Journal of Maps

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ISSN: (Print) 1744-5647 (Online) Journal homepage: http://www.tandfonline.com/loi/tjom20

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JOURNAL OF MAPS, 2016
http://dx.doi.org/10.1080/17445647.2016.1211896

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SCIENCE

Geology of the Mt. Cosce sector (Narni Ridge, Central Apennines, Italy)

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ABSTRACT

This paper is companion to a 1:15,000 scale geological map of the southern sector of the Narni Range in Central Italy. This sector of the Apenninic Chain was affected by the western Tethyan rifting stage during the Early Jurassic, and the inherited architectural setting in turn influenced the Mesozoic stratigraphy and the Neogene-Quaternary tectonic evolution of the area. Based on stratigraphic and structural field evidence, a Jurassic structural high has been identified in the Mt. Cosce sector, flanked northward and westward by deeper basins. The basin that had to exist to the east, as well as the top of the horst-block, cannot be observed due to recent erosion and orogenic deformation. The western margin of the Mt. Cosce High was rejuvenated during an extensional tectonic phase which took place in the late Early Cretaceous. This syn-sedimentary faulting is reported in this area for the first time, and is documented by a sedimentary breccia (Mt. Cosce Breccia) resting unconformably on the Jurassic footwall-block.

ARTICLE HISTORY
Received 1 February 2016
Revised 9 June 2016
Accepted 29 June 2016

KEYWORDS
Geological mapping; Umbria–Marche–Sabina Succession; Jurassic architecture; Early Cretaceous tectonics; Narni Ridge; Central Apennines

1. Introduction

A number of previously unreported tectono-stratigraphic features were identified through a geological mapping project covering the southern part of the Narni Ridge, in the Central Apennines (see Main Map) (Figure 1). The analyzed sector represents the westernmost and structurally highest unit of the 'Umbro-Sabine pre-Apennine' (Bigi, Mandrone, Pierantoni, & Rossi, 2000), with a typical NW–SE trend, and is characterized by a sedimentary succession of the Umbria–Marche–Sabina (UMS) type (Figure 2) (see Galluzzo & Santantonio, 2002 and references therein for further information). This consists of Meso-Cenozoic calcareous-marly-siliceous lithologies overlying shallow water carbonates (Calcare Massiccio Fm., Hettangian). The multilayer stratigraphy was deformed by thrust-and-fold propagation during the Neogene (e.g. Calamita & Pierantoni, 1996; Doglioni, 1991) and by normal faults related to the formation of the 'Paglia-Tiber Graben' since the late Early Pliocene (Ambrosetti et al., 1987; Mancini, Girotti, & Cavinato, 2004).

The Narni Range is a somewhat under-investigated area in the region, with the exception of a limited number of papers, mainly focused on the structural geology (e.g. Boncio, Brozzetti, Lavecchia, Bacheca, & Minelli, 2000 and references therein; Calamita, Pierantoni, & Pontoni, 1996 and references therein; Chiocchini et al., 1975; Conforto & Parboni, 1963; Lotti, 1902, 1903; Rau, 1962; Storti & Salvini, 2001; Verri, 1886). Based on a new data set of stratigraphic and structural field evidence, the Meso-Cenozoic paleogeographic and paleotectonic evolution of the area can now receive a partly novel interpretation. New insights come from an analysis of the relationships existing between the inherited architecture and the Neogene-Quaternary extensional deformation involving this sector of the Apennines.

2. Methods

Field mapping was performed on the 1:10,000 scale CTR (*Carta Tecnica Regionale*) of the Umbria and Latium regions (available online), covering an area totaling about 50 km^2. The classical field methods of geological mapping were used, along with dedicated methods made necessary by the peculiar paleotectonic architecture of the region (e.g. Fabbi, 2014; Galluzzo & Santantonio, 2002).

The mapping of unconformities, and identification of diagenetic features typical of bedrock exposure at the sea-bottom and subsequent burial (e.g. silicification; Santantonio, Galluzzo, & Gill, 1996), combined with facies associations analysis (*sensu* Santantonio, 1993, 1994) of the Jurassic-Lower Cretaceous deposits, revealed the geometries and architecture of the local depositional system during the Mesozoic. The classic stratigraphy of the UMS Succession was utilized, albeit with a few departures, as suggested by Galluzzo and Santantonio (2002). The Middle-Upper Jurassic pelagites should formally be labeled the Calcari Diasprigni Fm., based on the distinctive abundance of chert, and subdivided in two members: the 'selciferous member'

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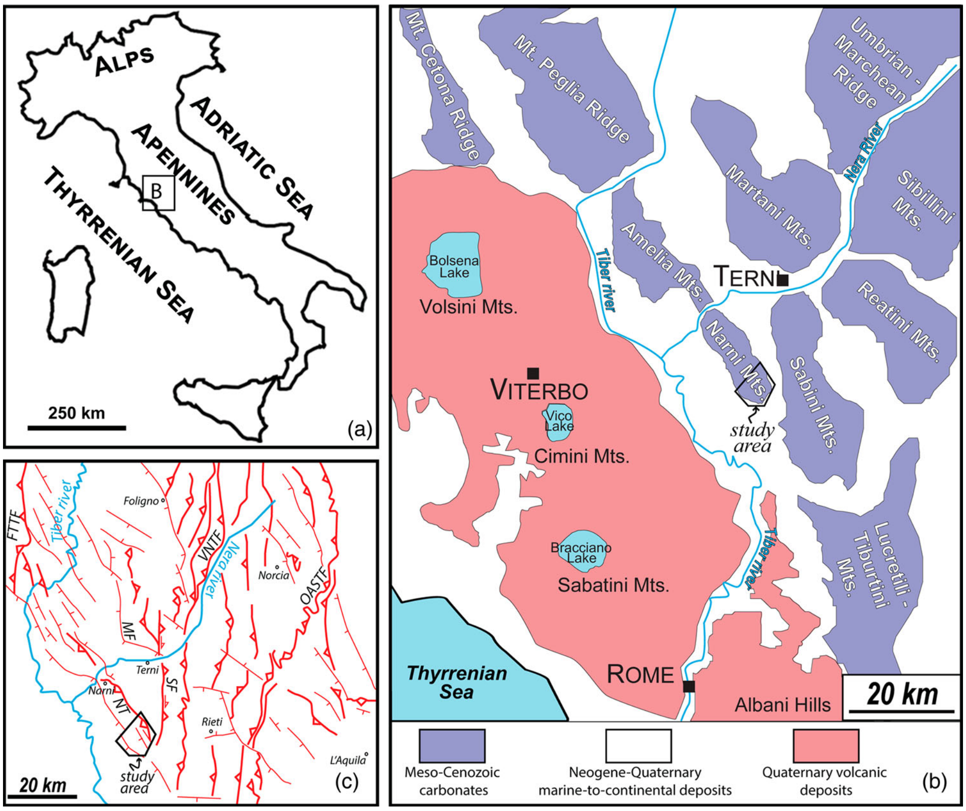

Figure 1. (a, b) Regional overview of the study area. (c) Simplified structural scheme of the Central Apennines. FTTF: Falterona-Trasimeno Thrust Fault; NT: Narni Thrust; MF: Martana Fault; SF: Sabina Fault; VNTF: Val Nerina Thrust Fault; OASTF: Olevano-Antrodoco-Sibillini Thrust Fault (modified from Bigi et al., 2000).

and the 'Calcari a *Saccocoma* e aptici member' (Cita et al., 2007). Galluzzo and Santantonio (2002) subdivided the cherty interval into three lithofacies based on the lithogenetic role played by the faunal components ('pelagic bivalves', radiolarians, crinoids and cephalopods, respectively) and practicability in the field: a lower lithofacies corresponding to the uppermost part of the 'Calcari e Marne a *Posidonia* Fm.', followed by the 'Calcari Diasprigni *s.s.*' and then by the 'Calcari ad aptici e *Saccocoma*'. Another exception is represented by an informal member, called the 'Rocchette' member, between the Marne a Fucoidi Fm. and the Scaglia Bianca Fm. This can be easily identified in the field on lithological grounds, and mapped accordingly due to its thickness (tens of meters).

3. Lithostratigraphy of the Mt. Cosce area

In this section the stratigraphic and sedimentological features of the outcropping units will be described, along with a brief outline of the facies.

Calcare Massiccio Fm. According to Cita et al. (2007), the Calcare Massiccio Fm. is subdivided into three members: 'Calcare Massiccio A', 'Calcare Massiccio B' and 'Calcare Massiccio C' (Centamore, Chiocchini, Deiana, Micarelli, & Pieruccini, 1971; Fabbi & Santantonio, 2012; Galluzzo & Santantonio, 2002; Marino & Santantonio, 2010; Morettini et al., 2002).

'*Calcare Massiccio A*' *member* (?Rhaetian/Hettangian-Sinemurian *p.p.*). White, grey and light brown massive or thickly bedded limestones and dolostones indicating shallow water carbonate platform conditions. Shallowing-upward cycles with oncoidal and peloidal wackestones to grainstones (Figure 6(a)), homogeneous mudstones-wackestones, *fenestrae*-rich levels, cryptalgal laminites, paleokarst breccias and vadose pisoids within reddish horizons, testify to deposition on a peritidal platform, subjected to episodic subaerial exposure (Figure 3(a)). The Calcare Massiccio is normally a chert-free carbonate limestone, but in some localities chert nodules and crusts occur (silicification). The silicification of the Calcare Massiccio is a clue for the Jurassic basin-margin analysis, and is related to the unconformable contacts of the peritidal facies with cherty pelagic units, as a result of the through-flow of silica-rich diagenetic fluids (Santantonio et al., 1996) (Figure 3(b)). This is the oldest unit exposed in the area. Its base, and passage to the underlying Mt. Cetona Fm. (Ciarapica, Cirilli, & Passeri, 1982), is not exposed such as its top. The minimum thickness of the unit has been evaluated in cross-section, and is approximately 600 m.

'*Calcare Massiccio C*' *member* (Hettangian/Sinemurian boundary). This lithofacies is characterized

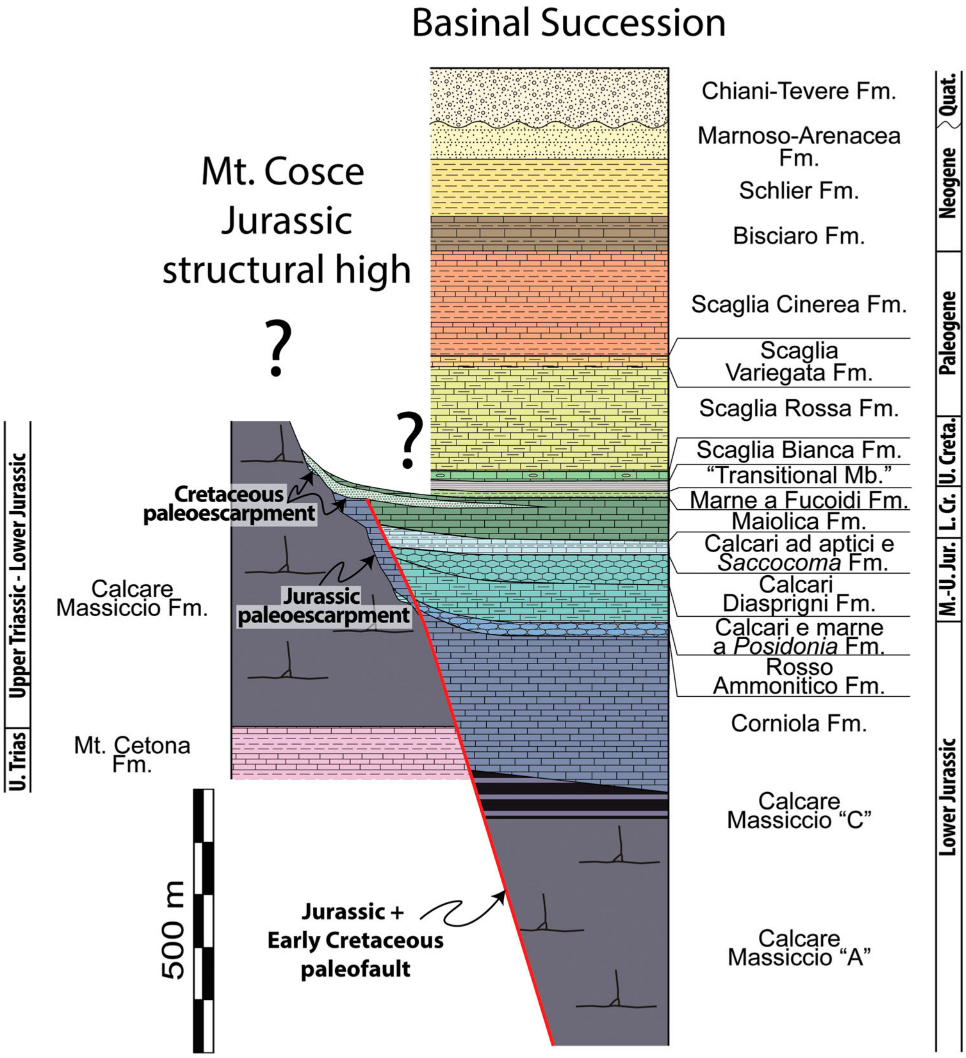

Figure 2. Stratigraphic setting and sedimentary succession of the study area.

by muddy textures with both benthic biota (gastropods, brachiopods, echinoderms and large algal oncoids, >2 cm in diameter) and pelagic elements (radiolarians) and benthic organisms typical of pelagic deposits (siliceous sponge spicules) (Figures 3(c) and 6(b)). Defined by Marino and Santantonio (2010) as the 'drowning succession' of the hanging wall blocks during the Jurassic rifting, this lithosome was deposited in a subtidal ramp setting. The thickness of this lithofacies ranges from 50 m to about 100 m (Cima Testone).

'*Calcare Massiccio B' member* (Sinemurian *p.p.*-early Pliensbachian; Morettini et al., 2002). White to light brown bioclastic packstones and wackestones, sometimes floatstones. A benthic fauna with brachiopods (Terebratulidae and Rhynchonellidae), crinoid fragments, gastropods, calcareous sponges (Sphinctozoa), benthic foraminifers (valvulinids and *Agerina martana*) and assorted products of the benthic carbonate factory (micro-oncoids and peloids) is associated with siliceous sponge spicules, radiolarians and ammonites (Figures 3(d–e) and 6(c)). This lithofacies, interpreted as the 'drowning succession' of structural highs (Marino & Santantonio, 2010), can be observed in the northern slopes of Mt. Cosce and in the Cima Boschetto area, forming thin discontinuous patches resting unconformably on the pre-rift bedrock. The thickness cannot be estimated.

Corniola Fm. (Sinemurian *p.p.*-Toarcian *p.p.*). Light grey-brown grainstones to mudstones and marly limestones, rich in grey chert. The background sedimentation is typically pelagic, with radiolarians, siliceous sponge spicules, benthic foraminifers and ammonites. The Corniola Fm. occupies a vast area of the analyzed sector, and can be subdivided in four different lithofacies: (i) a clastic lithofacies, overlying the Calcare Massiccio C, in which chert is missing and gravity flow deposits are dominant, bearing peloids, benthic forams, fragments of algae, mollusks and echinoderms. These deposits make up thick beds, often graded. Megabreccias and olistoliths of Calcare Massiccio are frequent (Figure 3(g)); (ii) a micritic, chert-rich pelagic lithofacies; (iii) a red, marly nodular interval with red chert. Burrows and ammonites are common, such as crinoid fragments. The thickness of this lithofacies is about 8 m at Colle Petrucciano, while it is about 3 m near Configni; (iv) the uppermost lithofacies, transitional to

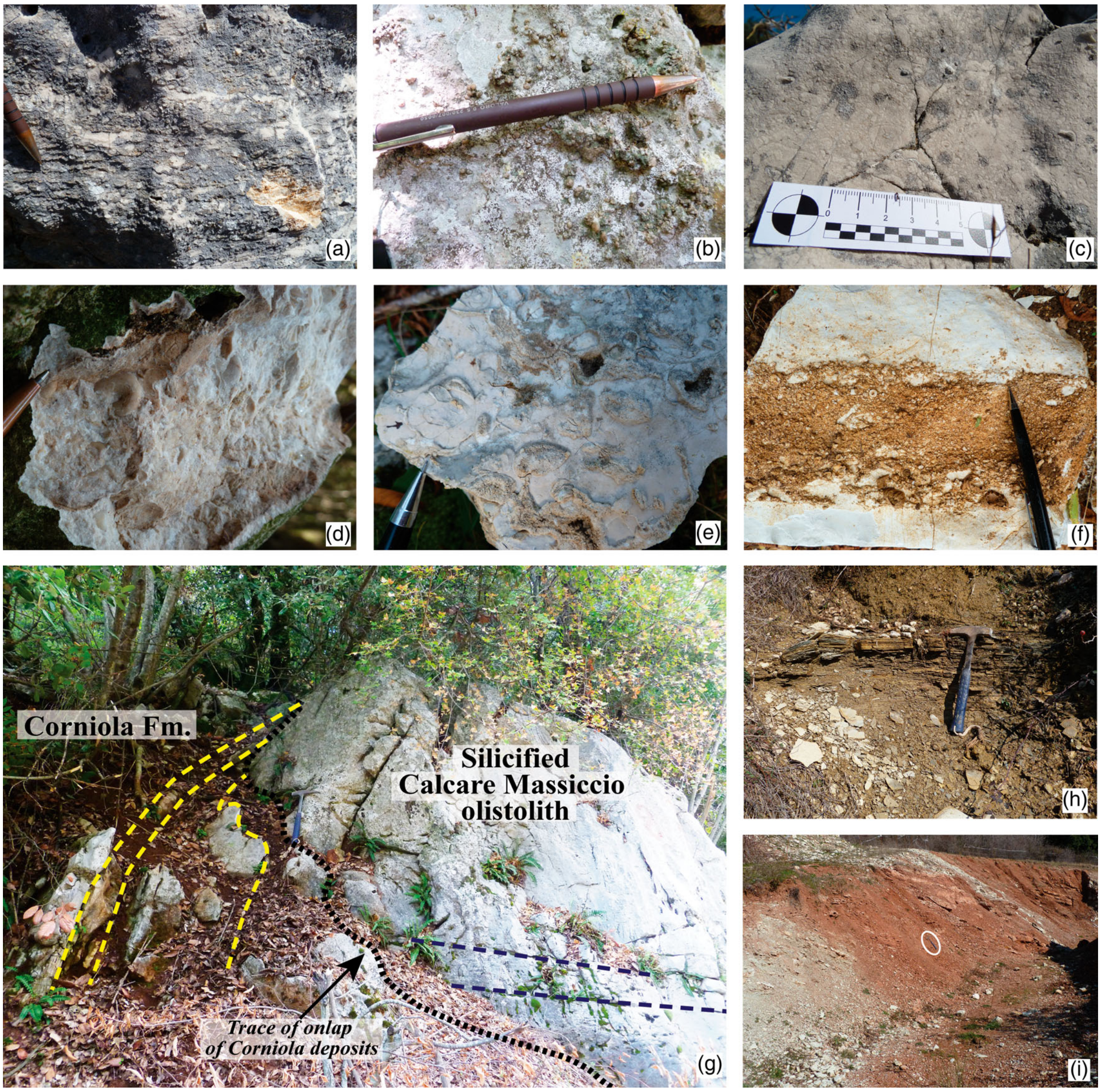

Figure 3. Field view of the stratigraphic units described in the text: (a) fenestral facies of the Calcare Massiccio Fm. (Piano Lago); (b) typical aspect of silicified Calcare Massiccio, made of small-size chert nodules and representing Jurassic paleosurfaces; (c) Calcare Massiccio C member (Cima Testone); (d) ammonite-bearing Calcare Massiccio B (Cima Boschetto); (e) brachiopods-rich lithofacies of the Calcare Massiccio B (Piano Lago); (f) Coarse-grained, graded gravity-driven encrinites interbedded in the Corniola Fm. (Configni); (g) Calcare Massiccio olistolith embedded in the Corniola Fm. (Colle Prata, see hammer for scale); (h) organic-rich black shales referable to the Early Toarcian Anoxic Event (OAE1) (Casal Monastero, about 3 km NW of Vacone); (i) Rosso Ammonitico Fm. (Casal Monastero, see hammer for scale).

the Rosso Ammonitico Fm., is made of greenish-grey to purple marls and shales interbedded with light brown limestone, with nodules of dark chert and oxidized ammonites. This last lithofacies near Configni is replaced by chert-free brown-to-light orange limestones, rich in ammonites and bearing graded encrinites (Figure 3(f)). The thickness of the unit is about 400 m.

Rosso Ammonitico Fm. (Toarcian *p.p.*). This unit can be subdivided in two lithofacies: (i) the lowermost lithofacies, made of gray-greenish marls and shales bearing a black shale interval 0.4 m thick which outcrops in the Mt. Pizzuto area, and referable to the Early Toarcian Oceanic Anoxic Event (Jenkyns, 1985) (Figure 3(h)). This lithofacies, which is about 1.5 m thick near the village of Configni and reaches about 4 m at Mt. Pizzuto, is correlatable as a whole with the Marne del Monte Serrone Fm. (Pialli, 1969); (ii) the Rosso Ammonitico *s.s.*, represented by bioturbated red and green nodular marls and shales, bearing ammonites and thin-shelled bivalves (Figures 3(i) and 6(d)). Chert is missing throughout the unit. The total thickness of the Rosso Ammonitico Fm. is 23 m in the northern part of the analyzed sector, while in the western sector of the Narni Range it exceeds 30 m.

Calcari e Marne a Posidonia Fm. (Toarcian *p.p.*-? Bajocian *p.p.*). Alternations of yellow-greenish limestones and purple/red-green marls, sometimes nodular and ammonitiferous, followed by chert-rich green limestones with green shales. The texture is mainly a wackestone, with occasional laminated packstone-grainstone with iso-oriented posidoniids (Figures 4(a)

Figure 4. Field view of the stratigraphic units described in the text: (a) gravity-driven, laminated Calcari e Marne a *Posidonia* facies, made of iso-oriented shells of posidoniid bivalves; (b) Folded Calcari Diasprigni Fm. (Rocchette, see hammer for scale); (c) ammonite-bearing, pseudonodular marly limestones of the Calcari adaptici e *Saccocoma* Fm. (Colle di Lugnola); (d) Maiolica Fm. (2 km NW of Colle di Lugnola, see hammer for scale); (e, f) heterometric clastic deposits of the 'Mt. Cosce Breccia'; (g) unconformable contact between the Mt. Cosce Breccia and the horst-block Calcare Massiccio, exposed in the north-eastern slopes of Mt. Cosce near the Vorgone locality (500 m NE of Cima Fosso d'Iselmo, see hammer for scale).

and 6(e)). Beds are up to 20 cm thick, and the faunal assemblage is essentially made of thin-shelled posidoniid bivalves (*Bositra buchii* and *Lentilla humilis*; Conti & Monari, 1992), radiolarians and rare ammonoids. The stratigraphic boundary with the underlying unit is conventionally placed at the lowest occurrence of chert, while the passage to the overlying unit is placed at the disappearance of posidoniids. The thickness of the unit is about 60–70 m.

'*Calcari Diasprigni*' *Fm.* (?Bajocian *p.p.*/Bathonian-early Kimmeridgian; Bartolini, Baumgartner, & Hunziker, 1996). Polychrome radiolarian cherts and subordinately cherty limestones are with thin (1–2 cm) interbeds of green shales. Up to 10 cm thick-beds are tabular or alternatively show 'pinch and swell' geometries (Figure 4(b)). The texture is mainly a mudstone, rarely wackestone. This silica-rich event is related to paleoclimatic, paleoceanographic and paleotectonic changes, which caused an increase in fertility within the upper water column (Baumgartner, 2013). No macrofossils are generally observed in this unit, as the faunal assemblage is dominated by radiolarians. The thickness is about 60 m.

'*Calcari ad aptici e* Saccocoma' *Fm.* (early Kimmeridgian-late early Tithonian). Thin-bedded yellow-to-greenish limestones and marly limestones with nodules of green and blue chert. Fragments of the crinoid *Saccocoma* sp., sometimes forming laminated and graded sands, aptychi, bioclasts, radiolarians and calcisphaerulids are common; the texture is wackestone-packstone. In the northern part of the study area this unit is an incipiently nodular marly limestone, bearing ammonoids of Tithonian age (*Ptychophylloceras* sp., Simoceratids) (Figures 4(c) and 6(f)). The stratigraphic passage to the following unit is marked by the disappearance of *Saccocoma*. The thickness is about 20 m.

Maiolica Fm. (late early Tithonian-early Aptian *p.p.*). Well-bedded white mudstones, rarely wackestones, with white or grey chert (Figure 4(d)). The fossiliferous content includes radiolarians, calcisphaerulids, calpionellids (in the lower part of the unit), ammonites and very rare small gastropods. The thickness of the unit in the analyzed sector is 50–75 m.

'*Mt. Cosce Breccia*' (Barremian). A peculiar feature of the study area is represented by clastic deposits forming sparse to laterally continuous outcrops on the eastern slopes of Mt. Cosce, and unconformably resting on the Calcare Massiccio and Corniola Fms. (Figure 4(g)). These are massive polymictic and chaotic breccias (Cipriani & Santantonio, 2014a) made of: (i) heterometric clasts derived from the Calcare Massiccio Fm., Jurassic-Early Cretaceous basinal units, and condensed pelagites typical of Jurassic paleohighs (i.e. brachiopods-rich 'coquina-like' deposits and cephalopod-rich limestones); (ii) white pebbly mudstones of Maiolica-type facies (with and without calpionellids). The texture is rudstone-floatstone with a greenish matrix, while the thickness of the unit cannot be estimated as its top is the present-day topographic surface (Figures 4(e–f) and 6(g)). The occurrence of rare individuals of *Hedbergella* sp. in the matrix, the lack of clasts younger than the Early Cretaceous as well as the absence of calpionellids in the groundmass, coupled with nannoplankton analysis constrain the age of these deposits as being 'middle' Barremian (NC5D Nannofossil Zone – Erba et al., 1999) (E. Erba & C. Bottini, personal communication).

Marne a Fucoidi Fm. (early Aptian *p.p.*-late Albian). Thin-bedded polychrome shales, marls and marly limestones (Figure 5(a)). A prominent black-shale horizon, indicating anoxic or dysoxic conditions, represents the OAE1a ('Selli Level'; Coccioni, Nesci, Tramontana, Wezel, & Moretti, 1987). Intercalations of Maiolica-type pebbly mudstones are observed near the Colli di Lugnola village (Figure 6(h)). The faunal association is dominated by planktonic foraminifers (*Hedbergella* spp., *Ticinella* spp., *Biticinella* spp. and *Parathalmanninella* spp.) and radiolarians; also burrows (*Chondrites* and *Zoophycos*) are common. The thickness is variable from 5.80 m (north of Configni) to 13 m near Rocchettine village.

Scaglia Bianca Fm. (Albian *p.p.*-early Turonian). According to Cita et al. (2007), the occurrence of chert nodules marks the boundary between the Marne a Fucoidi and the Scaglia Bianca Fms. In the study area, however, the occurrence of chert is associated with a peculiar marl/limestone alternation. This alternation characterizes the base of the unit and allows definition of an informal lithofacies, easily recognizable in the field, called the 'Rocchette' member.

'*Rocchette*' *member* (late Albian-Cenomanian *p.p.*). Cyclic alternations of thin (up to 15 cm) whitish limestones and grey-green shales and marls. Pink, brown and dark chert is characteristic, as well as the gradual disappearance of marly interbeds (Figure 5(b)). Mudstone-wackestone textures, with radiolarians and planktonic forams (rotaliporids and *Planomalina buxtorfi*) are dominant. The thickness changes from about 6 m in the northern area up to 24 m at Rocchettine.

Scaglia Bianca s.s. (Cenomanian *p.p.*-early Turonian). Well-bedded white or pale limestones, with grey-brown chert (Figure 5(c)). The texture is mudstone-wackestone with planktonic organisms (*Thalmanninella* spp., radiolarians). The OAE2 ('Bonarelli Event'; Premoli Silva, Erba, Salvini, Locatelli, & Verga, 1999), which should occur in the upper part of this formation, is not observed. The passage to the above unit is placed at the first occurrence of pink-red chert. The unit is about 16–20 m thick.

Scaglia Rossa Fm. (early Turonian-middle Eocene *p.p.*). Pink to red cherty limestones and marly limestones, in 10–15 cm thick beds. The lithotypes are anomalous in the north-eastern sector of the analyzed area, with thin marl beds, pale yellow in color and rich in pyrite. Shallow water-derived, graded, carbonate turbidites sourced from a productive carbonate platform (e.g. Latium-Abruzzi Platform) are found in the unit at different stratigraphic levels. The textures are fine rudstone to packstone (Figure 5(d)), and in the loose shallow water grains were recognized *Orbitoides* sp., *Siderolites* sp., *Cuneolina* sp., *Goupillaudina* sp., *Sirtina* sp., rotaliids, echinoderms, algae and fragments of radiolitid rudists (Figure 5(i)). The faunal content of the embedding pelagites include planktonic foraminifers (*Dicarinella* spp., *Marginotruncana sigali*,

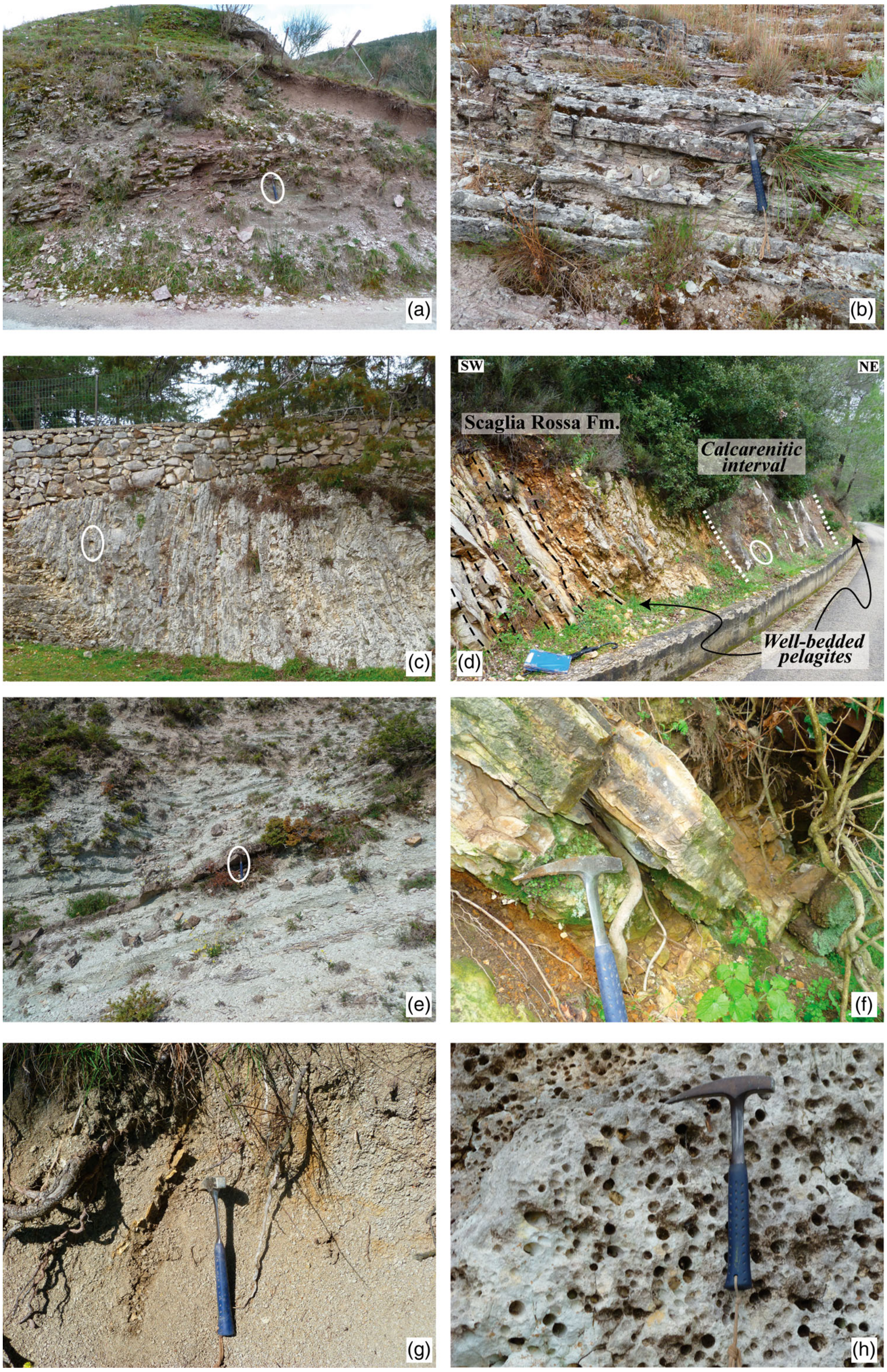

Figure 5. Field view of the stratigraphic units described in the text: (a) Marne a Fucoidi Fm. (Rocchettine, see hammer for scale); (b) cherty facies of the 'Rocchette' member (Rocchettine); (c) thinly bedded and folded limestones of the Scaglia Bianca Fm. (Vacone, see hammer for scale); (d) benthic material-bearing carbonate turbidites embedded in Upper Cretaceous deposits of the Scaglia Rossa Fm. (St. Sebastiano, about 1 km SW of Vacone); (e) shallow water-derived calcarenites interbedded in grey marly limestones of the Scaglia Cinerea Fm. (Configni, see hammer for scale); (f) black chert in pale-hazel limestones of the Bisciaro Fm. (Colle di Lugnola, see hammer for scale); G) Schlier Fm. (Colle di Lugnola, see hammer for scale); (h) Calcare Massiccio deposits riddled by traces of lithophagous mollusks (Montebuono).

Globotruncana arca, *Globotruncana linneiana*, *Globotruncana lapparenti*, *Globotruncanita conica*, *Globotruncanita stuarti*, *Contusotruncana contusa*, heterohelicids, *Morozovella* spp. and *Globorotalia* spp.) and radiolarians. The thickness is more than 150 m.

Scaglia Variegata Fm. (middle Eocene *p.p.*-late Eocene *p.p.*). Polychrome marls and marly limestones, thinly bedded, with scarce pink chert. The top of the unit is green-gray in color. The paleontological content includes planktonic forams

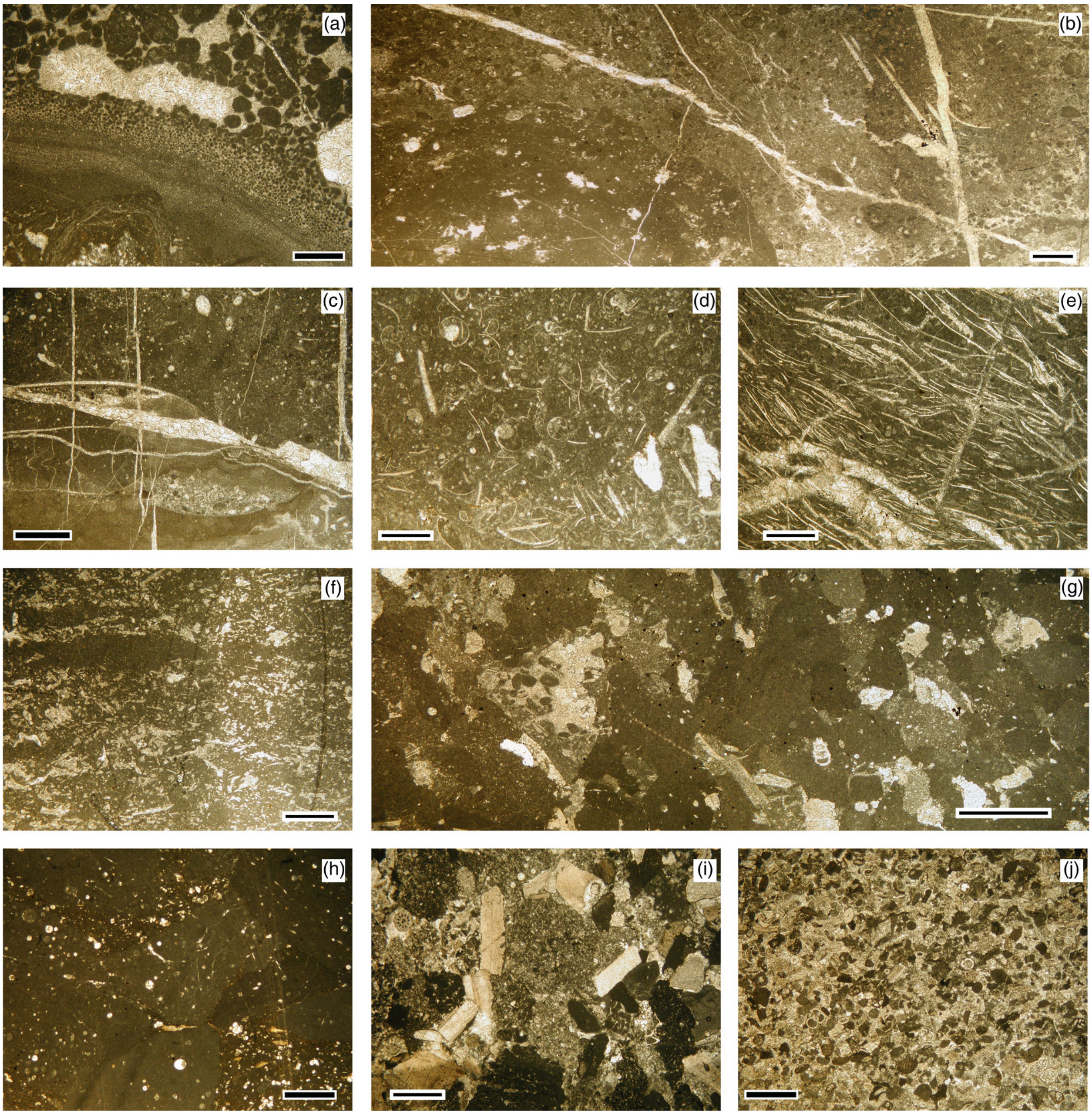

Figure 6. Microscopic views of some characteristic facies: (a) fenestral, oolitic and oncolitic grainstone (Calcare Massiccio Fm., Mt. Cosce); (b) fine, micropeloidal wackestone with a large algal nodule (up to 2 cm in diameter) associated with sponge spicules (Calcare Massiccio C, Cima Testone); (c) spiculitic and ammonitic wackestone. The phragmocone is partially filled with a micropeloidal micrite bearing *Agerina martana* (Calcare Massiccio B, Cima Boschetto); (d) ammonite-rich wackestone, associated with radiolarians and thin-shelled bivalves (Rosso Ammonitico Fm., Casal Monastero); (e) bioclastic wackestone made of iso-oriented shells of posidoniids (Calcari e marne a *Posidonia* Fm., Configni); (f) bioclastic wackestone rich in fragments of the crinoid *Saccocoma*, associated with radiolarians (Calcari a aptici e *Saccocoma* Fm.; Valle Aperta); (g) microclastic rudstone made of elements of Jurassic-to-Lower Cretaceous facies (Mt. Cosce Breccia). In particular, can be recognized clasts of: (i) *Microcodium*-bearing, oolitic and peloidal grainstones (Calcare Massiccio Fm.); (ii) mudstones with sponge spicules, crinoids and benthic forams (Corniola Fm.); (iii) radiolarian cherts (?Calcari Diasprigni Fm.); (iv) packstones with *Saccocoma* fragments (Calcari ad aptici e *Saccocoma* Fm.); (v) calpionellid-rich wackestones (Maiolica Fm.); (vi) mudstones with abundant radiolarians (Maiolica Fm.); (h) wackestones rich in planktonic foraminifers (*Hedbergella* sp., *Biticinella* sp.) bearing radiolarian pebbly mudstones of Maiolica-type facies (Marne a Fucoidi Fm., Colle di Lugnola); (i) Coarse grainstone made of shallow water-derived bioclasts associated with Upper Cretaceous planktonic forams (globotruncanids) (Scaglia Rossa Fm., St. Sebastiano); (j) fine-grained calcarenite with benthic foraminifers, mollusk and echinoid fragments and indeterminable bioclasts associated with globigerinids (Scaglia Cinerea Fm., Configni).

(*Globigerinatheka* spp., *Turborotalia* sp. and *Turborotalia cerroazulensis*) and radiolarians. The unit is about 30 m thick.

Scaglia Cinerea Fm. (late Eocene *p.p.*-Aquitanian *p.p.*). Shaly-marls, marls and subordinate marly limestones in thin bed, grey-greenish in color. Thin (3–20 cm) gravity-flow deposits with benthic elements characterize the lower part of the unit (Figure 5(e)). These graded and laminated grainstones-packstones are made of shallow water bioclasts (*Amphistegina* sp., *Nummulites* spp., peneroplids, mollusk fragments), also with common planktonic foraminifers (globigerinids) (Figure 6(j)). The transition to the following unit is sharp and marked by the appearance of thick-bedded limestones with dark chert. The age is late Eocene *p.p.*-Aquitanian *p.p.*, and the thickness is 150 m.

Bisciaro Fm. (Aquitanian *p.p.*-Burdigalian *p.p.*). Alternations of glauconite-bearing yellow-pale brown cherty limestones, organized in 30–50 cm thick beds and dark shales and marls (10–15 cm) (Figure 5(f)). The lowermost part of the unit is characterized by the 'Raffaello Level' (Montanari et al., 1991), a volcanoclastic bed representing a regional marker of the Aquitanian *p.p.*, well exposed near the Configni village. The paleontological content is characterized by planktonic and benthic foraminifers, radiolarians, burrows (*Zoophycos*, *Chondrites*), siliceous sponge spicules, fish-teeth. The unit outcrops only in the eastern part of the analyzed area, and is about 50 m thick.

Schlier Fm. (Burdigalian *p.p.*-Langhian *p.p.*). Dark-to-blue laminated shales/marls and subordinate calcareous marls, rich in *Orbulina universa* in the upper part of the unit (Figure 5(g)). This formation forms small, sparse outcrops. The thickness cannot be evaluated.

Marnoso-Arenacea Fm. (Langhian *p.p.*-?Tortonian *p.p.*). Well-bedded (30–40 cm) turbiditic deposits made-up of an alternation of sandstone and pelite; the thickness of this unit cannot be assessed here due to the fact that only a small outcrop can be observed, near the Casa Castiglione locality. This unit testifies to a foredeep environment of the Apennine orogen, and represents the end of the Meso-Cenozoic marine sedimentary cycle of the UMS Succession.

Chiani-Tevere Fm. (Gelasian-Santernian; Mancini et al., 2004). This unit represents the post-orogenic sedimentary cycle with deposits indicating marine-to-continental environments. The unit rests unconformably on the Meso-Cenozoic carbonate bedrock of the Narni Chain and on Neogene rocky shore paleobreccias, as highlighted by boring traces made by lithophagous mollusks (Figure 5(h)). The lithotypes are grey sandy clays rich in organic matter, with lenses of conglomerate ('*sabbie siltose e di ambiente salmastro*' member – Mancini et al., 2004), passing upward to clinostratified conglomerates ('*Torrita Tiberina*' member – Mancini et al., 2004). The faunal assemblage consists of benthic foraminifers and mollusks (*Ammonia* sp., *Cibicides* sp., *Elphidium* sp., ostreids). The thickness cannot be estimated.

Pleistocene-Recent continental deposits. Various continental deposits of the Main Map, including alluvial and debris fans, alluvial deposits, river beds deposits, scree, *eluvium-colluvium*. *Eluvium-colluvium* and lateritic soils are common, in particular, on the topographically higher zones (e.g. Mt. Cosce and Colle Petrucciano).

4. Structural setting and geological evolution of the Mt. Cosce area

In this sector the tectono-sedimentary evolution of the Mt. Cosce area will be briefly discussed. Four main tectonic deformations can be identified.

4.1. Hettangian-Early Sinemurian rifting stage

Evidence for the Early Jurassic rift-related extensional phase is found in the study area in the form of a complex horst-and-graben system. A Jurassic structural high corresponds to the Mt. Cosce area, flanked northward and westward by basins (respectively, Piano Lago-Colle Prata and Vacone-Montebuono basins). While the footwall-block top condensed succession is not preserved due to modern erosion and tectonics, its margins are locally observed. North of Mt. Cosce the onlap of basin-fill deposits on a Calcare Massiccio paleoescarpment is spectacularly exposed (Figure 7). The occurrence of chert nodules and crusts in the Calcare Massiccio (silicification) along the paleoescarpment contacts is a clue for interpreting it as a Jurassic margin. Silicification also affects the Calcare Massiccio-dominated mega-clastic deposits, produced by several rockfall events which affected the Jurassic paleoescarpments. These deposits are embedded in the basin-margin successions (well-exposed in the Piano Lago-Colle Prata area) and are dominated by huge olistoliths (up to >500 m across; the Colle di Lugnola, Piano Lago and Mt. Mandrione blocks). The paleoescarpment margins of the Mt. Cosce structural high also host small and sparse unconformable pockets of fossiliferous Calcare Massiccio B member in the form of epi-escarpment deposits (Galluzzo & Santantonio, 2002).

4.2. Early Cretaceous post-rift extensional tectonics

During the Early Cretaceous a new extensional phase affected the Mt. Cosce sector, as evidenced by the Mt. Cosce Breccia. Due to its sedimentological-stratigraphic features and the unconformable contacts with the Calcare Massiccio and Corniola Fms., the breccia is interpreted as a syn-tectonic deposit related to a re-activation of an Early Jurassic fault (Figure 8(a)). This event caused exhumation of a Jurassic paleoescarpment tract of the Mt. Cosce High, producing erosion, back-stepping and rejuvenation of the pre-existing Early Jurassic margin; this involved the onlap wedge of the basinal units, as well as the peritidal substrate (Calcare Massiccio boulders) and the former epi-escarpment deposits. At Mt. Il Pago (1 km east of Vacone), a huge block made of silicified Calcare Massiccio and of

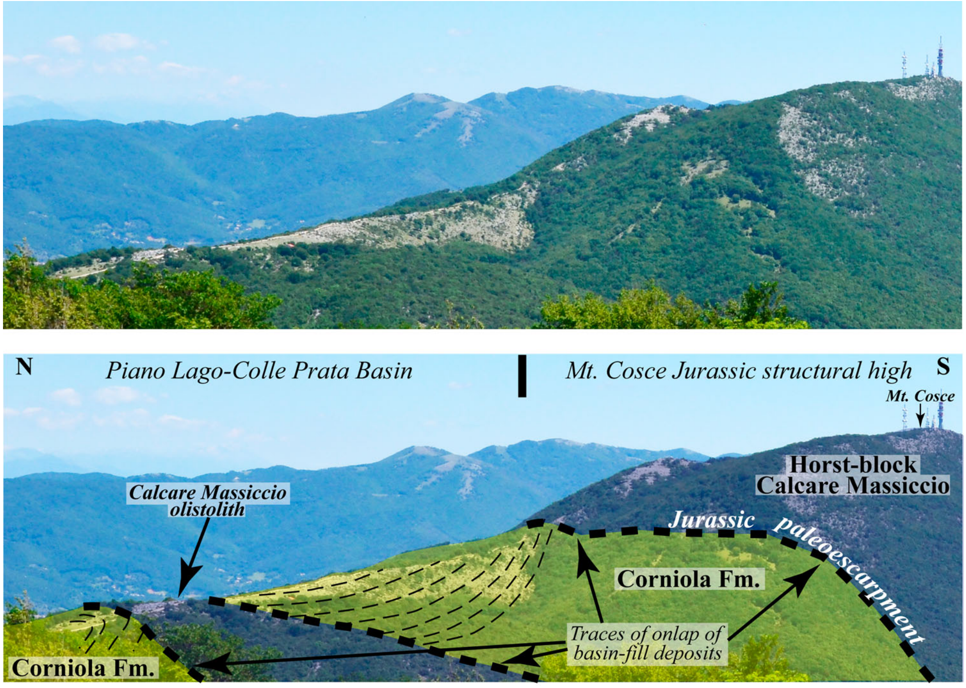

Figure 7. Panoramic view and geological interpretation of the Mt. Cosce-Piano Lago area. Here the northern margin of the Mt. Cosce Jurassic structural high is well exposed, and onlapped by Lower Jurassic, megabreccia- and olistolith-bearing, pelagites of the Corniola Fm.

unconformable dark cherty radiolarites is embedded in the younger deposits of the Maiolica Fm. This block physically represents a tract of the western Jurassic escarpment of the Mt. Cosce horst-block onlapped by the Upper Jurassic chert-rich deposits, detached and fallen into the Early Cretaceous basin. These data, coupled with the occurrence of Maiolica-facies pebbly mudstones in the younger Marne a Fucoidi Fm. (Colle di Lugnola), suggest a rejuvenated paleotopography of the seafloor in the late Early Cretaceous.

4.3. Miocene orogenic deformation

The main reverse structure of the Narni Ridge is the Mt. Cosce thrust (southern continuation of the Narni Thrust sensu Calamita et al., 1996), outcropping in the eastern part of the Narni Ridge (Figure 8(b and d)). This is a SW-dipping structural element dissected by tear faults and lateral-oblique ramps trending SW–NE, WSW–ENE and W–E. Several minor thusts referable to the 'forelimb shear thrusts' (Mitra, 2002) displace the overturned flank of the footwall syncline, made of Meso-Cenozoic units.

The orogenic deformations in the whole UMS Domain were controlled by the Mesozoic paleotectonic setting (e.g. Cello, Deiana, Marchegiani, Mazzoli, & Tondi, 2000; Mazzoli, Pierantoni, Borracini, Paltrinieri, & Deiana, 2005; Pierantoni, Deiana, & Galdenzi, 2013; Scisciani, 2009; Tavarnelli, 1995), and the Jurassic structural highs are generally part of the hanging wall blocks of the Miocene thrusts, while their margins are usually preserved in strike sections of the thrusts. In the analyzed area, these relationships are clearly exposed. In particular, the hangingwall of the Mt. Cosce thrust is characterized by the Jurassic Mt. Cosce structural high. Due to the rheological differences between the horst-block Calcare Massiccio and the onlapping pelagites, the Mt. Cosce Thrust, in proximity to the northern margin, changes into a left-lateral ramp, and the basinal succession of the Colle Prata area forms a fault-propagation fold related to a blind thrust. It is interesting also to note that compressive shear contacts, overprinting the original stratigraphic contacts, develop at the boundaries between the olistoliths and the embedding units (i.e. Mt. Mandrione, Mt. Il Pago and Colle di Lugnola olistoliths). This is interpreted here as being due to the contrasting mechanical behavior between the well-bedded pelagites and the Calcare Massiccio boulders (Cipriani & Santantonio, 2014b). This rheological anisotropy is evident in the south-western sector of the study area, where a short-wavelength succession of anticlines and overturned synclines, involving the megablock-bearing Jurassic-to-Oligocene pelagites of the Vacone-Montebuono Basin, was produced as a result of buttressing against the western margin of the Mt. Cosce High during the Miocene.

4.4. ?latest Miocene-early Pliocene normal faulting

Due to the birth of the 'Paglia-Tiber Graben', normal faulting involved the Narni Ridge in the ?latest Miocene-early Pliocene (Ambrosetti et al., 1987; Mancini

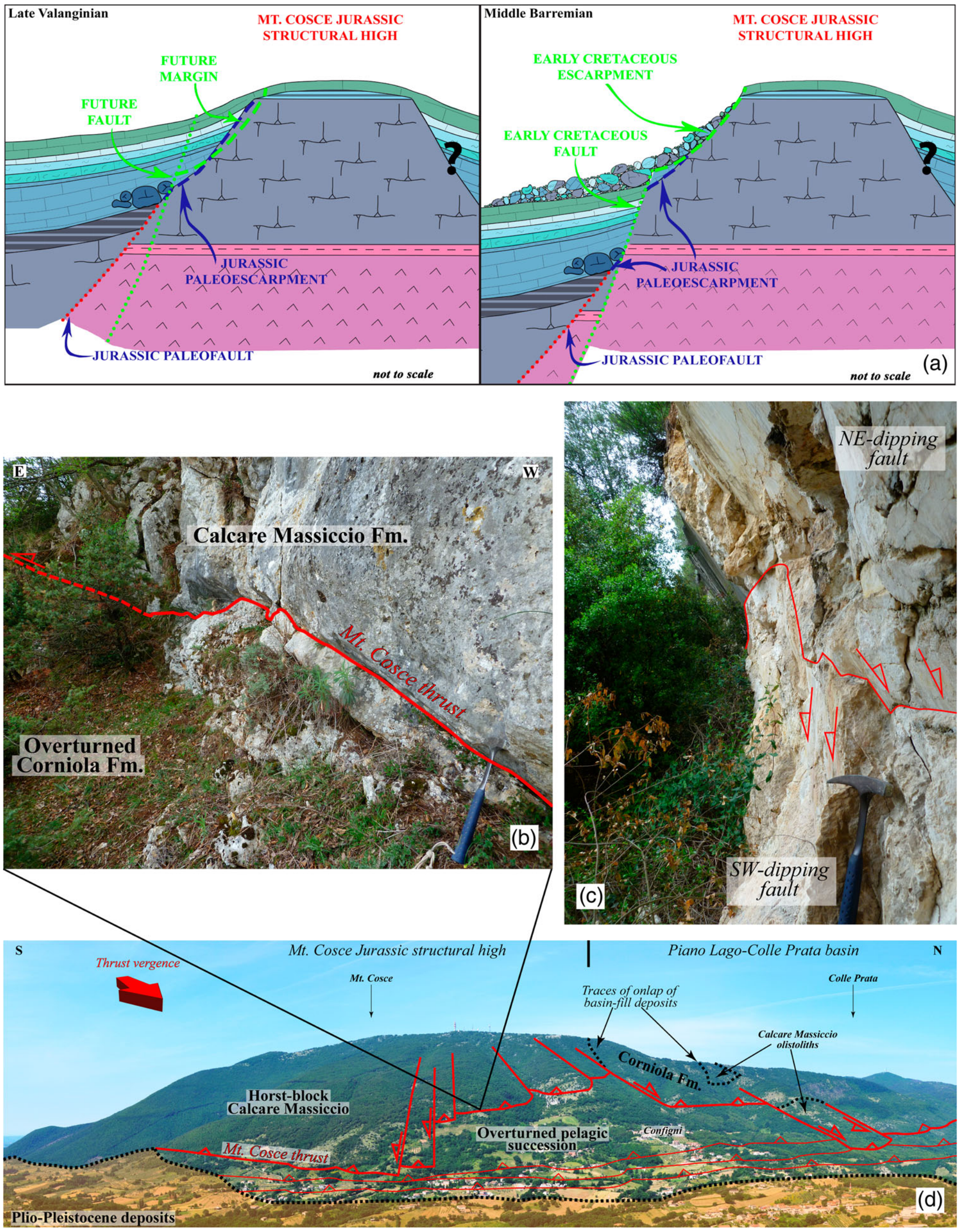

Figure 8. Interpretation of the late Early Cretaceous extensional tectonic affecting the western margin of the Mt. Cosce Jurassic structural high; (b) field evidence of the Mt. Cosce thrust exposed near the Configni village; (c) conjugated normal faults system spectacularly exposed along the western margin of the Narni Ridge, near the village of Montebuono (see hammer for scale); (d) panoramic view of the eastern sector of the study area. Here, the Mt. Cosce Jurassic structural high is onlapped northward by basinal deposits of the Corniola Fm.; huge olistoliths are embedded in the basinal succession. The paleo-architecture is deformed by the SW-dipping Mt. Cosce thrust (and minor splays).

et al., 2004). A conspicuous number of normal faults characterize the south-western part of study area, having a typical apenninic trend (NNW–SSE and NW–SE strike) also associated with anti-apenninic (NNE–SSW- and NE–SW-trending) structures. One of the main faults is the Mt. Cosce-Vacone Line. This 5 km-long and WSW-dipping extensional fault which bounds to the west the Mt. Cosce Jurassic structural high. The normal fault clearly runs along the strike of the Jurassic fault, but it cut across the Jurassic fault and paleoescarpment while no reactivation occurs, a result of the rotation of the Jurassic horst-block produced by Miocene thrusting.

Other important WSW-dipping Pliocene faults are (i) the Casal Monastero-Fonte Bandusia line; (ii) the Mt. Pizzuto-St. Sebastiano line; (iii) the Malepasso-Rocchette line. Several antithetic (i.e. ENE-dipping) faults are associated with the previously described extensional features, forming a complex conjugated system which is well exposed along the western margin of the Narni Ridge (Figure 8(c)).

5. Conclusions

A new geological map of the southern part of the Narni Ridge reveals the typical stratigraphical and sedimentological features associated with Early Jurassic rifting, providing the tools for interpreting the Mesozoic paleogeography and reconstructing the tectono-sedimentary evolution of the area. A Jurassic structural high corresponds to Mt. Cosce, resulting from the Hettangian-Sinemurian extensional phase, flanked by deeper basins. Clastic wedges and huge olistoliths occur at the basin-margins, related to the erosional back-stepping of the Jurassic submarine escarpments. These Jurassic escarpments are well exposed along the northern and south-western slopes of Mt. Cosce. During the Early Cretaceous, the western margin of the Jurassic Mt. Cosce high was rejuvenated by a post-rift extensional stage, as testified to by the occurrence of the Mt. Cosce Breccia. During the Miocene the Apenninic orogeny affected the study area, and an array of structures and geometries demonstrate that the inherited Mesozoic elements (i.e. horst-blocks, paleoescarpments and olistoliths) had a profound influence on the later compressive structures. Lastly, Neogene normal faulting further dissected the folded and thrusted rocks of the Meso-Cenozoic succession.

Software

The topographic base and the geological map have been redrawn using Adobe Illustrator CC, based on the Umbria and Latium C.T.R. at 1:10,000 scale and from a hand-drawn map, respectively.

Acknowledgments

For suggestions and critical review of an early version of the manuscript Prof. Massimo Santantonio is warmly thanked. Gratefully acknowledged are Prof. Massimo Santantonio and Prof. Umberto Nicosia for helpful geological discussions, Prof. Elisabetta Erba and Dr. Cinzia Bottini for nannoplankton analysis and Dr. Domenico Mannetta for helping hand in preparation of the thin sections. Many thanks to Scilla Roncacè, Angelo Coletti, Simone Cocomello and Simone Giannetti for their support during field work. The Editor-In-Chief Mike J. Smith and the reviewers Jennifer E. Carrell, Simone Fabbi and Pietro Paolo Pierantoni are kindly thanked for improving the manuscript and the map. A very special thanks to Dr. Simone D'Orazi Porchetti and his family for the immeasurable kindness and hospitality.

Disclosure statement

No potential conflict of interest was reported by the author.

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References

Ambrosetti, P., Carboni, M. G., Conti, M. A., Esu, D., Girotti, O., La Monica, G. B., … Parisi, G. (1987). Il Pliocene ed il Pleistocene inferiore del bacino del Fiume Tevere nell'Umbria meridionale. *Geografia Fisica e Dinamica Quaternaria*, *10*(1), 10–33.

Bartolini, A., Baumgartner, P. O., & Hunziker, J. (1996). Middle and late Jurassic carbon stable-isotope stratigraphy and radiolarite sedimentation of the Umbria–Marche basin (Central Italy). *Eclogae Geologicae Helvetiae*, *89*(2), 811–844.

Baumgartner, P. O. (2013). Mesozoic radiolarites – Accumulation as a function of sea surface fertility on Tethyan margins and in ocean basins. *Sedimentology*, *60*, 292–318. doi:10.1111/sed.12022

Bigi, S., Mandrone, S., Pierantoni, P. P., & Rossi, D. (2000). Structural analyses and restoration of structural cross-section in the northern central sector of the Narni-Amelia ridge (Central Apennines). *Memorie della Società Geologica Italiana*, *55*, 185–192.

Boncio, P., Brozzetti, F., Lavecchia, G., Bacheca, A., & Minelli, G. (2000). Note stratigrafiche e strutturali alla carta geologica del settore centrale della Catena Narnese-Amerina (Umbria, scala 1:25.000). *Bollettino della Società Geologica Italiana*, *119*(1), 69–83.

Calamita, F., & Pierantoni, P. P. (1996). Modalità della strutturazione neogenica nell'Appennino Umbro-Sabino (Italia Centrale). *Studi Geologici Camerti*, *1*, 153–169.

Calamita, F., Pierantoni, P. P., & Pontoni, R. (1996). Il sovrascorrimento di Narni (Appennino Centrale). *Studi Geologici Camerti*, *1*, 183–201.

Cello, G., Deiana, G., Marchegiani, L., Mazzoli, S., & Tondi, E. (2000). Imprinting of pre-orogenic tectonics in the Umbria–Marche thrust belt. *Memorie della Società Geologica Italiana*, *55*, 205–209.

Centamore, E., Chiocchini, M., Deiana, G., Micarelli, A., & Pieruccini, U. (1971). Contributo alla conoscenza del Giurassico dell'Appennino Umbro-Marchigiano. *Studi Geologici Camerti*, *1*, 1–89.

Chiocchini, M., Manfredini, M., Manganelli, V., Nappi, G., Pannuzi, L., Tilia Zuccari, A., & Zattini, N. (1975). *Note illustrative della Carta Geologica d'Italia, alla scala 1:100.000, Fogli 138-144, Terni-Palombara Sabina. Arti Grafiche Panetto and Petrelli*. Spoleto.

Ciarapica, G., Cirilli, S., & Passeri, L. (1982). La serie triassica del M. *Cetona (Toscana meridionale) e suo confronto con quella di La Spezia. Memorie della Società Geologica Italiana*, *24*(2), 155–167.

Cipriani, A., & Santantonio, M. (2014a, August). *Early Cretaceous tectonic rejuvenation of an Early Jurassic margin at Mt. Cosce (Narni Ridge, Central Apennines, Italy)*. Poster session presented at the 19th International Sedimentological Congress of IAS, Geneva, Switzerland.

Cipriani, A., & Santantonio, M. (2014b). Mesozoic architecture and tectono-sedimentary evolution of the Mt. Cosce sector (Narni Ridge, Central Apennines, Italy). *Rendiconti Online della Società Geologica Italiana*, *31*, 656. doi:10.3301/ROL.2014.140

Cita, M. B., Abbate, E., Aldighieri, B., Balini, M., Conti, M. A., Falorni, P., … Petti, F. M. (2007). Carta Geologica d'Italia 1:50.000. Catalogo delle formazioni – Unità tradizionali (1) Fascicolo VI. *Quaderni del Servizio Geologico d'Italia, Serie III*, *7*(6), 318.

Coccioni, R., Nesci, O., Tramontana, M., Wezel, F. C., & Moretti, E. (1987). Descrizione di un livello-guida 'radiolaritico-bituminoso-ittiolitico' alla base delle Marne a Fucoidi nell'Appennino Umbro-Marchigiano. *Bollettino della Società Geologica Italiana*, *106*, 183–192.

Conforto, B., & Parboni, F. (1963). Contributo alla conoscenza dei monti di Narni. *Bollettino della Società Geologica Italiana*, *82*, 181–193.

Conti, M. A., & Monari, S. (1992). Thin-shelled bivalves from the Jurassic Rosso Ammonitico and Calcari a Posidonia formations of the Umbrian-Marchean Apennine (Central Italy). *Palaeopelagos*, *2*, 193–213.

Doglioni, C. (1991). A proposal for the kinematic modelling of W-dipping subduction – Possible applications to the Tyrrhenian–Apennines system. *Terra Nova*, *3*, 423–434.

Erba, E., Channell, J. E. T., Claps, M., Jones, C., Larson, R., Opdyke, B., … Torricelli, S. (1999). Integrated stratigraphy of the Cismon Apticore (Southern Alps, Italy): A 'reference section' for the Barremian–Aptian interval at low latitudes. *Journal of Foraminiferal Research*, *29*(4), 371–391.

Fabbi, S. (2014). Geology and Jurassic paleogeography of the Mt. Primo-Mt. Castel Santa Maria ridge and neighbouring areas (Northern Apennines, Italy). *Journal of Maps*, *11*(4), 645–663.

Fabbi, S., & Santantonio, M. (2012). Footwall progradation in syn-rift carbonate platform-slope systems (Early Jurassic, Northern Apennines, Italy). *Sedimentary Geology*, *281*, 21–34.

Galluzzo, F., & Santantonio, M. (2002). The Sabina Plateau: A new element in the Mesozoic palaeogeography of Central Apennines. *Bollettino della Società Geologica Italiana*, *1*, 561–588.

Jenkyns, H. C. (1985). The Early Toarcian and Cenomanian-Turonian anoxic events in Europe: Comparisons and contrasts. *Geologische Rundschau*, *74*(3), 505–518. doi:10.1007/BF01821208

Lotti, B. (1902). Sulla costituzione geologica del gruppo montuoso d'Amelia (Umbria). *Bollettino del Regio Comitato Geologico d'Italia*, *4*(3), 89–103.

Lotti, B. (1903). I terreni secondari nei dintorni di Narni e di Terni. Relazione sulla campagna geologica del 1902. *Bollettino del Regio Comitato Geologico d'Italia*, *34*, 4–33.

Mancini, M., Girotti, O., & Cavinato, G. P. (2004). Il Pliocene e il Quaternario della media valle del Tevere (Appennino Centrale). *Geologica Romana*, *37*, 175–236.

Marino, M., & Santantonio, M. (2010). Understanding the geological record of carbonate platform drowning across rifted Tethyan margins: Examples from the Lower Jurassic of the Apennines and Sicily (Italy). *Sedimentary Geology*, *225*, 116–137.

Mazzoli, S., Pierantoni, P. P., Borracini, F., Paltrinieri, W., & Deiana, G. (2005). Geometry, segmentation pattern and displacement variations along a major Apennine thrust zone, Central Italy. *Journal of Structural Geology*, *27*, 1940–1953.

Mitra, S. (2002). Fold-accommodation faults. *AAPG Bulletin*, *86*(4), 671–694.

Montanari, A., Deino, A., Coccioni, R., Langenheim, V. E., Capo, R., & Monechi, S. (1991). Geochronology, Sr isotope analysis, magnetostratigraphy, and plankton stratigraphy across the Oligocene-Miocene boundary in the Contessa section (Gubbio, Italy). *Newsletters on Stratigraphy*, *23*(3), 151–180.

Morettini, E., Santantonio, M., Bartolini, A., Cecca, F., Baumgartner, P. O., & Hunziker, J. C. (2002). Carbon isotope stratigraphy and carbonate production during the Early-Middle Jurassic: Examples from the Umbria-Marche-Sabina Apennines (Central Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, *184*, 251–273.

Pialli, G. (1969). *Un episodio marnoso del Lias superiore nel Bacino Umbro-Marchigiano: Le Marne di M. Serrone. Bollettino della Società dei Naturalisti di Napoli, 78*, 3–23.

Pierantoni, P. P., Deiana, G., & Galdenzi, S. (2013). Stratigraphic and structural features of the Sibillini Mountains (Umbria-Marche Apennines, Italy). *Italian Journal of Geosciences*, *132*(3), 497–520. doi:10.3301/IJG.2013.08

Premoli Silva, I., Erba, E., Salvini, G., Locatelli, C., & Verga, D. (1999). Biotic changes in cretaceous oceanic anoxic events of the Tethys. *Journal of Foraminiferal Research*, *29*(4), 352–370.

Rau, A. (1962). Studio tettonico della zona di convergenza tra due anticlinali fra Terni e Rieti. *Bollettino della Società Geologica Italiana*, *81*(3), 323–344.

Santantonio, M. (1993). Facies associations and evolution of pelagic carbonate platform/basin systems: Examples from the Italian Jurassic. *Sedimentology*, *40*, 1039–1067.

Santantonio, M. (1994). Pelagic carbonate platforms in the geologic record: Their classification, and sedimentary and paleotectonic evolution. *AAPG Bulletin*, *78*(1), 122–141.

Santantonio, M., Galluzzo, F., & Gill, G. (1996). Anatomy and palaeobathymetry of a Jurassic pelagic carbonate platform/basin system. Rossa Mts., Central Apennines (Italy). Geological implications. *Palaeopelagos*, *6*, 123–169.

Scisciani, V. (2009). Styles of positive inversion tectonics in the Central Apennine and in the Adriatic foreland: Implications for the evolution of the Apennine chain (Italy). *Journal of Structural Geology*, *31*, 1276–1294.

Storti, F., & Salvini, F. (2001). The evolution of a model trap in the Central Apennines, Italy: Facture patterns, fault reactivation and development of cataclastic rocks in carbonates at the Narni anticline. *Journal of Petroleum Geology*, *24*(2), 171–190.

Tavarnelli, E. (1995). Controllo delle faglie dirette giurassiche e cretaceo-paleogeniche sullo sviluppo dei sovrascorrimenti neogenici nell'Appennino Umbro-Marchigiano. *Studi Geologici Camerti*, *1*, 601–609.

Verri, A. (1886). Relazione sulle escursioni nei dintorni di Terni. *Bollettino della Società Geologica Italiana*, *5*, 507–514.