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

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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, Pierantonii, & Rossii, 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 (Calcari 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, & Cavina, 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, Pierantonii, & 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 km². 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. Fabbri, 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. silification; 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 ‘seliciferous member’...
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.

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

‘Calcarea Massiccio A’ member (?Rhaetian/Hettangian-Sinemurian boundary). 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, cryatalgal 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 Calcarea Massiccio is normally a chert-free carbonate limestone, but in some localities chert nodules and crusts occur (silicification). The silicification of the Calcarea 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 (Santantionio 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.

‘Calcarea Massiccio C’ member (Hettangian/Sinemurian boundary). This lithofacies is characterized
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 (Sphinctozoans), 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.

**Cerniola 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 Cerniola 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. Megabrecias 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
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)
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 adapti 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, aptichs, 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 ammonites and very rare small gastropods. The thick-fossiliferous content includes radiolarians, calcisphaerulids, Ptychophragmodiids, Saccocoma, Onicocoenia, Biticinella, Marginotruncana sigali, Marginotruncana s.p., 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 foraminifers (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 (Thal-manninella sp., 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., rotalids, echinoderms, algae and fragments of radiolitid rudists (Figure 5(i)). The faunal content of the embedding pelagites include planktonic foraminifers (Dicarinella sp., Marginotruncana sigali, Marginotruncana s.p., Ticinella sp., Biticinella sp., Parathalmanninella sp. 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.

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, Nesi, 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 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., rotalids, echinoderms, algae and fragments of radiolitid rudists (Figure 5(i)). The faunal content of the embedding pelagites include planktonic foraminifers (Dicarinella sp., Marginotruncana sigali, 
Globotruncana arca, Globotruncana linneiana, Globotruncanita conica, Globotruncanita stuarti, Contusotruncanita 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 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. (Confini, 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).
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., peneropids, 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.-Aquitianian p.p., and the thickness is 150 m.

Bisciaro Fm. (Aquitianian 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 Confini 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 estimated.

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-Santantonian; 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 paleo breccias, 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 fauna 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-Monte-buono 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 (silification) along the paleoescarpment contacts is a clue for interpreting it as a Jurassic margin. Silification also affects the Calcare Massiccio-dominated mega-elastic 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
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 thrusts 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
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 thrust 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.

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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.

Disclosure statement

No potential conflict of interest was reported by the author.

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