016). These thin and fossil-rich successions accumulated in basinal settings. As a result, these condensed-like basinal successions were previously mis-interpreted as PCP-top successions (e.g. Podere Casanova olistolith vs. Fornole structural high in Boncio et al., 2000). Since these condensed-like facies assume an important palaeogeographic meaning, were lithostratigraphically differentiated as informal members from their pure basinal, formation-rank, parents.

Fine-grained calcarenites made of shallow water-derived material were found embedded in the upper Pliensbachian-Bajocian part of the basin-fill succession in the eastern sector of the study area (Foce). This occurrence is unexpected as these deposits postdate the drowning of the local Calcare Massiccio carbonate platform, which suggests provenance from the Latium-Abruzzi Platform. This provides new evidence for restoring the Jurassic palaeogeography of Central Apennines, and for deciphering the itineraries of resedimented carbonate sands from this relatively distant source-area (Cipriani et al., 2016b).

Evidence for an Early Cretaceous extensional tectonic phase, which is well-documented in the southern part of the Narni Ridge (Cipriani and Santantonio, 2014; Cipriani, 2016; Cipriani and Bottini, 2019a, 2019b), was also recognised in the Amelia area (Cipriani and Santantonio, 2016). Here the Marne a Fucoidi (Aptian-Albian) rests unconformably on the Hettangian shallow-water carbonates of the Calcare Massiccio and on the Corniola formations (Podere Capalto - Amelia). This angular unconformity was interpreted as a result of rejuvenation and erosion of the Early Jurassic margin of the Amelia intra-basinal high during the late Early Cretaceous. In support of this synsedimentary tectonics are the occurrence of slumps and clastic facies embedded in the Maiolica and Marne a Fucoidi formations, reported for the first time by Fazzini (1968, p. 454).

According to Cello et al. (2000), development and propagation of Miocene compressive deformations were controlled by inherited Mesozoic elements (i.e. horst-blocks, palaeoescarpments, olistoliths). In particular, the Jurassic structural highs characterise the hangingwall blocks of the thrusts over-thrusting the surrounding basinal successions and their margins are usually displaced with small shortening amounts by frontal thrusts or lateral ramps (Bollati et al., 2012; Cipriani, 2016). This is clear near Amelia, where the southern margin of the homonymous PCP overthrusts through a lateral ramp onto basin-fill succession onlapping it. Contrarily, the NE-trending, right-lateral strike slip, Fornole-Mt Arnata fault represents a tear faults of the basal, buried, thrust of the lower unit acting along an inherited discontinuity. This shear zone displaces the SE-facing margin of the Jurassic Fornole-Mt Arnata PCP, juxtaposing the horst-block Calcare Massiccio with the onlap succession.

The shear contacts, overprinting the original stratigraphic contacts, between the Calcare Massiccio olistoliths and the embedding pelagites are related to the contrasting mechanical behaviour between the well-bedded pelagites and the Calcare Massiccio boulders during buttressing-related folding (Bollati et al., 2012; Cipriani and Santantonio, 2014, 2016; Cipriani, 2016).

Folded and thrusted Meso-Cenozoic rocks were later dissected by Pliocene normal faults and unconformably covered by the post-orogenic sedimentary cycle.

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