Sedimentary Geology 331 (2016) 94–113

Contents lists available at ScienceDirect

Sedimentary Geology

journal homepage: www.elsevier.com/locate/sedgeo

Mesozoic architecture of a tract of the European–Iberian continental margin: Insights from preserved submarine palaeotopography in the Longobucco Basin (Calabria, Southern Italy)

Massimo Santantonio [1], Simone Fabbi *, Luca Aldega

Università degli Studi di Roma "La Sapienza", Dipartimento di Scienze della Terra, Piazzale Aldo Moro, 5, 00185 Rome, Italy

ARTICLE INFO

Article history:
Received 30 July 2015
Received in revised form 20 October 2015
Accepted 23 October 2015
Available online 10 November 2015

Editor: B. Jones

Keywords:
Rift basins
Sedimentology
Carbonates
Stratigraphy
Jurassic

ABSTRACT

The sedimentary successions exposed in northeast Calabria document the Jurassic–Early Cretaceous tectonic–sedimentary evolution of a former segment of the European–Iberian continental margin. They are juxtaposed today to units representing the deformation of the African and Adriatic plates margins as a product of Apenninic crustal shortening. A complex pattern of unconformities reveals a multi-stage tectonic evolution during the Early Jurassic, which affected the facies and geometries of siliciclastic and carbonate successions deposited in syn- and post-rift environments ranging from fluvial to deep marine. Late Sinemurian/Early Pliensbachian normal faulting resulted in exposure of the Hercynian basement at the sea-floor, which was onlapped by marine basin-fill units. Shallow-water carbonate aprons and reefs developed in response to the production of new accommodation space, fringing the newborn islands which represent structural highs made of Paleozoic crystalline and metamorphic rock. Their drowning and fragmentation in the Toarcian led to the development of thin caps of Rosso Ammonitico facies. Coeval to these deposits, a thick (>1 km) hemipelagic/siliciclastic succession was sedimented in neighboring hanging wall basins, which would ultimately merge with the structural high successions. Footwall blocks of the Early Jurassic rift, made of Paleozoic basement and basin-margin border faults with their onlapping basin-fill formations, are found today at the hanging wall of Miocene thrusts, overlying younger (Middle/Late Jurassic to Late Paleogene) folded basinal sediments. This paper makes use of selected case examples to describe the richly diverse set of features, ranging from paleontology to sedimentology, to structural geology, which are associated with the field identification of basin-margin unconformities. Our data provide key constraints for restoring the pre-orogenic architecture of a continental margin facing a branch of the Liguria–Piedmont ocean in the Western Tethys, and for estimating displacements and slip rates along synsedimentary faults.

1. Introduction

Along the northeastern slopes of the Sila Mountains in northern Calabria, facing the Ionian Sea, the ?latest Triassic/Jurassic to Early Cretaceous sedimentary successions which non-conformably overlie the Paleozoic basement (Magri et al., 1965; Teale, 1988; Perrone et al., 2006) are an anomaly in the Mesozoic geology and stratigraphy of peninsular Italy. Unlike neighboring regions (Apennines, Maghrebides), where Mesozoic rocks clearly represent the deformed passive margin of the Africa/Adria plates (or one plate: Channel et al., 1979; Schettino and Turco, 2011, and references therein), these Calabrian successions document the Mesozoic history of a sector of the European/Iberian continental margin (Haccard et al., 1972; Bouillin, 1984; Bouillin et al., 1988; Dietrich, 1988; Schettino and Turco, 2011; Santantonio and Carminati, 2011; Passeri et al., 2014) or, according to different authors, of a sector of the Africa/Adria plate formerly involved in the Alpine orogeny (Austroalpine or Insubric domain: Amodio-Morelli et al., 1976; Scandone, 1979; Bonardi et al., 1982). Certain authors (Bonardi et al., 2008; Critelli et al., 2008; Carminati et al., 2012; Perri et al, 2013), furthermore, believe Calabria belonged to a separate plate, named "AlKaPeCa" or Mesomediterranean Plate, which would become detached from the European margin (Bouillin et al., 1986; Handy et al., 2010; Carminati et al., 2012) in either Middle Jurassic or Cretaceous times. The geological uniqueness of Calabria, mentioned above, is the result of drift to the Southeast, from its original position attached to the Sardinia–Corsica Block, of the so-called Calabria–Peloritani Arc (Fig. 1), linked with opening of the back-arc Tyrrhenian Sea basin (Scandone, 1979; Carminati et al., 2012). This process was driven by the North West-dipping subduction, starting in the Miocene, of crust of possible oceanic origin flooring the Ionian Basin. The Calabrian sector of the arc also exhibits a peculiar post-Hercynian/pre-Alpine stratigraphy, as the Jurassic rests directly on the basement, with no Permian or Triassic successions interposed (with the exception of thin Rhaetian

* Corresponding author.
E-mail addresses: massimo.santantonio@uniroma1.it (M. Santantonio), simone.fabbi@uniroma1.it (S. Fabbi), luca.aldega@uniroma1.it (L. Aldega).
[1] Tel.: +39 06 4991 4185.

http://dx.doi.org/10.1016/j.sedgeo.2015.10.010
0037-0738/

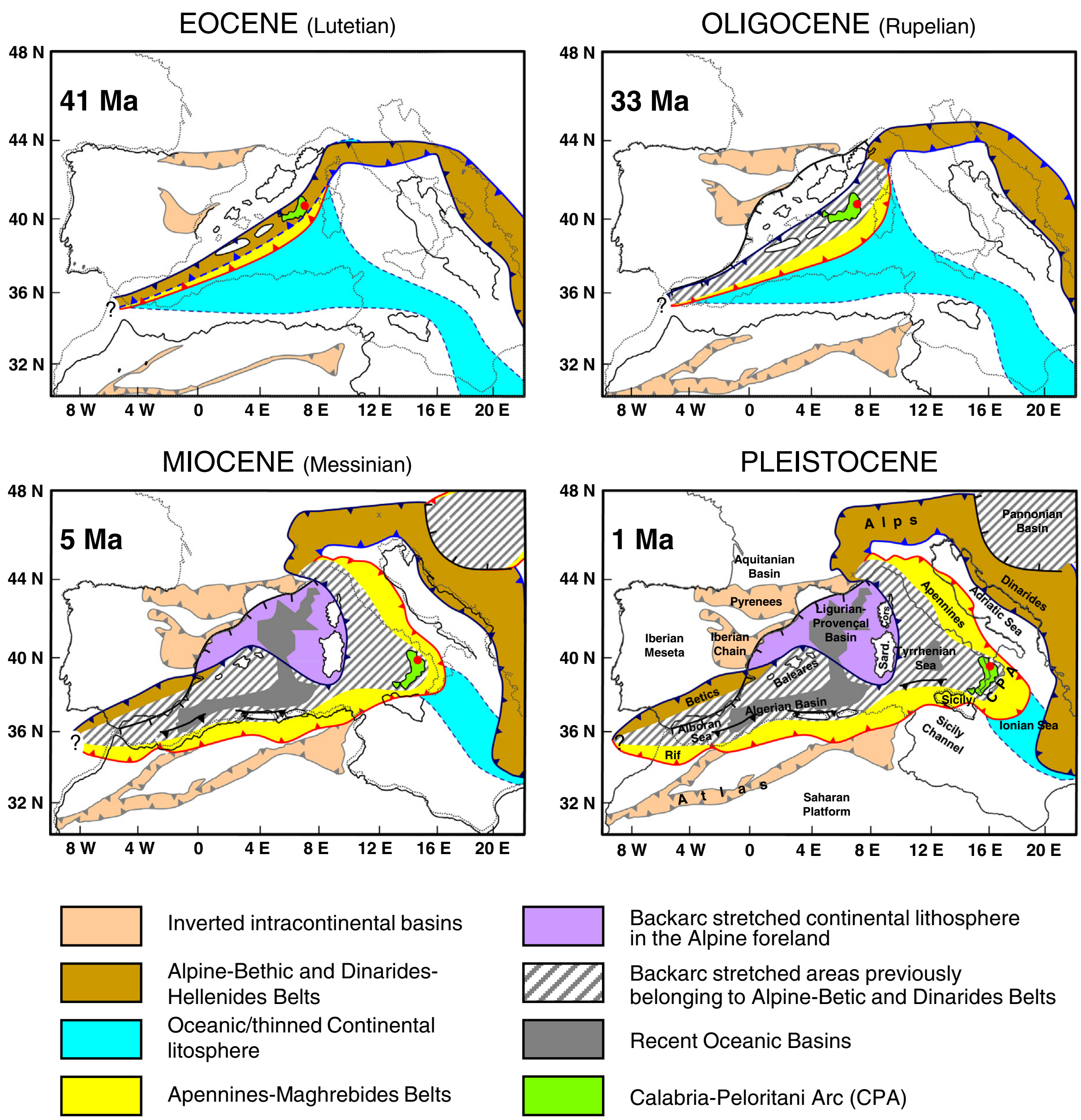

Fig. 1. Geological evolution of the Western Mediterranean region, with migration of the Calabria–Peloritani Arc. The study area is indicated by the red circle (modified after Carminati et al., 2010). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

redbeds) (Santantonio and Carminati, 2011). Elsewhere across most of the Southern Alps and the Apennines, the Upper Triassic alone is up to about 2 km thick and made up of dolostone, evaporite, or limestone (Ciarapica and Passeri, 2005). This lack or reduced thickness of Triassic successions is a shared feature, though with some partial exceptions (local existence of relatively thin Triassic deposits), with the western Southern Alps and the Briançonnais region, the Sardinia–Corsica block, and south-western Tuscany, which led Santantonio and Carminati (2011, and regional references therein) to envisage the existence of a broad high of the Hercynian basement, which would become permanently submerged only in the Early (or Middle, e.g. Eastern Sardinia) Jurassic.

Synsedimentary tectonics, active during much of the Early Jurassic, produced a submarine topography which resulted in a complex pattern of unconformities and of lateral thickness and facies changes. Tracts of Jurassic fault-related submarine escarpments can be mapped in the field, where an intriguing set of associated paleomorphological, sedimentological, paleobiological, diagenetic, and structural characters can be examined directly. The close encounters of typical Tethyan carbonate and siliceous marine facies with the Paleozoic crystalline and metamorphic basement, which was exposed at the sea bottom due to footwall unroofing, resulted in an array of highly unusual sedimentary facies as a product of carbonate/siliciclastic mixing. This paper describes and discusses, also making use of new biostratigraphic data, selected outcrops of eminently instructive, preserved submarine paleomorphologies and Jurassic fault zones, each documenting a distinctive case history, and addresses their spatial relationships with Eocene–Miocene orogenic faults and the deformation patterns of basin-margin strata. Our multidisciplinary approach, which could be duplicated in other rifted continental margin successions, led us to document the Jurassic–Early Cretaceous tectonic–sedimentary evolution of a segment of the European–Iberian continental margin. This revealed similarities and differences with neighboring regions in the Jurassic Tethys, which will be discussed in the final sections of this paper.

2. The Longobucco and Caloveto Groups of Northern Calabria

The Mesozoic sedimentary cycle, overlying the Hercynian Paleozoic basement made of low-grade metamorphic (Cambrian to Devonian; Bouillin et al., 1984, 1987) and crystalline rocks, is currently subdivided into two groups having major differences in stratigraphic composition, thickness, and age (Fig. 2): the Longobucco Group (Young et al., 1986) and the Caloveto Group (Santantonio and Teale, 1985, 1987). These differences reflect the irregular sea-bottom morphology of the area during the Jurassic, a product of rift-tectonics (Santantonio, 1993; Santantonio and Carminati, 2011), which also explains the present-day geographic distribution of the two groups (Fig. 3). The Longobucco Group starts with continental redbeds in the latest Rhaetian?–earliest Hettangian (Monte Paleparto and Torrente Duno Formations; see also Bouillin et al., 1988; Baudelot et al., 1988), followed by mixed siliciclastic/carbonate shelf deposits with a rich invertebrate fauna, common ooids, and abundant plant remains (Bocchigliero Formation, Hettangian *p.p.*/lower Sinemurian; Young et al., 1986; see also Magri et al., 1965, and references therein). The overlying Fosso Petrone Formation (Sinemurian *p.p.*/Pliensbachian *p.p.*) is essentially made of marls, representing a deeper-shelf to basin environment, which are followed by very thick (>1 km) mostly siliciclastic turbidites (Fiume Trionto Formation: Pliensbachian *p.p.*/Toarcian *p.p.*) (Perri et al., 2008). Synsedimentary extension caused foundering of the Longobucco Basin around the late Sinemurian (Lotharingian)/early Pliensbachian (Carixian) boundary, also producing a belt of offshore highs at its shoulders, which gave rise to the Caloveto Group. In the Caloveto Group (Santantonio and Teale, 1985, 1987; Santantonio, 2012), sedimentation started in the form of narrow aprons of shallow water carbonates and coral reefs (Lower Caloveto Formation), fringing small islands representing the fault-bounded highs of the Paleozoic basement. Their drowning and pervasive tectonic fragmentation resulted in deposition of a Rosso Ammonitico condensed pelagic facies (Upper Caloveto Formation, Toarcian *p.p.*) and development of a complex network of neptunian dykes (Santantonio and Teale, 1985; Bouillin and Bellomo, 1990). The Sant'Onofrio Subgroup (*sensu* Santantonio, 2012) is bounded by a basal angular unconformity which corresponds to the rugged fault-induced submarine topographic surface. It starts with bioturbated

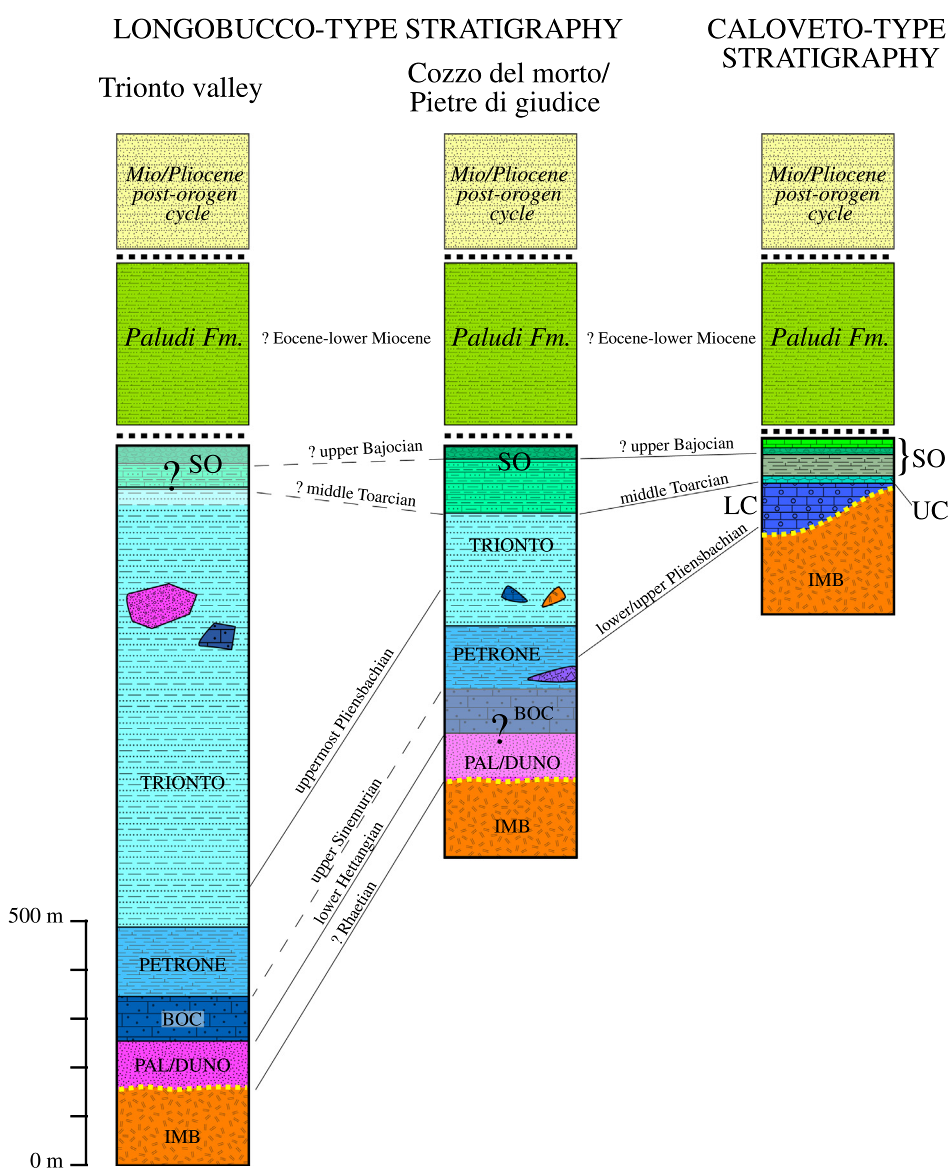

Fig. 2. General stratigraphy of the study area. IMB: Igneous/metamorphic basement; *Longobucco Group* sensu Young et al. (1986): PAL/DUNO—Monte Paleparto/Torrente Duno Fm.; BOC—Bocchigliero Fm.; PETRONE—Fosso Petrone Fm.; TRIONTO—Fiume Trionto Fm. *Caloveto Group* sensu Santantonio and Teale (1987): LC—Lower Caloveto Fm.; UC—upper Caloveto Fm.; SO—Sant'Onofrio Subgroup ("Posidonia" marls, radiolarian cherts, and Maiolica).

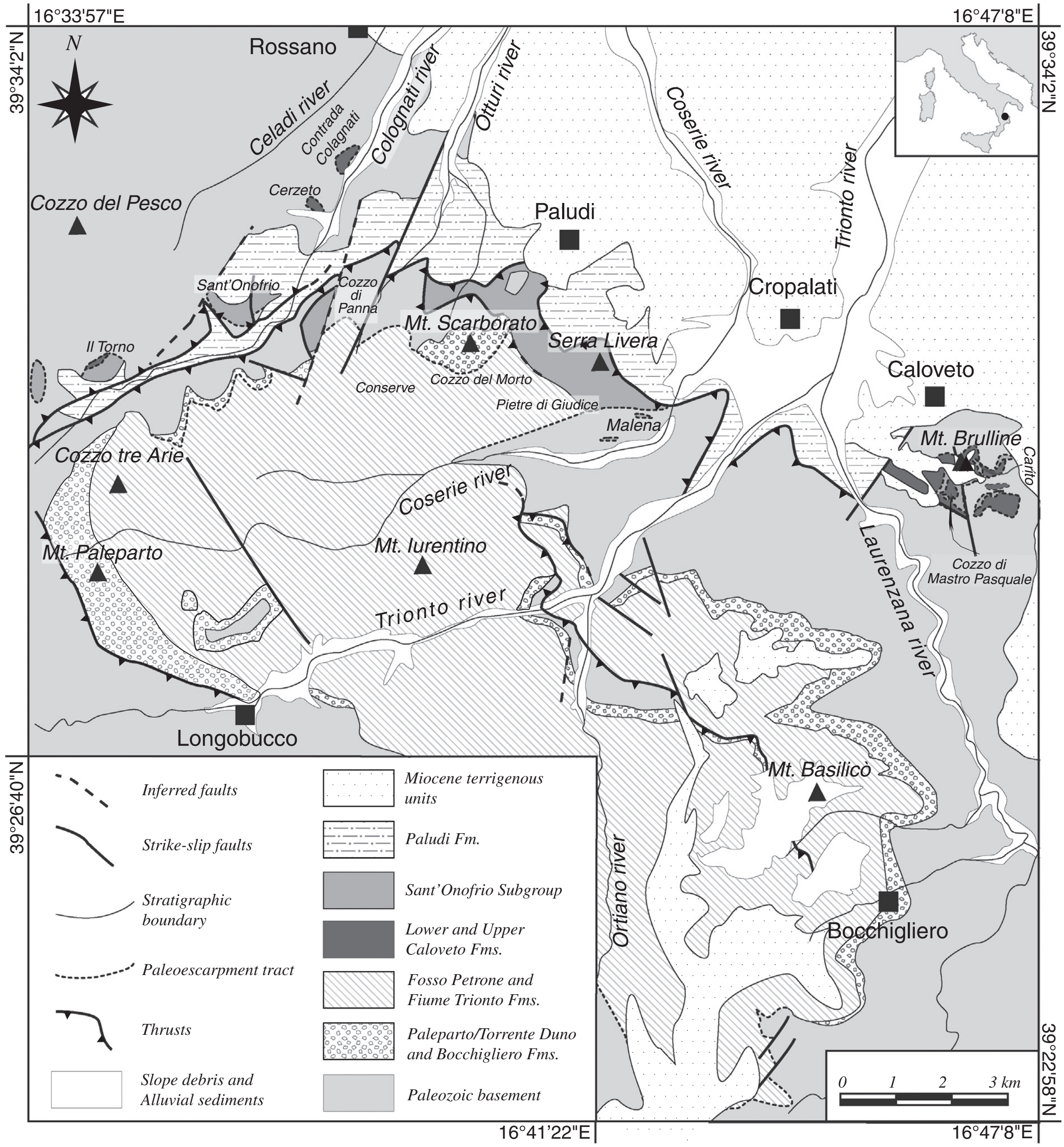

Fig. 3. Schematic geological map of the study area.

(*Zoophycos*) red Posidonia marls (uppermost Toarcian–lower Bajocian), followed by radiolarian cherts (upper Bajocian–?Kimmerdigian *p.p.*), Aptychus limestone (?Kimmeridgian *p.p.*–Tithonian *p.p.*), and Calpionellid limestone ("Maiolica facies"; Tithonian *p.p.*–Hauterivian). While this is the established stratigraphy of these Calabrian successions, geological mapping around the village of Paludi, between the valleys of the Colognati and the Coserie Rivers, demonstrates that the Fiume Trionto Formation of the Longobucco Group continues upward with gray Posidonia limestones, associated with marls and carbonate turbidites, bearing characteristic black chert (*circa* 100 m thick; Magri et al., 1965; Santantonio, 2012; see also Sant'Antonio Unit in Bouillin et al., 1988), which are time equivalents of the red marls of the Sant'Onofrio Subgroup. The Longobucco Group must therefore be re-defined to include also the gray Posidonia limestone with black chert (Toarcian *p.p.*–Bajocian *p.p.*). The limestone is then followed by those same radiolarian cherts which were originally described in the Caloveto Group succession (see above), which represent a datum level where the two groups merge, coincident with the establishment of widespread pelagic conditions. This took place at a time of reduced tectonic activity (no direct evidence for synsedimentary extension is found after the Toarcian) and suggests a syn-drift regime coincident with sea-floor spreading in the neighboring branch of the Liguria–Piedmont Ocean.

3. Jurassic fault zones and submarine paleomorphologies

3.1. The Paludi area

A number of contacts of the Paleozoic basement with deep-water formations of the Longobucco Group (Fosso Petrone and Fiume Trionto Formations), found 2–4 km to the southwest of the village of Paludi (Fig. 3) and mapped in Teale (1988) as of probably (Tertiary) tectonic origin, document the basin-margin onlap of Pliensbachian and Toarcian deep-water formations. The Carboniferous granite and thin discontinuous remnants of its sedimentary cover (continental redbeds and black limestone of the Mt. Paleparto/Torrente Duno and Bocchigliero Formations) represent an eroded footwall block in the local extensional system and constitute an alignment stretching for about 3 km in a W-E direction (Scarborato–Cicchello High). The marginal deposits of hanging wall basins host wedges of boulder beds with clasts of crystalline rocks and of fluvial sandstones and shelf limestones, forming a megaclastic belt which runs for a few kilometers parallel to the basin paleo-margin. The basinal strata are often tightly folded near (<0.5 km) the onlap contacts, which is interpreted as an effect of Tertiary buttressing against Jurassic synsedimentary–fault escarpments (Underhill and Paterson, 1998).

3.1.1. Syndepositional faulting and basement exhumation, the vestiges of a basin-margin reef, and buttressing of basin-margin beds—Cozzo del Morto/Conserve

At Cozzo del Morto (Fig. 4), the basin-margin succession, made of hemipelagic marls and turbidites, bears a clastic interval (first described by Teale and Young, 1987 and mapped in Teale, 1988), up to about 35 m thick (Fig. 4a). 3–25 cm thick beds of dark bioturbated (*Chondrites*) and locally coal-rich marl, and up to 60 cm thick beds,

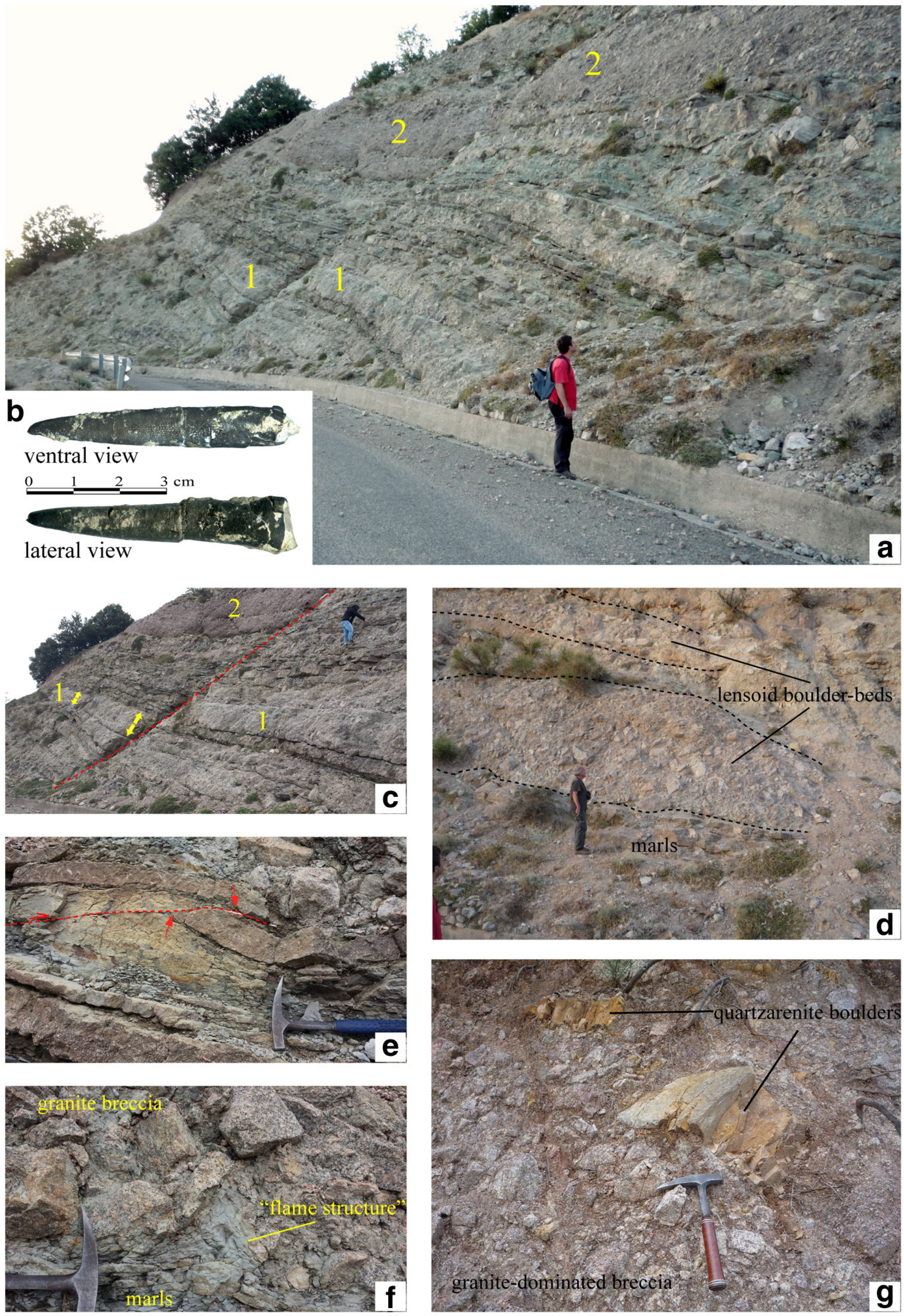

Fig. 4. Cozzo del Morto. A) panoramic view of the Cozzo del Morto outcrop (latest Sinemurian—clastic body embedded in the Fosso Petrone Fm.), the numbered marker levels (1,2) are the same as in Fig. 4c; b) lateral and ventral views of the"*Passaloteuthis*" *krimholzi* specimen found in the marls of Cozzo del Morto; c) detail of the synsedimentary normal fault described in text, note the thickening of bed 1 at the hanging wall of the fault; d) non-tectonic thrust displacing a sandstone bed; arrows indicate homologous points; e) detail of a flame structure at the base of a conglomerate bed; f) view of the granite-dominated lensoid boulder-beds; g) close-up of the Torrente Duno Fm. blocks encased in a granite-dominated breccia.

commonly lensoid, of graded and laminated sandstones and dominantly clast-supported breccias, separate decimeter- to several meters-thick boulder beds (Fig. 4f). The marls bear a belemnite association with members of the family Passaloteuthididae ("*Passaloteuthis*" *krimholzi* CINCUROVA, Fig. 4b.), being the latest representatives of the genus *Nannobelus* or earliest representatives of the genus *Passaloteuthis*, which indicate the latest Sinemurian or earliest Pliensbachian (Nino Mariotti, pers. comm. 2014). The clasts in the breccias are angular, up to 90 cm across, and are made of granite, as well as of sandstone/conglomerate of the Mt Paleparto/Torrente Duno Formations (Fig. 4g), and dark limestone of the Bocchigliero Formation. The clast composition is highly variable in the lower beds, while granite gradually becomes almost exclusive upsection. Cut-and-fill structures abound, and load structures (e.g. "flame structures"—Fig. 4e) are common. A lateral accretion pattern (toward the south-eastern quadrants) is observable with meter-thick stacks of low-angle clinoform beds, while small-scale non-tectonic thrusts (Fig. 4d), seen in thin sandstone beds, also have the same general vergence. This set of features indicates growth of an inclined clastic wedge. The vertical trend of clast composition suggests ongoing exhumation of the uplifted basement, following erosion of the pre-/early syn-rift cover, as an effect of synsedimentary extension due to a master fault which, based on map data, had a dip toward the southern quadrants. At least two minor normal faults, having a throw of few meters and dipping roughly toward the NW, are locally linked with thickening of hanging wall clastic beds (Fig. 4c). They can be interpreted as

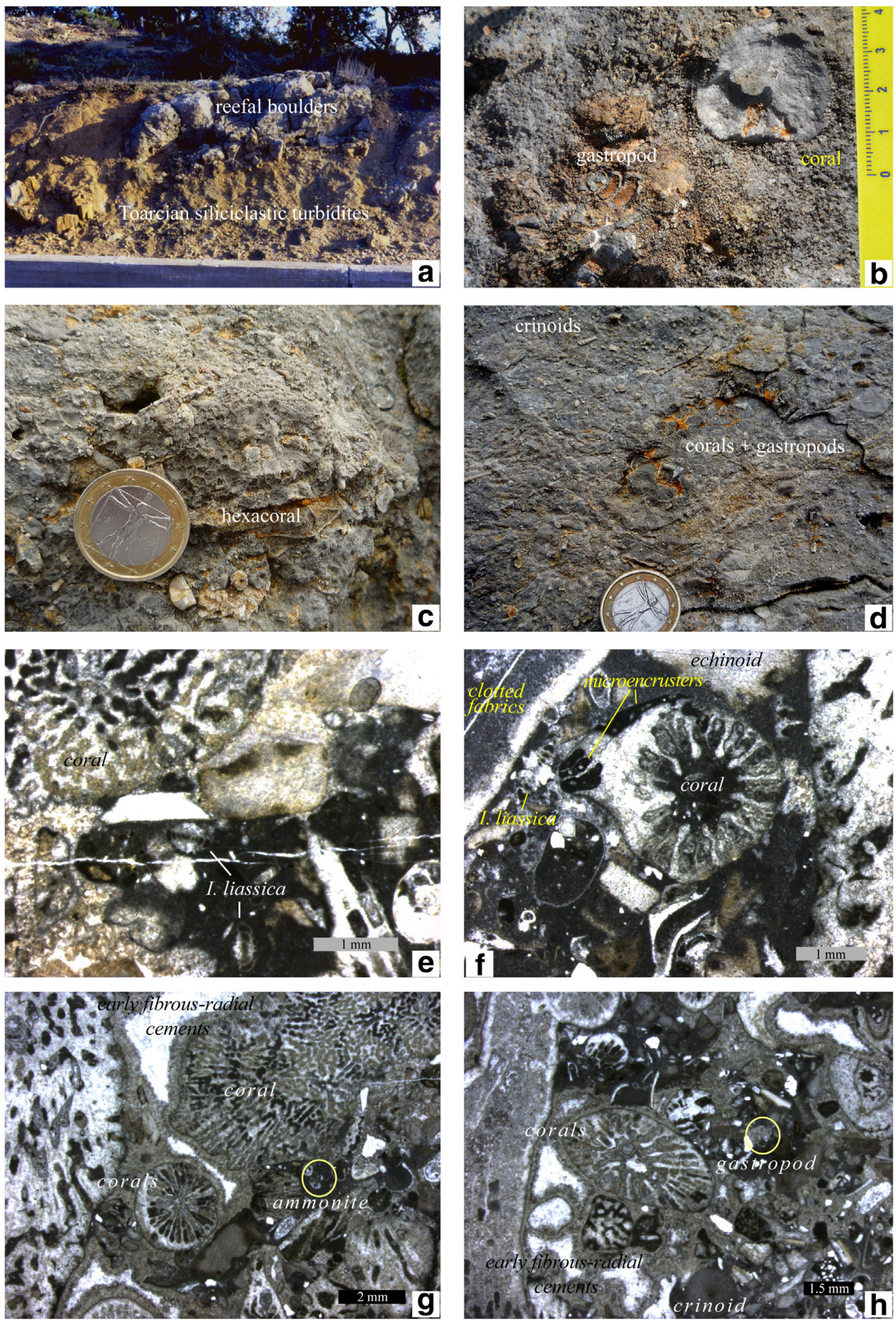

Fig. 5. Outcrop and thin section views of the carbonate boulders encased in the siliciclastic turbidites at "Le Conserve."

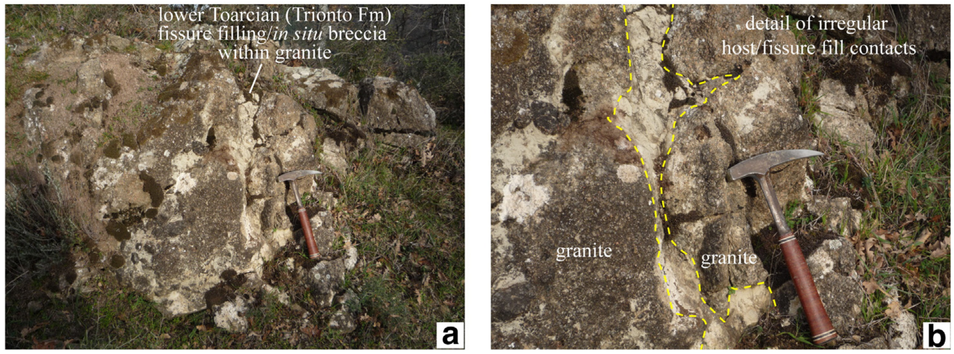

Fig. 6. The "Cozzo di Panna" Jurassic paleoescarpment: fractures in the granite of the footwall block, filled with lower Toarcian pelites.

antithetic synsedimentary faults, which might suggest the underlying growth of a rollover anticline. As this clastic body is encased in the lower part of the Fosso Petrone Formation (see calcareous nannofossil ages in Young et al., 1986), the post-Bocchigliero Fm. (the unit sourcing the younger clasts) deepening of the Longobucco Group Basin was driven by tectonic extension.

Few hundred meters westward of Cozzo del Morto, in a locality named "Conserve," an interval with large (up to >5 m across) boulders made of reefal carbonates with siliciclastic debris (Fig. 5), resembling the Lower Caloveto Formation, is embedded in the ?upper Pliensbachian siliciclastic turbidite succession (dominantly fine-grained sandstone, with common quartzarenites), which is tightly folded and locally overturned. This deformation can be interpreted as a result of buttressing (Underhill and Paterson, 1998), since the basin-margin contact itself is not folded. The boulders, rich in corals, echinoids, crinoids, cephalopods (ammonoids and nautiloids), stromatoporoids, and microbial grains, and locally displaying ripple cross lamination, bear a micropaleontological assemblage with *Agerina martana* and *Involutina liassica*, which indicates an

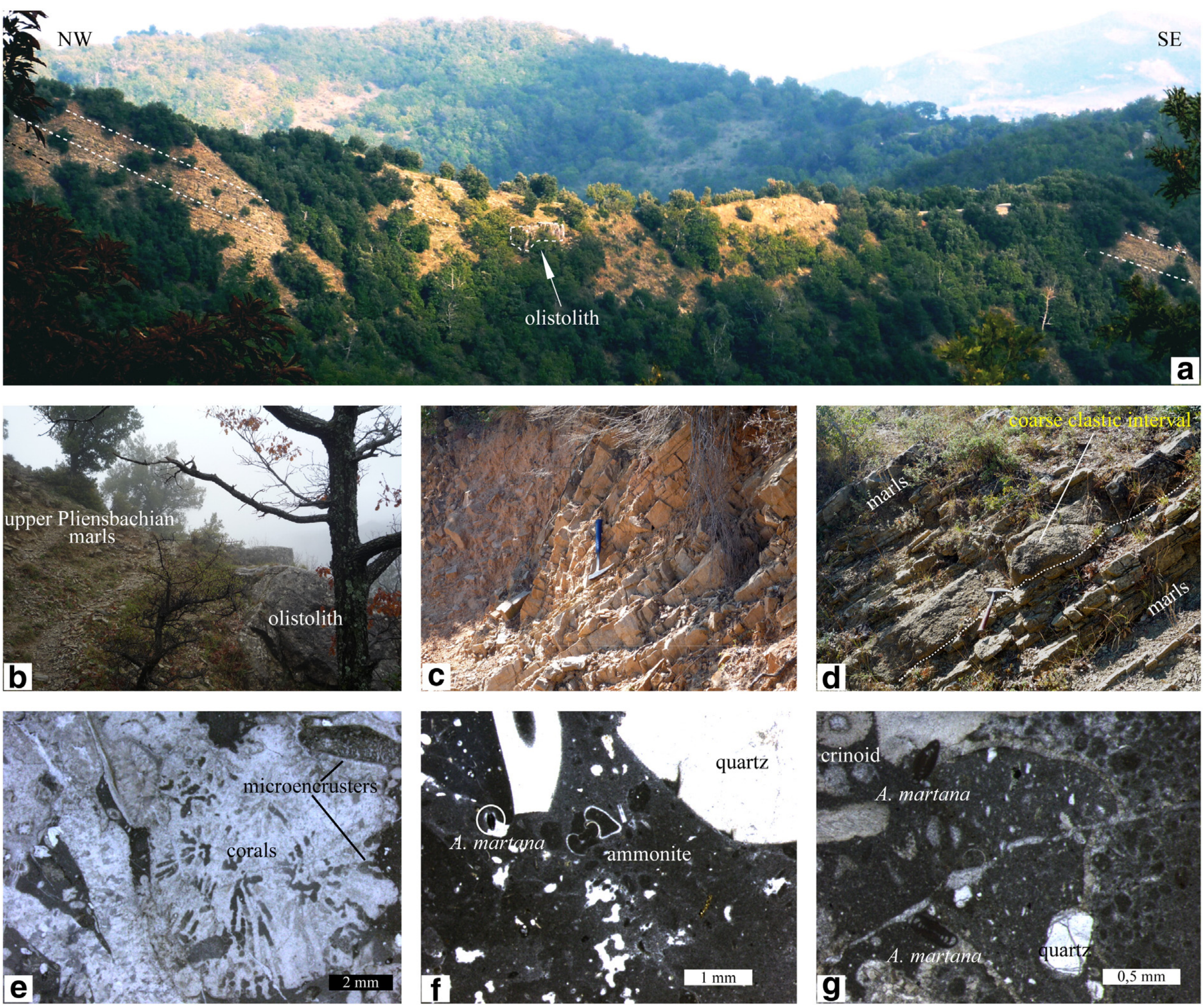

Fig. 7. The lower Jurassic succession at "Pietre di Giudice" (see Fig. 3 for location): a) panoramic view of the succession, with the encased olistolith described in the text; b) close-up of the carbonate olistolith embedded in the marls; c) cross-bedded quartzarenite olistolith (Torrente Duno Fm.) encased in the lower Jurassic marly succession; d) coarse clastic bed with erosional base; e) f) g) selected microfacies of the shallow-water carbonate olistolith shown in "Fig. 7a, b".

early Pliensbachian age for the source unit. A Sinemurian age should be excluded as the Sinemurian is known as a virtually reef-free time slice at global scale (Lathuilière and Marchal, 2009, and bibliography therein). This source formation has not been preserved *in situ*, but the obvious local derivation of clasts and vicinity to the basin-margin suggest it must have existed in the form of a narrow fringing reef attached to the basement high, analogous to the ones preserved in the Colognati valley (see below). The encasing sandstone turbidites, in contrast, were conceivably sourced by the Jurassic Calabrian mainland.

3.1.2. Neptunian dykes in the granite, and buttressing of basin-margin beds—Cozzo di Panna

In this area, the lower Toarcian turbidites of the Trionto Fm. directly abut the granite which constitutes the local basement. The stratigraphic nature of the high-angle contact is documented by a set of neptunian dykes penetrating the granite, made of pelites belonging to the turbidite succession (Fig. 6). The granite is locally overlain by laminated quartzarenites, with plant remains and quartz conglomerate levels, of the Torrente Duno Fm. This outcrop is interpreted as a preserved tract of the basin-margin submarine paleoescarpment whose dismantling, driven by gravity and tectonics, is documented by thick megaclastic lenses (clasts of granite and of continental sandstone) embedded in the onlapping basinal beds. These latter are a thin-bedded hemipelagite/turbidite succession that is folded as an effect of buttressing, in analogy with the previous example. The laterally continuous distribution of these clastic bodies suggests that one paleomargin existed, running from Cozzo del Morto to Cozzo di Panna and then further westwards.

3.1.3. Timing of reef growth at faulted margins, condensed epi-escarpment deposits and buttressing of basin-margin beds—Pietre di Giudice / Malena / Torrente Coserie

Three kilometers South of Paludi, the succession described at Cozzo del Morto as being Sinemurian/Pliensbachian continues for several hundred meters eastward, maintaining its mega-clastic character upsection (loc. Pietre di Giudice—Fig. 7). Marls are initially dominant, bearing plurimetric (to decametric) boulders of the Torrente Duno (including bedstacks of cross-bedded quartzarenite—Fig. 7c) and Bocchigliero Formations, of reefal carbonates of the Lower Caloveto Formation (Fig. 7b), and of granite. Clasts of phyllites are very rare. The top of this interval bears a cephalopod assemblage dated as latest Pliensbachian (late Domerian, Emaciatum Zone, with *Lioceratoides sp.*, and *Canavaria spp.*; F. Venturi pers. comm. 2014). This age suggests that this is a dominantly hemipelagic local facies that is lateral to the Fiume Trionto Fm. sandstone turbidites (see ages in Young et al., 1986). The presence of lithified reefal limestone clasts in the upper Pliensbachian but not in the lower part of the clastic sequence (upper Sinemurian/lower Pliensbachian) can be utilized as a tool for appreciating the start-up time taken by the carbonate factory to settle, at the flanks of the uplifted basement.

The marls are followed by turbidite sandstone (Fiume Trionto Fm.), with sparse granite blocks at the base, exhibiting increasing volumes of phyllite-dominated breccias. The succession then changes, via thin red marls, to the gray Posidonia marls and then pelagic limestone with chert and abundant carbonate turbidites, commonly oolitic (Fig. 8). The basal limestone levels bear a belemnite assemblage with possible representatives of the genera *Pseudohastites sp.* and *Passaloteuthis sp.* indicating a Pliensbachian to Early Aalenian age (N. Mariotti, pers. comm., 2014). Descending south, toward the Torrente Coserie Valley, the turbidites-to-Posidonia limestone succession (Toarcian–Bajocian) at Malena is severely folded. Vertical beds of the Posidonia limestone/radiolarian cherts transition abut the metamorphic basement which is exposed extensively along the Coserie Valley, marking a basin-margin paleoescarpment tract that is at an angle to that which delimits the Cozzo del Morto clastic wedge, where the substrate is granite. It is notable that lenses of gray to pink/red pelagic limestone of probable Pliensbachian age, with sponge spicules, crinoids, gastropods, ammonoids and abundant angular phyllite clasts (Fig. 8), are found interposed

Fig. 8. The Malena paleomargin: phyllite clasts are encased in a red condensed limestone matrix.

between the basement and the basin-filling turbidite sandstone succession. These can be interpreted as epi-escarpment deposits (Galluzzo and Santantonio, 2002; Carminati and Santantonio, 2005), being autochthonous condensed deposits, hosting locally derived debris, which constitute a thin laterally discontinuous drape over the substrate exposed at the basin-margin footwall escarpment. They represent an instructive example of how perched pelagic carbonate deposits can be sedimented, and locally preserved, at the escarpment margins of a siliciclastic basin. The folds seen in the basin-margin succession and vertical beds at the contact are interpreted as due to buttressing (Underhill and Paterson, 1998) as, here as in the previous examples, the paleo-escarpment itself is not folded.

3.2. The Torrente Colognati area

3.2.1. Pelagic deposits onlapping the Paleozoic granite, preserved slide scar, and condensed fossiliferous epi-breccia deposits, and buttressing of basin-margin beds—Higher Colognati Valley

Along the circa N60°E trending valley of the Colognati River (Fig. 3), an alignment of Jurassic to Oligocene rocks resting on the Paleozoic basement documents the preserved tract of a basin-margin, with a lateral continuity in excess of 10 km. Attached *via* a high angle unconformable contact to the basement, which is made of phyllites at lower elevations (see next section), and of granite higher in the valley, a discontinuous fringe of lime rud- to grainstones documents the growth of a narrow carbonate apron in the Pliensbachian, in shallow water high-energy conditions. Toarcian to Lower Cretaceous (very thin calpionellid limestone, “Maiolica” facies) hemipelagic and pelagic deposits (Upper Caloveto Formation Rosso Ammonitico, Posidonia marls, radiolarites, Aptychus limestone, calpionellid limestone) onlap and drape this complex (Fig. 9c). In one remarkable locality (Il Torno; Santantonio and Teale, 1987; Santantonio, 1991, 1993; Fig. 9), the pelagites (red Posidonia marls) onlap the granite directly (Fig. 9b), and downdip they bear megaclastic deposits in levels of latest Toarcian age (Fig. 9a), with clasts of both the granite and of the shallow-water limestone that had to be originally attached to the crystalline basement. The pile of clastic deposits formed a morphological high in the local sea-

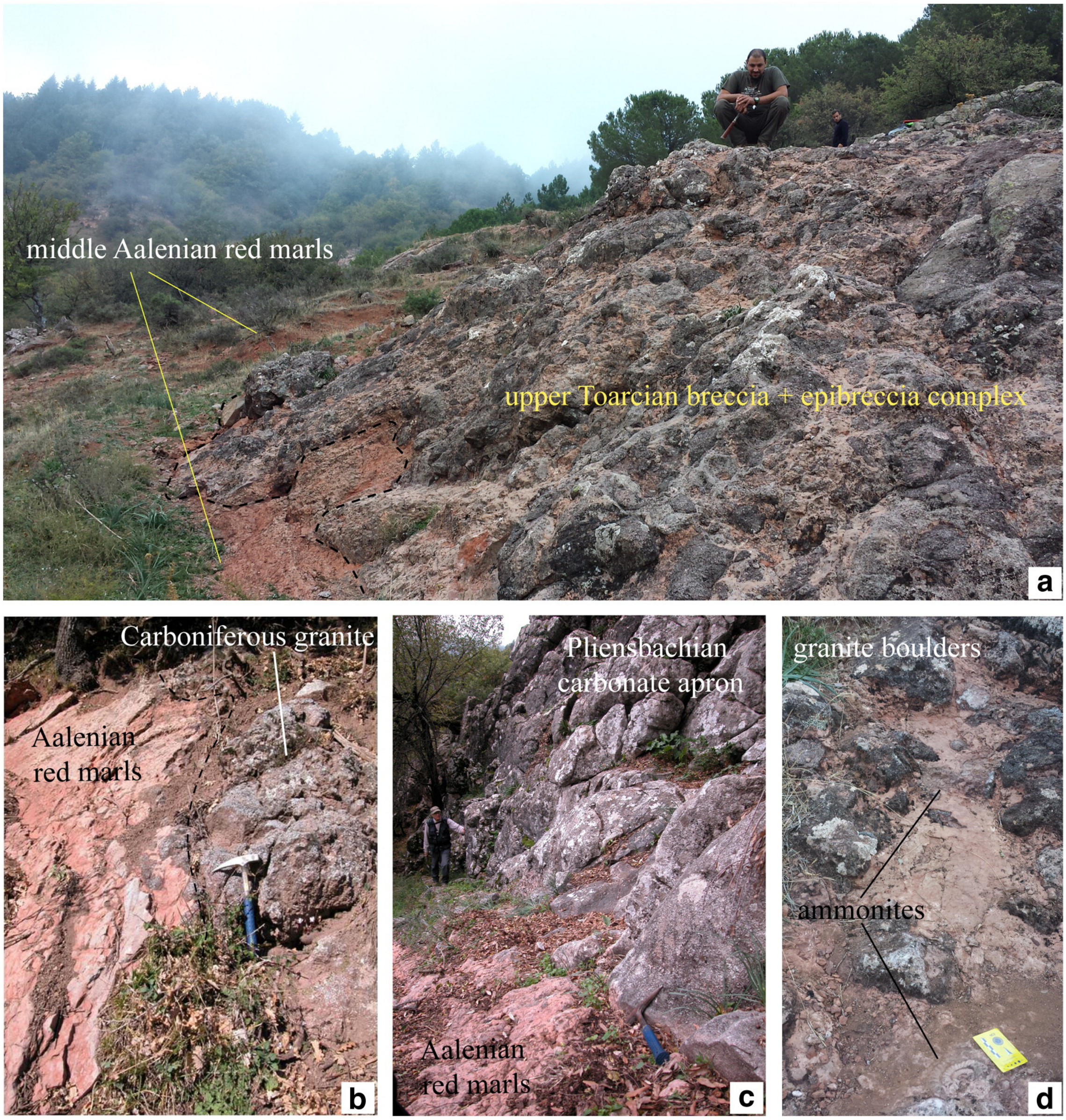

Fig. 9. Field views of key outcrops at "Il Torno": a) megabreccia onlapped by Aalenian marls; b) detail of the Aalenian marls directly onlapping the granite; c) onlap contact of the Aalenian marls on the carbonate apron; d) typical aspect of the condensed epibreccia limestone.

floor topography, and features as such a spectacular example of perched condensed pelagic drape (Fig. 9d), representing an epi-breccia deposit (Galluzzo and Santantonio, 2002). The thin drape, bearing a rich cephalopod assemblage with mixed latest Toarcian to early Aalenian ammonites, developed as Fe-Mn oxides encrusted the exposed surfaces of clasts and shells, and the submarine relief was being slowly smoothed out by hemipelagic sediment, a process which was completed in the middle Aalenian (Santantonio and Teale, 1987). The boulder beds represent the submarine slides that were triggered by catastrophic collapse of a tract of the local basin-margin, which left a 250 m across mappable hemicircular scar in the granite (Fig. 10), sealed by the onlapping basin-fill succession, which bears multiple pinch-out unconformities like the one caused by the lateral thin-out to zero of radiolarian cherts.

About 4 km down the Colognati valley from "Il Torno," at a locality called Sant'Onofrio (Santantonio, 1991, 1993; Fig. 11), the onlap of younger units on the granite, which exhibits pervasive Toarcian neptunian dykes (Fig. 11c), is documented by a succession of Posidonia limestone with black chert, radiolarites (Fig. 11b–d), clastic and marly Maiolica, with black shale levels in the Hauterivian–?Barremian (J. R. Young, pers. comm., 1985), all unconformably overlain by Oligocene glauconite-rich sandstone. An interesting structural feature is that the Maiolica and radiolarites, onlapping the granite, locally form an overturned succession which is cut by a subvertical strike-slip fault. This can be interpreted as a result of severe buttressing against the granite during the orogenic phase (Fig. 12), accompanied and accommodated by tear faulting as the paleomargin of the basin, at the hanging wall of a thrust, dipped obliquely (to the SSE) toward the developing thrust (tectonic transport to the N or NNE). The fact that buttressing is not observed at Il Torno can be interpreted as due to the local presence of a backthrust, having the paleomargin and onlapping basinal deposits at the hanging wall and vertical beds of pelagic marl and sandstone (Eocene–Oligocene) at the footwall. The backthrust would have accommodated some of the shortening, implied by the buttressing, through folding of the footwall beds (Fig. 12).

3.2.2. Marginal reefs, epi-escarpment deposits, and banded bacterial microbialites—Lower Colognati Valley

The lower Valley of the Colognati River, near the small town of Rossano (bridge at "Contrada Colagnati," Cerzeto), exposes the phyllite basement, which is here overlain by white to pink limestone of the

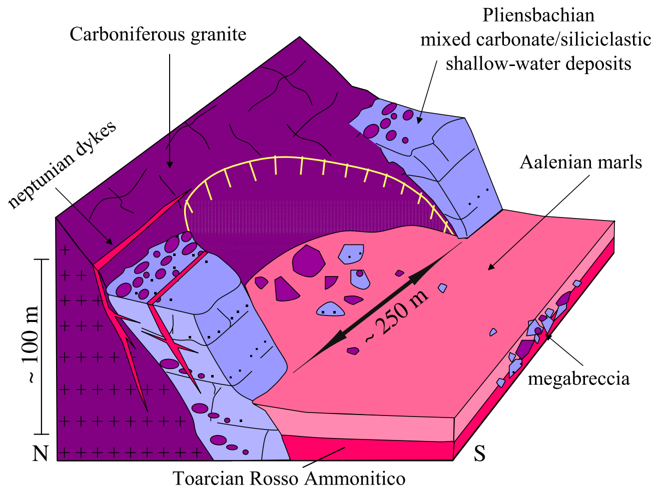

Fig. 10. Schematic reconstruction (not to scale) of the geological setting at "Il Torno"; the slide which produced the megabreccia carved a scar in the carbonate apron and the granite basement.

Lower Caloveto Formation, bearing a rich assemblage of crinoids, gastropods, lamellibranchs, brachiopods and nautiloids, and crystalline clasts. The complex is unconformably overlain by red pelagic limestone (Toarcian), with cephalopods and thin shelled bivalves ("posidoniids"). The condensed/lithoclastic nature of these pelagites is the typical feature or epi-escarpment deposits (Santantonio, 1993; Galluzzo and Santantonio, 2002), due to deposition and occasional preservation in perched sites on this dominantly erosional basin-margin. The contact of the white limestone with the Paleozoic is often poorly exposed, as modern erosion has caused the detachment of the limestone, producing chaotic piles of limestone boulders. Banded black/gray/red microbialites are found at the contact with the metamorphites, which host a network of pink pelagites filling fractures and sheet-like cavities along cleavage planes (Fig. 13b). This is in analogy with the Caloveto area (Santantonio, 2012), as will be described below.

3.3. The Caloveto area

3.3.1. Faulting and pervasive fracturing of the structural high, platform drowning, banded bacterial microbialites at basin-margin unconformity, and silicification of shallow-water limestone at the contact with basinal pelagites—Cozzo di Mastro Pasquale

The area around the village of Caloveto displays an only mildly deformed picture of the Jurassic submarine topography. Hills made essentially of phyllites are surrounded by narrow (generally <100 m across) wedge-like aprons of limestone of the Lower Caloveto Formation (Pliensbachian), up to about 100 m thick, with common reef facies, which developed in the syn-extensional regime envisaged above. The high-angle stratigraphic contact with the basement is locally marked by banded varicolored microbialites with associated cements and black *Frutexites* (Fig. 13e), which also grew utilizing and enlarging cleavage planes in the phyllites (Santantonio, 2012). The clotted fabrics, preserved filamentous remains, and odd "cement-supported" bands of peloid-rich sediment (Fig. 13d, f) strikingly resemble those described by Woods and Baud (2008) from the Triassic of Oman. The banded microbialites are cut by red Toarcian neptunian dykes (Fig. 13a,c), and they could be Pliensbachian in age. As the microbialites are found at several basin-margin localities in the Caloveto Group (see below), their occurrence can be now held as a field marker of the basin-margin unconformity even in those localities where the limestone/metamorphites contact is poorly preserved. The non-conformable shallow water deposits bear conglomerates with basement-derived debris,

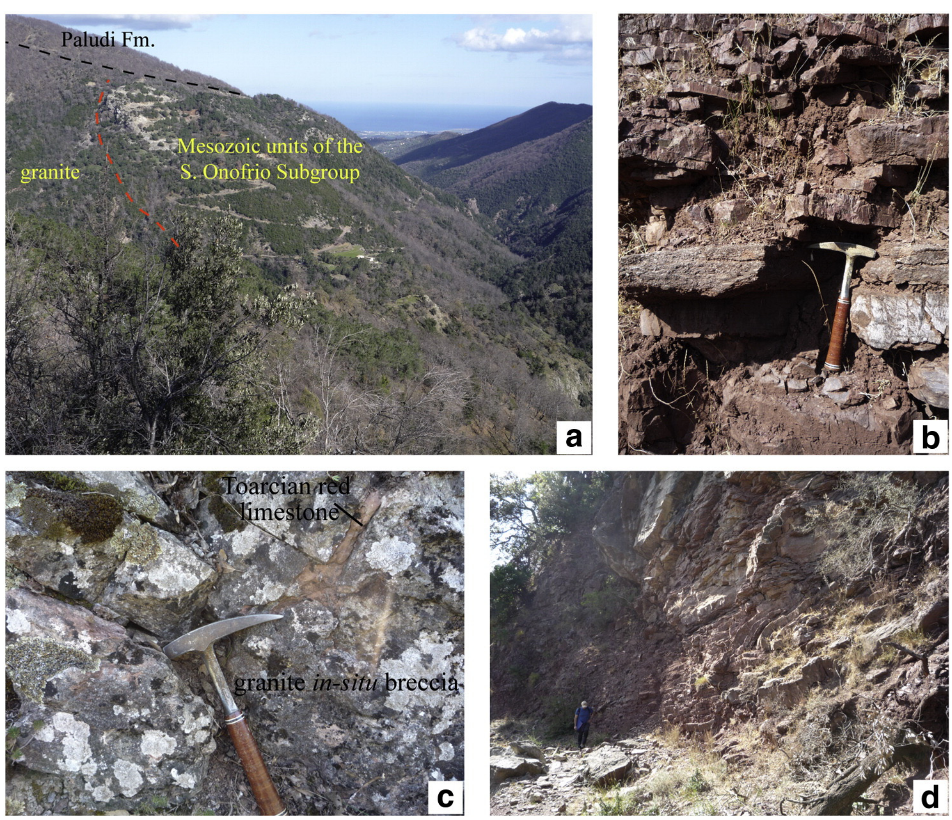

Fig. 11. The Sant'Onofrio Jurassic sequence: a) panoramic view of the Sant'Onofrio mountainside where the Mesozoic units are beautifully exposed; b) detail of a clastic level in the radiolarian cherts; c) aspect of the granite at the stratigraphic contact with the sedimentary units; d) view of the thickest section of radiolarian cherts to be observed in the whole study area (note: apparent thickness of the cherts is locally also a product of folding).

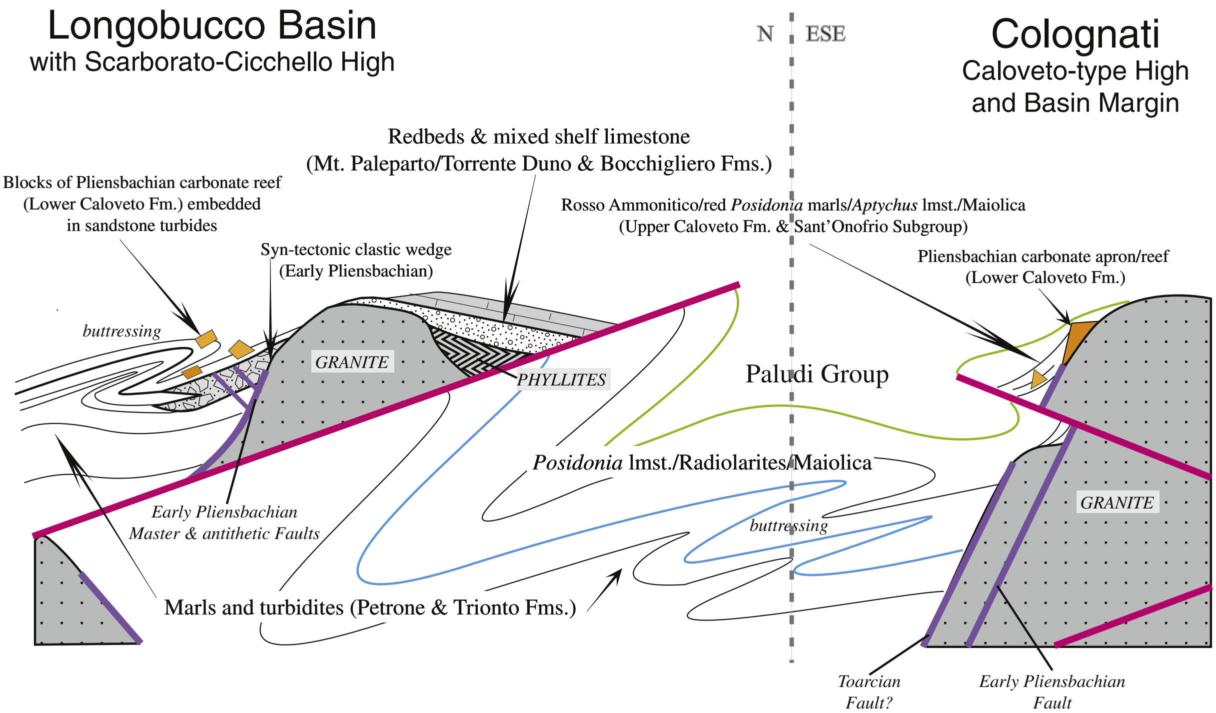

Fig. 12. Cartoon depicting the relationships existing between Jurassic extensional features and orogenic deformation in the study area. Note buttressing of the basinal strata against the paleoescarpments.

indicating a rocky shore environment surrounding small islands made of Paleozoic basement (Fig. 14). The final drowning of this carbonate factory is marked by thin Rosso Ammonitico (Upper Caloveto Formation—Fig. 15f–h), which also filled fractures affecting the early lithified limestone (Fig. 15g–f) and the basement as faulting continued through (or was resumed in) the Toarcian. The drowning unconformity of the Lower Caloveto Fm. is seen as a mineralized hardground on a tectonically downstepped terrace in the Cozzo di Mastro Pasquale area (Fig. 15e–f), with ammonites of the lower (not basal) Toarcian (*Eopolyplectus sp.*) (Santantonio, 1991). The Caloveto area displays, besides microbialites, an array of rather unusual features. The dense network of Toarcian faults and fractures produced *in situ* breccias

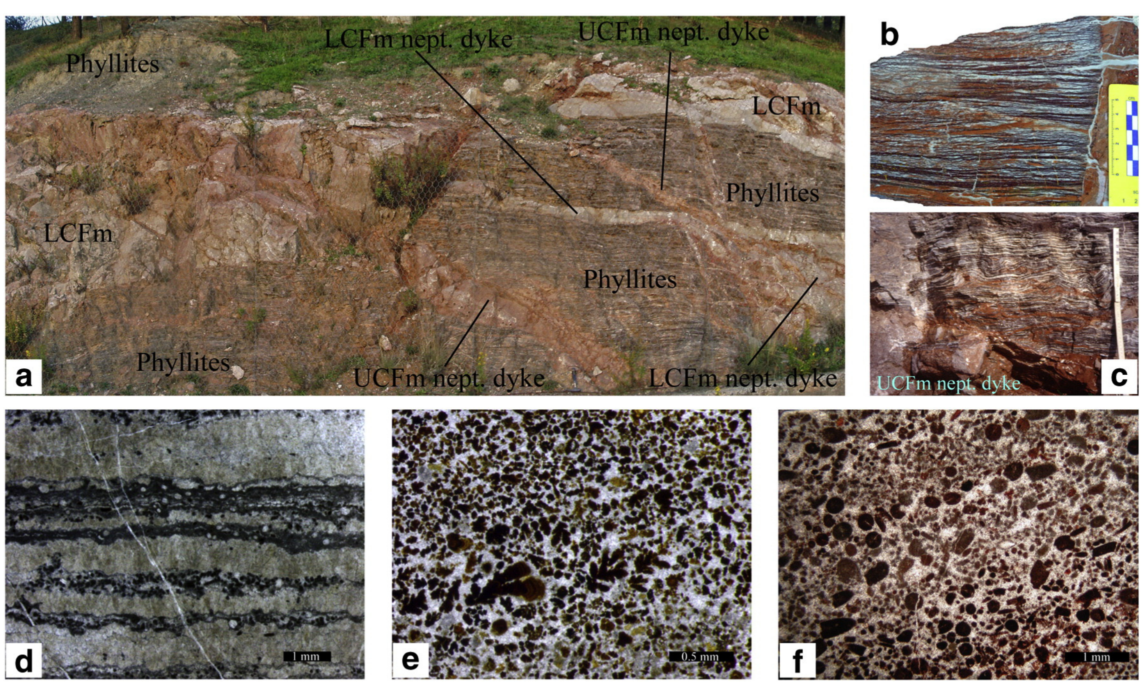

Fig. 13. Bacterial/microbial calcite precipitation affecting phyllites at basin-margin: a) spectacular outcrop along the road Caloveto–Bocchigliero; a network of diachronous neptunian dykes cuts the metamorphites bearing white cleavage-parallel calcite bands and red/black microbial/bacterial bands; b) polished surface of the phyllites, with calcite bands and red UCFm neptunian dykes (Contrada Colagnati); C) same features as in "Fig. 13b," outcrop view (Caloveto); d) thin section view of preserved micropeloidal "clotted" fabrics in "clear" calcite bands within the phyllites (Contrada Colagnati); e) *Frutexites*-dominated microfacies, marking the paleomargin tract at Contrada Colagnati; f) bacterial red facies along the Caloveto paleomargin (see Fig. 13a, c). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

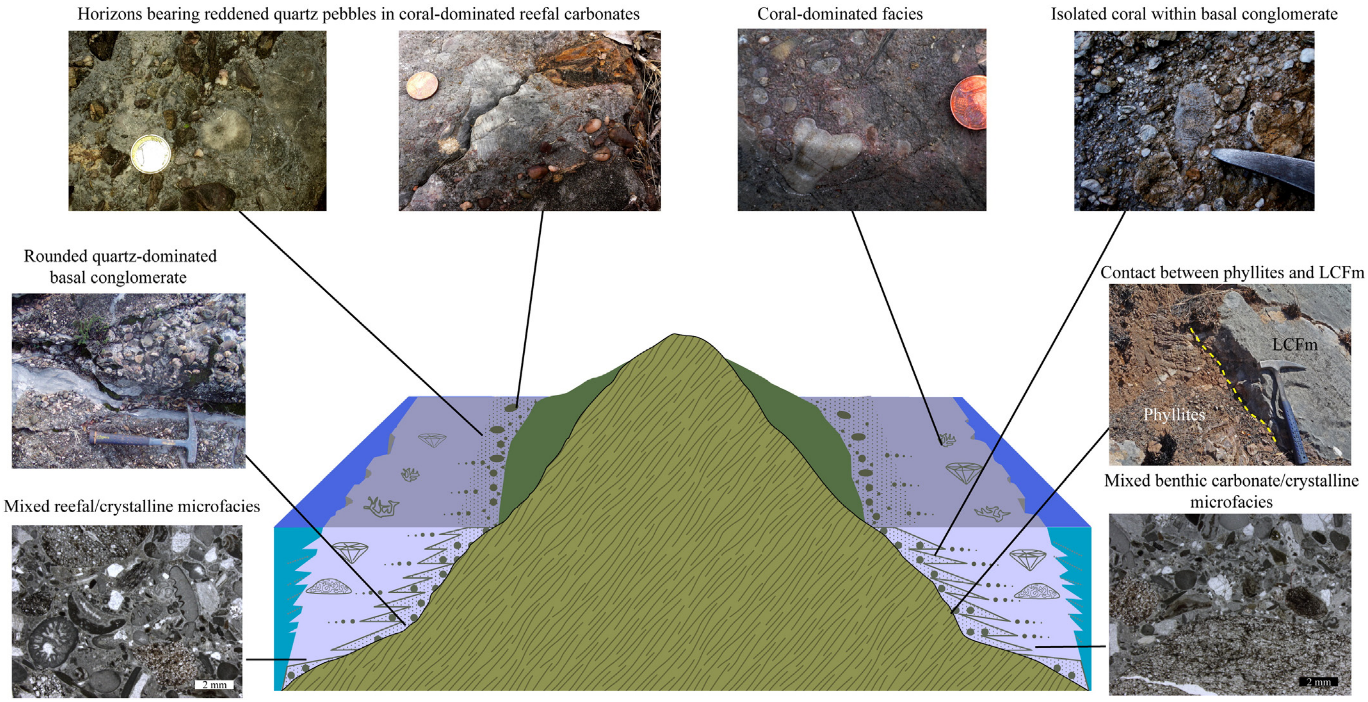

Fig. 14. The Lower Caloveto Fm.: Ideal sketch of the carbonate apron/island system exposed at Cozzo di Mastro Pasquale and Carito (see Fig. 3 for location), with distribution of the main facies. The outcrop pictures of the LCFm were taken at Carito, at Cozzo di Mastro Pasquale, and along the road Caloveto–Bocchigliero. The two photomicrographs are from samples collected along the northern slopes of the Carito area.

(Fig. 15a–c–d), with fabrics ranging from "fitted" to chaotic, and exhumed the metamorphic substrate, which was locally draped by thin veneers of Rosso Ammonitico (Fig. 15d). This complex was then onlapped by the Posidonia marls and the radiolarites (Fig. 15a–b–d–e–i), which sealed the rugged submarine topography. By striking analogy with Northern Apennines, the contact displays a strong diagenetic signature in the form of silicification of the Lower Caloveto limestone (Fig. 15g). This has been interpreted as the result of precipitation after silica-rich diagenetic fluids, sourced by the basinal formations bearing organisms with unstable (opaline) siliceous skeletons (*e.g.* the cherty radiolarites), which took place at the unconformity and outer rim of the shallow-water limestone, which was still porous (Santantonio et al., 1996; Galluzzo and Santantonio, 2002). The silicified surface and perched ponds of condensed pelagites (epi-escarpment deposits) define the beautifully preserved submarine topography with spurs, grooves, and terraces, which constitute the present-day landscape in this part of Calabria (Fig. 15a).

3.3.2. Drowning succession of the Lower Caloveto Fm. carbonate factory—Carito

At Carito (near Cozzo di Mastro Pasquale, see Fig. 3), the transition from the white shallow-water limestone of the Lower Caloveto Fm., which fringed the basement islands, to the pelagic Rosso Ammonitico facies of the Upper Caloveto Fm. (Toarcian *p.p.*) is documented by a bedset with spectacular pink brachiopod (mostly rhynchonellids)–coquina pack/grainstones (Fig. 16), about 4 m thick, with rare ammonites (*Arieticeras sp*., upper Domerian). They are overlain by an about 2 m thick encrinite, bearing angular metamorphic debris (Fig. 16). These levels have been interpreted (Santantonio, 2012) as the drowning succession (*sensu* Marino and Santantonio, 2010, and references therein) of the Lower Caloveto Fm. carbonate system, meaning a unit bearing the products of both the benthic and planktonic carbonate factories, and are capped by an erosional surface which is unconformably overlain by the red *Posidonia* marls (Aalenian). The preservation of this thin transitional interval here is unusual, as elsewhere across the area synsedimentary tectonic fragmentation fostered the detachment of the carbonate fringes from the basement, producing both *in situ* (with fitted fabrics) and chaotic breccias, and paving the way for the development of hardgrounds representing drowning unconformities, as mentioned above.

4. Sedimentary and tectonic evolution of the Calabrian continental margin (Fig. 17)

The Late Paleozoic–Early Mesozoic of Calabria was part of a vast non-subsident high of the Hercynian basement until the latest Triassic (Rhaetian), when thin fluvial deposits document the inception of the "Alpine" sedimentary cycle (Perrone et al., 2006; Zaghloul et al., 2010; Perri et al., 2011, 2013; Santantonio and Carminati, 2011). This occurred at the periphery of a continental rift, which elsewhere is documented by a few kilometers-thick succession of syntectonic continental to marginal marine deposits. A marine transgression is recorded by mixed carbonate-siliciclastic shelf deposits with common ooid bars and abundant plant material. While only local evidence exists for growth faulting during this early transgressive phase (Santantonio, unpublished data), this wide shelf became greatly extended around the Sinemurian/Pliensbachian boundary. As hanging wall basins subsided rapidly, hosting a deep shelf to turbidite basin succession up to >1 km thick in the Pliensbachian–early Toarcian, the footwall blocks stood proud to constitute an offshore belt of small islands encircled by ephemeral narrow fringes of dominantly reef carbonates. Interestingly, the exhumed phyllite basement along faults was initially colonized by microbial communities (Santantonio, 2012), documented by clotted fabrics, *Frutexites*, and bacterially induced cementation. Erosion of the crystalline basement at basin-margins, linked with ongoing faulting, was accompanied by frequent rockfalls, producing laterally continuous megaclastic belts which were the sites of free-fall (Teale and Young, 1987), debris flow, and rock avalanche processes (Teale, 1988; Santantonio, 1993). The widespread submarine exposure of basement rocks at the footwall of synsedimentary faults resulted in the onlaps of basin-fill units, both clastic and pelagic, on phyllites or granite. A new tectonic phase in the

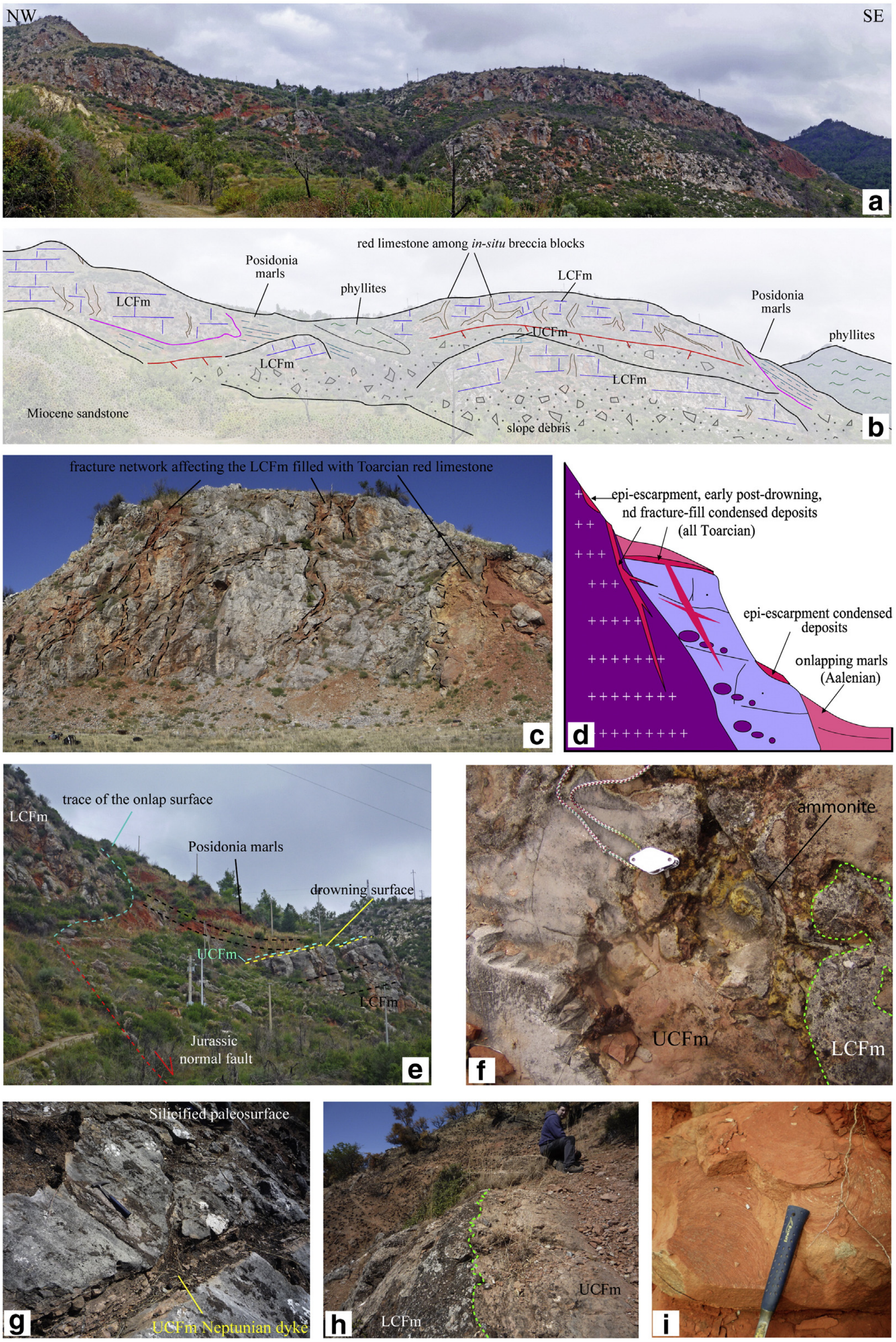

Fig. 15. The magnificently exposed and preserved Jurassic geology around the village of Caloveto (see Fig. 3 for location): a) Panoramic view of the Cozzo di Mastro Pasquale area, taken from the south; b) geological interpretation of Fig. 15a; c) LCFm cut by pervasive UCFm neptunian dykes at the "Cozzo di Mastro Pasquale" quarry (the cliff is about 50 m high); d) cartoon (not to scale) depicting the main stratigraphic relationships in the Caloveto area; e) field view and interpretation of preserved Jurassic geometries south of Cozzo di Mastro Pasquale; the LCFm lowered step is topped by a drowning surface, all unconformably sealed by Aalenian red marls (electric line pylons for scale are ~15 m high); f) detail of the very thin veneer of UCFm which covers the drowning surface indicated in "e": the microtopography of the surface was not totally flat, with "islands" of LCFm surrounded by the UCFm; g) silicified high angle paleoescarpment on the LCFm; the shallow water carbonate succession is here cut by a large UCFm neptunian dyke at Cozzo di Mastro Pasquale; h) unconformable contact between the LCFm and the UCFm along the southern slope of Cozzo di Mastro Pasquale; i) typical aspect of the Posidonia red marls with *Zoophycos* in the Caloveto area. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

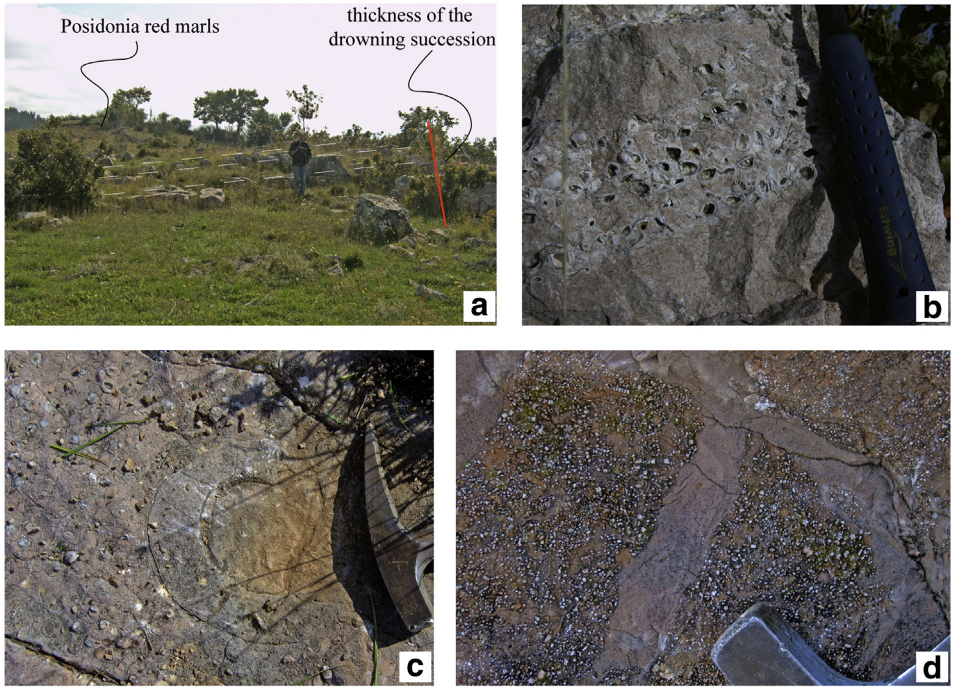

Fig. 16. Field view and details of the drowning succession at Carito: a) picture showing the entire thickness of the drowning succession; b) brachiopod coquina bed; c) detail of an ammonite in the brachiopod-rich bed; d) crinoid-rich facies, dissected by neptunian dykes of "Rosso Ammonitico" facies (UCFm).

Toarcian resulted in the rejuvenation of Pliensbachian margins, as well as in the fragmentation and foundering of the footwall-block islands, where drowning of the carbonate factories at their flanks is documented by Rosso Ammonitico caps. Widespread pelagic conditions in the Middle and Late Jurassic, in a dominantly post-rift regime possibly coeval with sea-floor spreading in the adjacent branch of the Liguria–Piedmont Ocean, are recorded by *Posidonia* limestone, cherty radiolarites, and *Aptychus* limestone, followed by Maiolica facies in the Early Cretaceous (these units are grouped in the Sant'Onofrio Subgroup). These pelagic deposits host resedimented levels which bear locally derived basement material, as well as distal turbidites with shallow water material which were sourced by unpreserved carbonate factories in the Longobucco Basin, like those found in Southern Calabria (Stilo Unit; Ogniben, 1973; Amodio-Morelli et al., 1976) and Eastern Sardinia (Costamagna and Barca, 2004; Jadoul et al., 2010 *cum bibl.*). The involvement of the Longobucco Basin in orogenic processes produced widespread unconformities at the base of the Eocene–early Miocene Paludi Group (Critelli, 1999; Critelli et al., 2011, 2013). This is also documented by spectacular buttressing of the basin-fill units against the submarine paleoescarpments in the Paludi area. The intrabasinal highs, marginal Early Jurassic fault escarpments, and onlapping basinal deposits are commonly found carried piggyback at the hanging wall of thrusts, with folded basinal deposits at the footwall.

5. Comparisons with other Jurassic Tethyan margins

The earliest papers that take into account modern concepts in their descriptions of rifted Tethyan margins are the seminal papers by Bernoulli (1964, 1971), Jenkyns and Torrens (1971), Jenkyns (1970), Bernoulli and Renz (1970), Colacicchi et al. (1970), Castellarin (1972), Bernoulli and Jenkyns (1974), and de Graciansky et al. (1979). Interestingly, most of the above papers are centered on the Italian Jurassic (Alps, Apennines, Sicily), and thus describe carbonate margins belonging to the African/Adriatic plate (or plates). Following this early bloom, a wealth of sedimentological/structural papers flourished on the peri-Mediterranean rifted margins (see reviews in Lemoine and Trümpy, 1987; Santantonio, 1994, and Santantonio and Carminati, 2011). The common denominator of the above regions, with the exception of western Southern Alps, is a post-Hercynian history of pronounced subsidence, accompanied by marine transgression and locally crustal stretching (e.g. Ladinian of Eastern Alps and the Adriatic subsurface; Čadjenović et al., 2008; Berra and Carminati, 2010), and deposition of several kilometers-thick Triassic carbonate and evaporite deposits. Due to this, the Paleozoic crystalline or metamorphic basement was deeply buried when extension started in the Hettangian. The Jurassic pre-, syn-, and early post-rift deposits are therefore dominantly carbonates, and examples of mixed siliciclastic/carbonate sediments are generally missing as the throw of synsedimentary faults was generally insufficient to unroof any basement non-carbonate rocks. The Umbria–Marche and Sabina regions in Northern Apennines are a good example in this respect, as the vertical displacement along individual late Hettangian–Sinemurian faults was relatively modest and can be estimated to range from ~1 km (most typical) to perhaps about 2 km (Sabina Basin; Galluzzo and Santantonio, 2002). This was a consequence of rift faults splaying from a shallow detachment horizon found in the thick (~1.5 km) Norian salt (Santantonio and Carminati, 2011), so that the tectonic displacement was of the same order of magnitude of the thickness of the Upper Triassic–Hettangian sedimentary succession. Individual deep seated, large-displacement faults, in contrast, can be traced in the Alps down to the brittle/ductile transition, in absence of any obvious shallower detachment level in the local stratigraphy (dolostones replace evaporites in the Norian) (Santantonio and Carminati, 2011, and references therein).

The sub-sections below will briefly address for comparative purposes the evolution of those Jurassic rifted regions which, following sea-floor spreading across the Western Tethys and plate separation, found themselves attached to the Iberian–European plate or, according to some authors (Bonardi et al., 2008; Perrone et al., 2006; Critelli et al., 2008; Carminati et al., 2012; Perri et al., 2013), to a separate microplate ("AlKaPeCa") (Fig. 18). It will become apparent to the reader that the

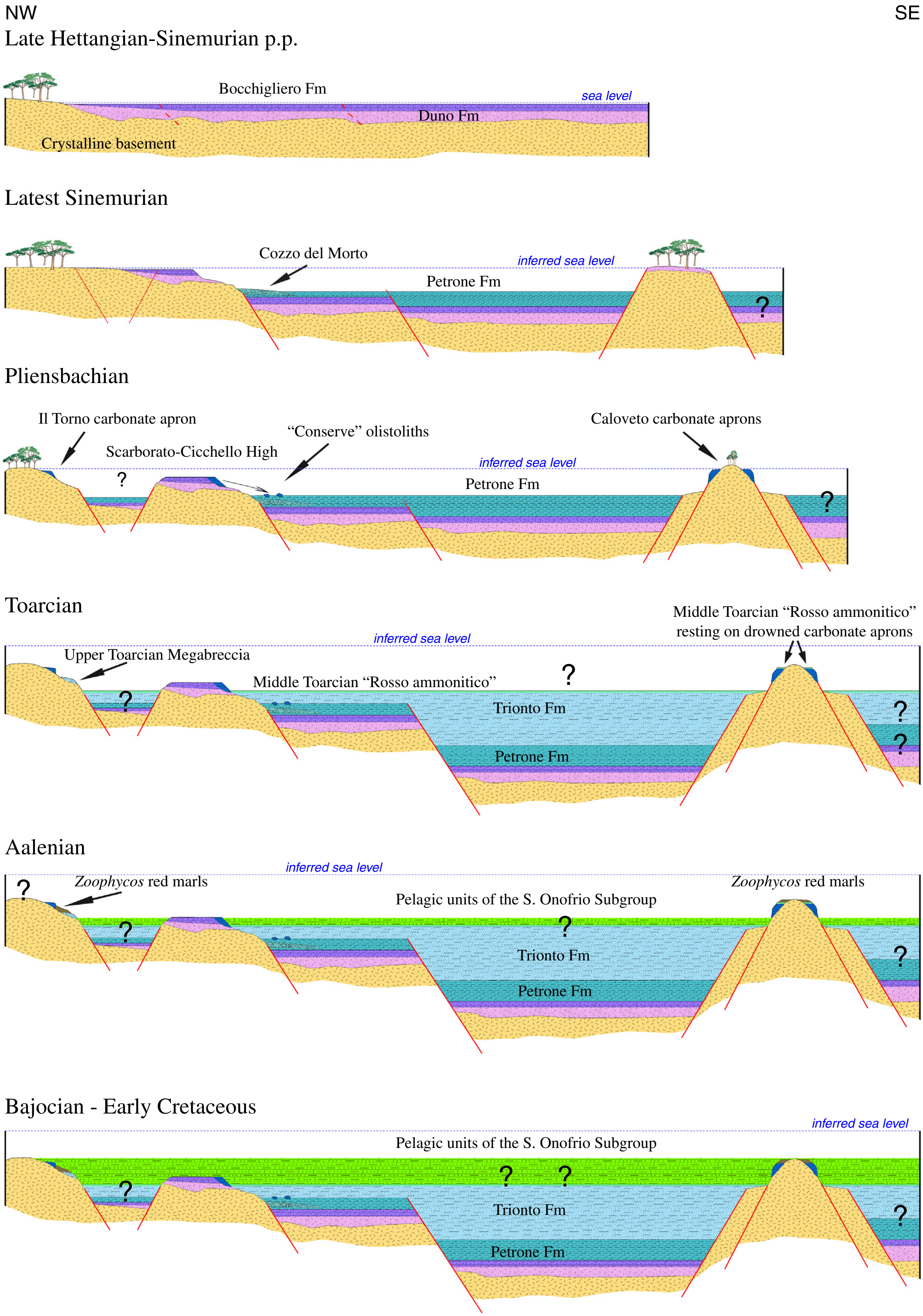

Fig. 17. Jurassic to Early Cretaceous tectono-stratigraphic evolution of the Longobucco Basin.

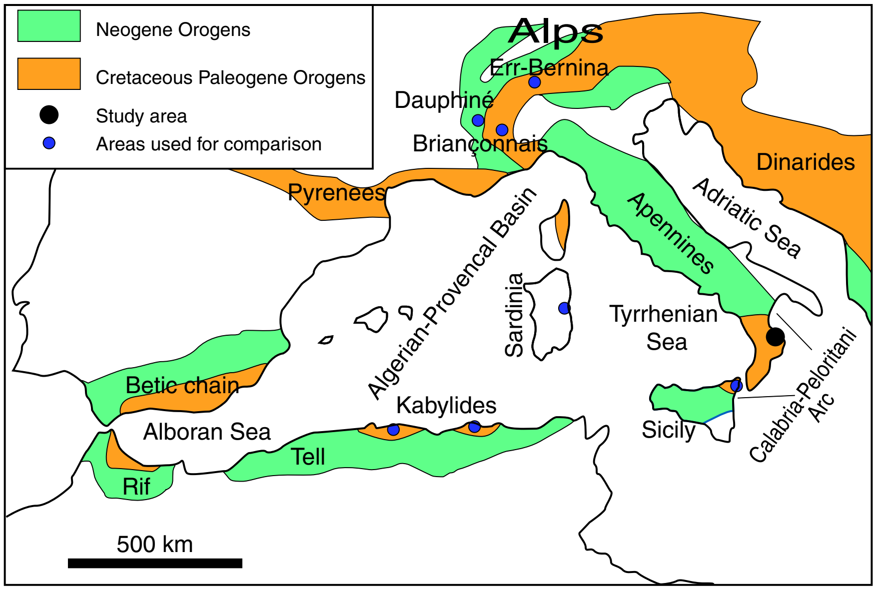

Fig. 18. Geological sketch map of the Western Mediterranean region, with location of the areas discussed in text.

spectacular preservation of basin-margin paleofaults/paleoescarpments in Calabria represents a very rare occurrence across the paleogeographic domain this part of Calabria had to be part of. As such, it can serve as a reference for other rift basins of the West-Tethyan Jurassic.

5.1. Eastern Sicily and Sardinia

Exposure of the basement at faulted basin-margins in Calabria is not itself an evidence for deep seating of the faults, but rather an indication of its topographically elevated initial position (as exposed landmass or shallow-buried substrate) as marine flooding progressed and rifting started. Other regions where the "Alpine" sedimentary cycle started in the Rhaetian–Hettangian or later, due to the existence of a broad high of the Hercynian basement, include the Peloritani Mts. in Sicily, and Sardinia.

The Peloritani Mts. of Eastern Sicily are considered to belong to the same paleogeographic domain as the northern Calabrian successions ("Calabride Units," Ogniben, 1973). In the Taormina area, the Hettangian red-beds, few tens of meters thick, rest non-conformably on the metamorphic basement, and are followed by less than 100 m (rarely up to 300 m) thick shallow-water shelf mixed carbonates and siliciclastics (Lentini and Vezzani, 1975; Servizio Geologico d'Italia, 2009; Perri et al., 2011). These in turn change vertically into a dominantly hemipelagic/pelagic succession, which is markedly condensed on the Early Jurassic structural highs (Lentini and Vezzani, 1975, and references therein). While the sedimentology of formations up to the Lower Cretaceous, bearing ubiquitous Paleozoic debris, indicates that the basement had been exposed at basin-margins throughout the Jurassic (Servizio Geologico d'Italia, 2009), there is apparently no field evidence of exhumed fault zones. Bouillin et al. (1992) describe small-scale (few meters vertical displacement) Early Pliensbachian faults in the carbonate succession, as well as neptunian dykes made of pelagic sediment (several generations, starting from the Lower Jurassic) penetrating the Hercynian basement.

Sardinia displays no, or only very thin (few tens of meters) Triassic and Lower Jurassic sediments in its Eastern sector, facing the Tyrrhenian Sea (Servizio Geologico d'Italia, 2002). The sedimentary cycle linked with opening of the Western Tethys had a delayed start in the Middle Jurassic (Bajocian), with thin fluvial conglomerates followed by marine carbonates documenting substantial (up to ~1 km) continental margin subsidence in the late Middle and Late Jurassic (Costamagna et al., 2007; Lanfranchi et al., 2011, and bibliography therein). No field evidence of the faults which are inferred to have initially accompanied this marine transgression has been described to date, with the partial exception of the growth faults reported in prograding Tithonian carbonates by Jadoul et al. (2014). Also, no pelagic basins are reported from the Sardinian Jurassic, which is evidence that foundering of the continental margin was compensated for by fast production of shallow water carbonates. Sardinia bears no direct evidence for any rift-phase extension in the Early Jurassic.

5.2. Dauphinois–Briançonnais zone

In the Western Alps, several authors have mentioned Jurassic normal faults producing a complex submarine paleotopography (Lemoine and Trümpy, 1987; Butler, 1989; Coward et al., 1991; Chevalier et al., 2003; Bertok et al., 2011). The Dauphinois zone is characterized by half-grabens, filled with km-thick lower Jurassic sequences, while on morpho-structural highs, the coeval successions are condensed, and only up to a few meters thick (Coward et al., 1991; Chevalier et al., 2003).

The main Jurassic faults (La Mure ft., Ornon ft., Grand Rousses ft.) show throws in excess of 1.5 km (Chevalier et al., 2003), with submarine exposure of the crystalline basement (Butler, 1989; Coward et al., 1991), as evidenced by paleozoic olistoliths in the graben-fill sequences (e.g. the Bourg d'Oisans basin). The main Jurassic high in the region was the fault-bounded Taillefer–Belledonne massif (Coward et al., 1991; Butler, 1989; Chevalier et al., 2003), but no description of the fault zone itself can be found in the literature. The basin-fill sequence is generally considered syn-tectonic as a whole (Butler, 1989), thus suggesting ongoing extension throughout the Jurassic. Other authors considered fault activity as being restricted to the early Jurassic (Lemoine and Trümpy, 1987; Coward et al., 1991; Chevalier et al., 2003), although with a rejuvenation in the Oxfordian (Coward et al., 1991), but did not describe the nature of contacts with the post-tectonic basin-fill succession at basin-margins.

The Briançonnais domain represented a crustal rise in the Late Triassic, which was affected by a rifting phase in the Early Jurassic (Lemoine and Trümpy, 1987; Bertok et al., 2011). This is the sole area in the Western Alps where preserved tracts of exhumed submarine paleoescarpments exist (Lemoine and Trümpy, 1987; Bertok et al., 2011).

A Toarcian–Middle Jurassic tectonic phase is held responsible for the exhumation of crystalline basement in the Err zone (Bernina–Switzerland), which was onlapped by basinal sediments and fringed by a rockfall breccia belt which bears resemblance with the examples described in this paper (Lemoine and Trümpy, 1987; Froitzheim and Manatschal, 1996).

5.3. The Kabylide Units of Northern Algeria

The Kabylide Units of Northern Algeria document the deposition of a Jurassic succession, mostly carbonate, overlying the Hercynian basement either via very thin Triassic sandstones or a relatively thick Permian–Triassic sequence (Wildi, 1983, and references therein; Gélard, 1979). Evidence for synsedimentary extension indicates two main phases of rifting ("rift 1" and "rift 2" in Cattaneo et al., 1999), one in the early Sinemurian and the other in the Domerian–Toarcian, this latter linked with widespread platform drowning and local deposition of condensed ammonite-rich beds. Bouillin and Naak (1989) and Cattaneo et al. (1999) document neptunian dykes, synsedimentary normal faults, and breccias interpreted as base-of-fault-scarp talus. The faults have a small displacement (typically a few meters) and typically offset blocks of Lower Jurassic shallow-water limestone. Although the Jurassic succession changes diachronously into hemipelagic/pelagic basinal deposits, which would become dominant in the Middle and Upper Jurassic, no basin-margin onlaps of the deeper-water succession are documented, and no field examples of the extended Paleozoic basement have so far been reported. Bouillin et al. (1986), while making mention of "AlKaPeCa," consider the region attached to Iberia and Sardinia during the Jurassic, facing a dominantly transform branch of the Western Tethys. In Bouillin et al.'s (1986) view, "AlKaPeCa" would become a separate plate only in the Cretaceous.

6. Rift mechanisms and sedimentation in Calabria: timing, accommodation space, slip rates, and sedimentation rates

6.1. Timing, products, and nature of rifting

Direct evidence for syndepositional extension in the Longobucco Basin is found in rocks as old as the Hettangian. The small-scale listric growth faults observed in the shallow shelf facies of the Bocchigliero Fm. exhibit throws in the order of a few meters (Santantonio, unpublished data). This activity is precursor of the brutal dismembering of the shelf which took place around the Sinemurian/Pliensbachian boundary. Vertical displacements produced by this major tectonic phase were in the order of several hundred meters up to 1 km. The next extensional phase (late early/early middle Toarcian) is documented in the Caloveto area (northern shoulder of the Longobucco Basin in modern orientation) by a dense network of fractures and normal faults associated with deposition of the nodular Rosso Ammonitico facies of the Upper Caloveto Formation. The Caloveto structural high as a whole covered an area of less than 5 km^2, and the two master faults that bordered it, facing the basins lying to the north and south (present orientation) of it, respectively, display a separation of <2 km in cross-section. Downstepped fault blocks at its margins, made of reef/apron limestone, display vertical displacements in the order of <100 m.

The two peaks of extensional faulting in Calabria are broadly coincident with the "Rift 1" and "Rift 2" phases identified in the Southern Alps (Bertotti et al., 1993) (see discussion in Santantonio and Carminati, 2011) and in the Kabylide units of Algeria (Cattaneo et al., 1999). They represent key turning points in the local paleogeographic evolution: (a) the destruction of the Hettangian–early Sinemurian carbonate shelf, with rapid subsidence into the deep-water realm of hanging wall basins; (b) the dissection of structural highs and drowning of the carbonate factories that fringed them. This latter event probably marks, as mentioned above, the inception of sea-floor spreading in this branch of the Western Tethys, as indicated by the apparent halt of tectonic activity after the Toarcian, and onset of widespread pelagic facies during the Middle Jurassic.

The Cozzo del Morto to Pietre di Giudice section (see Sections 3.1.1 and 3.1.3 above, and Figs. 4, 7) includes coarse clastic bodies interbedded with the hemipelagic/turbidite succession, with clasts made of footwall-block lithologies (basement, plus continental and carbonate shelf pre-rift deposits). This indicates that repeated episodes of rockfall occurred at the basin-margin during the ~8.4 Myrs interval (base Pliensbachian to base middle Toarcian; Gradstein et al., 2004) which separates the two peaks, or at least during part of it, as the basin-margins were still seismically active and underwent erosion.

While the generic term "extension" is used throughout this paper, the role played by lateral slip must not be underestimated. Bouillin et al. (1986) envisage the paleo-position of Jurassic Calabria in a region where a seaway connecting the Western Tethys to the embryonic Atlantic Ocean was being produced as a result of dominantly right lateral relative motion of the African and European plates. Santantonio and Teale (1987) discuss the possible pull-apart nature of the Longobucco basin, based on its paleogeographic confinement and on the uniqueness of the thick Pliensbachian–lower Toarcian siliciclastic turbidites of the Trionto Formation, which have no coeval counterparts in the rest of the Calabria–Peloritani Arc (e.g. Eastern Sicily). More research will be needed to test this hypothesis, and to reconstruct the original paleogeographic relationships of Jurassic Calabria with the neighboring regions, a task made difficult by the fact that, due to opening of the Tyrrhenian Basin in the Miocene and drift to the South East overriding the subducting Ionian Basin (Carminati et al., 2012), Calabria became detached from its parent continental margin and at least partly accreted to the Adriatic/African plate.

6.2. Sedimentation rates, and slip rates along synsedimentary faults

Our set of new field and biostratigraphic data provides constraints for computing sedimentation rates of the succession infilling the Longobucco rift basin, and for estimating slip rates along rift faults.

The dominantly siliciclastic/hemipelagic succession spanning the basal Pliensbachian to Early Toarcian at Cozzo del Morto-Pietre di Giudice is ~550 m thick, the sole Lower Toarcian being ~150 m thick. This succession spans 8.4 Myrs according to Gradstein et al. (2004), which produces sedimentation rates (uncompacted) of about 65.5 m/Myr. A comparison with the Adria Plate margin reveals these Calabrian values are higher than those computed in the Umbria–Marche succession (Northern Apennines), where the immediately post-faulting Sinemurian succession, spanning equal time (~8.5 Myrs; International Commission on Stratigraphy, 2015), is generally less than 150 m thick. In contrast, non-compacted sedimentation rates were significantly higher in the Lombardy Basin in Southern Alps, where the circa 17 Myrs-long latest Hettangian to top Pliensbachian interval (International Commission on Stratigraphy, 2015) can be covered by an up to 4 km thick succession (Bernoulli, 1964; Bertotti et al., 1993), resulting in maximum values of about 235 m/Myr. It must be noted that the Adria margin basin-fill successions are all-carbonate in nature, with locally very significant volumes of added resedimented material sourced by shallow water areas (e.g. the Sabina Basin; Galluzzo and Santantonio, 2002), whereas the Calabrian hanging wall-basin successions were essentially fed by a siliciclastic shelf (unexposed at present).

Slip rates along faults can be computed/estimated by applying the method used in Santantonio and Carminati (2011), which takes into account (i) the age of the condensed pelagic deposits draping a given tract of the local submarine fault escarpment (epi-escarpment deposits; see Chapter 3); (ii) the timing of fault inception; (iii) the position of the oldest and paleotopographically lowest condensed drape with respect to the topographically highest part of the local escarpment. This method is based on the notion that the oldest age detected with epi-escarpment deposits provides the minimum age for the existence of said escarpment tract, as these unconformable condensed deposits seal the local paleomorphology thus providing a "snapshot" of the submarine escarpment at the time they were sedimented (Santantonio, 1993). Once the escarpment is retrodeformed by undoing any subsequent tectonic rotation, one can estimate the minimum rate at which the footwall was being unroofed along a given synsedimentary fault by computing the age difference between fault inception and the deposition of the pelagic drape, and plotting it against the paleotopographic relief existing at the time.

While in the Apennines the epi-escarpment deposits are markedly ammonitiferous, lending themselves to an analysis at ammonite zone or subzone level (see for example Galluzzo and Santantonio, 2002), their counterparts in Calabria provide somewhat less tight constraints. The common pink to gray veneers of sponge spicule-rich mud-/wackestones in our study area bear crinoids and the benthic foram *Agerina martana*. This is a late Sinemurian/Pliensbachian (Chiocchini et al, 2008) taxon that in the Apennines is common up to the lower Pliensbachian but rare or absent in the upper Pliensbachian (Marino and Santantonio, 2010). These epi-escarpment deposits are ubiquitous along exhumed paleoescarpment tracts down to about 350 m below the local footwall block tops, and are onlapped by basin-fill deposits having an early Pliensbachian to early Middle Jurassic age. If one considers the inception of faulting as being late Sinemurian, and the age of the epi-escarpment deposits as being early Pliensbachian, based conservatively on the peak of occurrence of *Agerina martana*, this would produce a very narrow time window (.5-2 Myrs?) for the unroofing of an at least 350 m thick section of the footwall, which in turn equals the vertical displacement of the hanging wall. It must be stressed, however, that the epi-escarpment deposits indicate condensed pelagic deposition on perched sites facing the basin, topographically higher than the basin floor, and therefore they do not quite mark the toe of the escarpment. The unroofing indicated by the lowest veneer of sediment only gives the *minimum* figure of hanging wall subsidence, and some downwards continuation of the escarpment should also be taken into account. Consequently, a less conservative figure of 5–600 m vertical displacement in .5–1.0 million years would also be fully consistent with our dataset.

7. Conclusions

The submarine architecture of the Early Jurassic rift in North East Calabria is revealed by the onlaps of deep marine hemipelagic/turbiditic deposits on the Paleozoic crystalline and metamorphic basement, which is locally capped by remnants of the pre- or early syn-rift fluvial to shallow marine carbonate succession. Hanging wall basin-margin successions host wedges of megaclastic material derived from erosion of the footwall and are folded due to buttressing during inversion. Narrow aprons of siliciclast-rich reefal limestone developed with a high-angle lateral contact, marked by microbial crusts, to the uplifted basement which formed islands, facing a siliciclastic basin fed by the mainland Hercynian Calabria. The highs were drowned and fragmented by a further extensional phase in the Toarcian, and hosted condensed pelagic deposits, unconformity-bounded, until a siliceous facies (late Bajocian–Oxfordian/early Kimmeridgian) became widespread across the entire rift basin. The exhumation of basin-margins, and their surprisingly good preservation down to minute details of the Jurassic submarine topography, is a peculiar feature of our study area, which might therefore serve as a reference for neighboring (in the Jurassic) regions where a severe orogenic overprint prevents a direct observation of the rift geometries.

Acknowledgements

The authors are indebted to the reviewers Dan Bosence and Salvatore Critelli, and to the Editor Brian Jones for their valuable comments and suggestions, which greatly improved the first version of the manuscript. Nino Mariotti ("Sapienza" University, Rome) is gratefully thanked for the identification of belemnites. Federico Venturi (Perugia University) kindly identified some Early Jurassic ammonites. Maurizio Chiocchini and Rita Pichezzi (ISPRA–Geological Survey of Italy) are thanked for their help in the analysis of Mesozoic microfacies. Maria Grazia Rossi (ISPRA–Geological Survey of Italy) kindly analyzed pelite samples for nannofossils determination. The thin section technician Domenico Mannetta is warmly thanked for his willingness and competence. SF would like to thank Giorgio Guarini, Marco Lesti, and Renzo Petrungaro for memorable days spent in the field and for freely sharing their bachelor's degree theses data on the Caloveto area, and Simona Caruso for additional field photographs. MS would like to thank Maurizio Sonnino (University of Calabria) for help in the field during the Eighties and, thirty years after his premature death, fondly remembers the late Tarquin Teale (Imperial College, London), acknowledging his outstanding research carried out in Calabria and wise guidance in the field.

References

Amodio-Morelli, L., Bonardi, G., Colonna, V., Dietrich, D., Giunta, G., Ippolito, F., Liguori, V., Lorenzoni, S., Paglionico, A., Perrone, V., Piccarreta, G., Russo, M., Scandone, P., Zanettin Lorenzoni, E., Zuppetta, A., 1976. L'arco Calabro-Peloritano nell'orogene Appenninico-Maghrebide. Memorie della Societa Geologica Italiana 17, 1–60.

Baudelot, S., Bouillin, J.P., Delga, M.D., Giunta, G., Olivier, P., 1988. Datazioni palinologiche dell'Hettangiano alla base della trasgressione mesozoica sul "Verrucano" della Sila (Calabria) e dei monti Peloritani (Sicilia). Bollettino della Societa Geologica Italiana 107, 51–61.

Bernoulli, D., 1964. Zur Geologie des Monte Generoso (Lombardische Alpen). Beitr. Geol. 118 (Karte Schweiz, Neue Folge, 134 pp.).

Bernoulli, D., 1971. Redeposited pelagic sediments in the Jurassic of the central Mediterranean area. Annales. Instituti Geologici Publici Hungarici 54, 71–90.

Bernoulli, D., Jenkyns, H.C., 1974. Alpine, Mediterranean, and Central Atlantic Mesozoic facies in relation to the early evolution of the Tethys. SEPM Special Publication 19 (129), 160.

Bernoulli, D., Renz, O., 1970. Jurassic carbonate facies and new ammonite faunas from Western Greece. Eclogae Geologicae Helvetiae 63, 573–607.

Berra, F., Carminati, E., 2010. Subsidence history from a backstripping analysis of the Permo-Mesozoic succession of the Central Southern Alps (Northern Italy). Basin Research 22, 952–975.

Bertok, C., Martire, L., Perotti, E., d'Atri, A., Piana, F., 2011. Middle-Late Jurassic syndepositional tectonics recorded in the Ligurian Briançonnais succession (Marguareis–Mongioie area, Ligurian Alps, NW Italy). Swiss Journal of Geosciences 104, 237–255.

Bertotti, G., Picotti, V., Bernoulli, D., Castellarin, A., 1993. From rifting to drifting: tectonic evolution of the South-Alpine upper crust from the Triassic to the Early Cretaceous. Sedimentary Geology 86, 53–76.

Bonardi, G., Cello, G., Perrone, V., Tortorici, L., Turco, E., Zuppetta, A., 1982. The evolution of the northern sector of the Calabria-Peloritani Arc in a semiquantitative palynspastic restoration. Bollettino della Societa Geologica Italiana 101, 259–274.

Bonardi, G., Compagnoni, R., Del Moro, A., Macaione, E., Messina, A., Perrone, V., 2008. Rb-Sr age constraints on the Alpine metamorphic overprint in the Aspromonte nappe (Calabria-Peloritani composite terrane, Southern Italy). Bollettino della Societa Geologica Italiana 127, 173–190.

Bouillin, J.P., 1984. Nouvelle interprétation de la liaison Apennin-Maghrébides en Calabre: conséquences sur la paléogéographie téthysienne entre Gibraltar et les Alpes. Revue de Géologie Dynamique et de Géographie Physique 25, 321–338.

Bouillin, J.P., Bellomo, D., 1990. Les filons sédimentaires Jurassique de Longobucco-Caloveto (Calabre, Italie); application à l'étude des paléostructures d'une marge téthysienne. Geodinamica Acta 4, 111–120.

Bouillin, J.P., Naak, M., 1989. Découverte de filons sédimentaires caractérisant une tectonique distensive jurassique dans le Djurdjura (Dorsale calcaire maghrébine, Algérie). Comptes rendus de l'Académie des sciences. Série 2, Mécanique, Physique, Chimie, Sciences de l'univers, Sciences de la Terre 309, 1371–1376.

Bouillin, J.P., Baudelot, S., Majesté-Menjoulas, C., 1984. Mise en évidence du Cambro-Ordovicien en Calabre centrale (Italie). Affinités paléogéographiques et conséquences structurales. Comptes Rendus de l'Academie des Sciences, Serie II: Mecanique, Physique, Chimie, Sciences de la Terre et de l'Univers 298, 89–92.

Bouillin, J.P., Durand Delga, M., Olivier, P., 1986. Betic–Rifian and Tyrrhenian arcs: distinctive features, genesis and development stages. In: Wezel, F.C. (Ed.), The origin of arcs. Elsevier, Amsterdam, pp. 321–338.

Bouillin, J.P., Majeste–Menjoulas, C., Baudelot, S., Cygan, C., Fournier–Vinas, C.H., 1987. Les formations Paleozoiques de l'Arc Calabro-Peloritain dans leur cadre structural. Bollettino della Societa Geologica Italiana 106, 683–698.

Bouillin, J.P., Mouterde, R., Olivier, P., Majesté-Menjoulas, C., 1988. Le Jurassique de Longobucco (Calabre, Italie), à la jonction de la Téthys Ligure et de la Téthys Maghrébin. Bulletin de la Societe Geologique de France 4, 93–103.

Bouillin, J.P., Dumont, T., Olivier, P., 1992. Organisation structurale et sédimentaire de la paléomarge nord téthysienne au Jurassique dans les monts Péloritains (Sicile, Italie). Bulletin de la Societe Geologique de France 163, 761–770.

Butler, R.W.H., 1989. The influence of pre-existing basin structure on thrust system evolution in the Western Alps. Geological Society, London, Special Publications 44, 105–122.

Čadjenović, D., Kilibarda, Z., Radulović, N., 2008. Late Triassic to Late Jurassic evolution of the Adriatic Carbonate Platform and Budva Basin, Southern Montenegro. Sedimentary Geology 204, 1–17.

Carminati, E., Santantonio, M., 2005. Control of differential compaction on the geometry of sediments onlapping paleoescarpments: insights from field geology (Central Apennines, Italy) and numerical modeling. Geology 33, 353–356.

Carminati, E., Lustrino, M., Cuffaro, M., Doglioni, C., 2010. Tectonics, magmatism and geodynamics of Italy: what we know and what we imagine. Journal of the Virtual Explorer 36.

Carminati, E., Lustrino, M., Doglioni, C., 2012. Geodynamic evolution of the Central and Western Mediterranean: tectonics vs. igneous petrology constraints. Tectonophysics 579, 173–192.

Castellarin, A., 1972. Evoluzione paleotettonica sinsedimentaria del limite tra" piattaforma veneta" e" bacino lombardo" a nord di Riva del Garda. Giornale di Geologia 1, 1–171.

Cattaneo, G., Gelard, J.P., Aite, M.O., Mouterde, R., 1999. La marge septentrionale de la Téthys maghrébine au Jurassique (Djurdjura et Chellata, Grande Kabylie, Algérie). Bulletin de la Societe Geologique de France 170, 173–188.

Channel, J.E.T., D'argenio, B., Horvath, F., 1979. Adria, the African promontory in Mesozoic Mediterranean paleogeography. Earth-Science Reviews 15, 213–292.

Chevalier, F., Guiraud, M., Garcia, J.P., Dommergues, J.L., Quesne, D., Allemand, P., Dumont, T., 2003. Calculating the long-term displacement rates of a normal fault from the high-resolution stratigraphic record (early Tethyan rifting, French Alps). Terra Nova 15, 410–416.

Chiocchini, M., Chiocchini, R.A., Didaskalou, P., Potetti, M., 2008. Microbiostratigrafia del Triassico superiore, Giurassico e Cretacico in facies di piattaforma carbonatica del Lazio centro-meridionale e Abruzzo: revisione finale. Mem Descr Carta Geol It 84 pp. 5–170.

Ciarapica, G., Passeri, L., 2005. Ionian Tethydes in Southern Apennines. In: Finetti, I.R. (Ed.), Crop Project: deep seismic exploration of Central Mediterranean and Italy. Elsevier, Amsterdam, pp. 209–224.

Colacicchi, R., Passeri, L., Pialli, G., 1970. Nuovi dati sul Giurese Umbro-Marchigiano ed ipotesi per un suo inquadramento regionale. Memorie della Societa Geologica Italiana 9, 839–874.

Costamagna, C., Barca, S., 2004. Stratigrafia, analisi di facies, paleogeografia ed inquadramento regionale della successione Giurassica dell'area dei Tacchi (Sardegna orientale). Bollettino della Societa Geologica Italiana 123, 477–495.

Costamagna, L.G., Barca, S., Lecca, L., 2007. The Bajocian–Kimmeridgian Jurassic sedimentary cycle of eastern Sardinia: stratigraphic, depositional and sequence interpretation of the new 'Baunei Group'. Comptes Rendus Geoscience 339, 601–612.

Coward, M.P., Gillcrist, R., Trudgill, B., 1991. Extensional structures and their tectonic inversion in the Western Alps. Geological Society of London Special Publications 56, 93–112.

Critelli, S., 1999. The interplay of lithospheric flexure and thrust accomodation in forming stratigraphic sequences in the southern Apennines foreland basin system, Italy. Memorie dell'Accademia Nazionale dei Lincei 10, 257–326.

Critelli, S., Mongelli, G., Perri, F., Martin-Algarra, A., Martin-Martin, M., Perrone, V., Dominici, R., Sonnino, M., Zaghloul, M.N., 2008. Sedimentary Evolution of the Middle Triassic–Lower Jurassic continental redbeds from Western-Central Mediterranean Alpine Chains based on geochemical, mineralogical and petrographical tools. Journal of Geology 116, 375–386.

Critelli, S., Muto, F., Tripodi, V., Perri, F., 2011. Relationships between lithospheric flexure, thrust tectonics and stratigraphic sequences in foreland setting: the Southern Apennines foreland basin system, Italy. In: Schattner, U. (Ed.), Tectonics 2. Intech Open Access Publisher, pp. 121–170.

Critelli, S., Muto, F., Tripodi, V., Perri, F., 2013. Link between thrust tectonics and sedimentation processes of stratigraphic sequences from the southern Apennines foreland basin system, Italy. Rendiconti Online della Società Geologica Italiana 25, 21–42.

De Graciansky, P.C., Bourbon, M., De Charpal, O., Chenet, P.Y., Lemoine, M., 1979. Genese et evolution comparees de deux marges continentales passives; marge iberique de l'Ocean atlantique et marge europeenne de la Tethys dans les Alpes occidentales. Bulletin de la Societe Geologique de France 7 (21), 663–674.

Dietrich, D., 1988. Sense of overthrust shear in the Alpine nappes of Calabria. Journal of Structural Geology 10, 373–381.

Froitzheim, N., Manatschal, G., 1996. Kinematics of Jurassic rifting, mantle exhumation, and passive-margin formation in the Austroalpine and Penninic nappes (eastern Switzerland). GSA Bulletin 108, 1120–1133.

Galluzzo, F., Santantonio, M., 2002. The Sabina Plateau: a new element in the Mesozoic palaeogeography of Central Apennines. Bollettino della Societa Geologica Italiana 121, 561–588.

Gélard, J.P., 1979. Géologie du nord-est de la Grande Kabylie; un segment des zones internes de l'orogène littoral maghrébin. Mémoires géologiques de l'université de Dijon 5, 1–335.

Gradstein, F.M., Ogg, J.G., Smith, A.G., 2004. Geologic Time Scale 2004. Cambridge University Press (589 pp.).

Haccard, D., Lorenz, C., Grandjacquet, C., 1972. Essai sur l'évolution tectogénétique de la liaison Alpes-Apennines (de la Ligurie à la Calabre). Memorie della Societa Geologica Italiana 11, 309–341.

Handy, M.R., Schmid, S.M., Bousquet, R., Kissling, E., Bernoulli, D., 2010. Reconciling plate-tectonic reconstructions of Alpine Tethys with the geological–geophysical record of spreading and subduction in the Alps. Earth-Science Reviews 102, 121–158.

International Commission on Stratigraphy, 2015. International Stratigraphic Chart. http://www.stratigraphy.org/ICSchart/ChronostratChart2015-01.pdf.

Jadoul, F., Lanfranchi, A., Berra, F., Erba, E., Casellato, C.E., 2010. I sistemi carbonatici giurassici della Sardegna orientale (Golfo di Orosei) ed eventi deposizionali nel sistema carbonatico giurassico-cretacico della Nurra (Sardegna nord-occidentale). Geological field trips 2, 1–54.

Jadoul, F., Della Porta, G., Lanfranchi, A., 2014. Large scale detachments along low-angle slope depositional systems: the Tithonian disconformity of Eastern Sardinia ramp carbonates (Jurassic Southern European passive margin). Rendiconti Online della Società Geologica Italiana 31 (Suppl. 1), 136.

Jenkyns, H.C., 1970. The Jurassic of Western Sicily. Petroleum Exploration Society of Libya, 12th Annual Field Conference 245–254.

Jenkyns, H.C., Torrens, H.S., 1971. Palaeogeographic evolution of Jurassic seamounts in western Sicily. Annales. Instituti Geologici Publici Hungarici 54, 91–104.

Lanfranchi, A., Berra, F., Jadoul, F., 2011. Compositional changes in sigmoidal carbonate clinoforms (Late Tithonian, eastern Sardinia, Italy): insights from quantitative microfacies analyses. Sedimentology 58, 2039–2060.

Lathuilière, B., Marchal, D., 2009. Extinction, survival and recovery of corals from the Triassic to Middle Jurassic time. Terra Nova 21, 57–66.

Lemoine, M., Trümpy, R., 1987. Pre-oceanic rifting in the Alps. Tectonophysics 133, 305–320.

Lentini, F., Vezzani, L., 1975. Le unità meso-cenozoiche della copertura sedimentaria del basamento cristallino peloritano (Sicilia nord-orientale). Bollettino della Societa Geologica Italiana 94, 537–554.

Magri, G., Sidoti, G., Spada, A., 1965. Rilevamento geologico sul versante settentrionale della Sila (Calabria). Memorie e note dell'Istituto di Geologia Applicata dell'Università di Napoli 9, 5–59.

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.

Ogniben, L., 1973. Schema geologico della Calabria in base ai dati odierni. Geologica Romana 12, 243–585.

Passeri, L., Ciarapica, G., Reggiani, L., Rutledge, D.C., 2014. The significance of Longobucco unit (Calabria–Peloritani Arc) in the evolution of the Ionian and Alpine oceans. Instituti Journal Geosciencez 133, 249–270.

Perri, F., Cirrincione, R., Critelli, S., Mazzoleni, P., Pappalardo, A., 2008. Clay mineral assemblages and sandstone compositions of the Mesozoic Longobucco Group (North-Eastern Calabria): implications for burial history and diagenetic evolution. International Geology Review 50, 1116–1131.

Perri, F., Critelli, S., Mongelli, G., Cullers, R.L., 2011. Sedimentary evolution of the Mesozoic continental redbeds using geochemical and mineralogical tools: the case of Upper Triassic to Lowermost Jurassic Monte di Gioiosa mudstones (Sicily, southern Italy). International Journal of Earth Sciences 100, 1569–1587.

Perri, F., Critelli, S., Martin-Algarra, A., Martin-Martin, M., Perrone, V., Mongelli, G., Zattin, M., 2013. Triassic redbeds in the Malaguide Complex (Betic Cordillera – Spain): petrography, geochemistry and geodynamic implications. Earth Science Reviews 117, 1–28.

Perrone, V., Martin-Algarra, A., Critelli, S., Decandia, F.A., D'Errico, M., Estevez, A., Iannace, A., Lazzarotto, A., Martin-Martin, M., Martin-Rojas, I., Mazzoli, S., Messina, A., Mongelli, G., Vitale, S., Zaghloul, N.M., 2006. Verrucano" and "Pseudoverrucano" in the central-western Mediterranean Alpine chains. In: Chalouan, A., Moratti, G. (Eds.), Geology and Active Tectonics of the Western Mediterranean Region and North Africa. Geological Society of London Special Publication 262, pp. 1–43.

Santantonio, M., 1991. Itinerario geologico nei terreni mesozoici della Calabria nord-orientale, tra Longobucco, Bocchigliero e Caloveto. Escursione del "Gruppo Giurassico" (24-29 maggio).

Santantonio, M., 1993. Facies associations and evolution of pelagic carbonate platform/basin system: 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, 122–141.

Santantonio, M., 2012. Mesozoic evolution of the Caloveto group, NE Calabria. Rendiconti Online della Società Geologica Italiana 21, 295–297.

Santantonio, M., Carminati, E., 2011. Jurassic rifting evolution of the Apennines and Southern Alps (Italy): parallels and differences. GSA Bulletin 123, 468–484.

Santantonio, M., Teale, C.T., 1985. Jurassic condensed sedimentation on Hercynian basement (Calabria, Italy). Abstracts of the 6th European Meeting of the International Association of Sedimentologists. IAS, Lerida, pp. 459–460.

Santantonio, M., Teale, C.T., 1987. An example of the use of detrital episodes in elucidating complex basin histories: the Caloveto and Longobucco Groups of N.E. Calabria, S. Italy. In: Leggett, J.K., Zuffa, G.G. (Eds.), Marine clastic sedimentology. Graham and Trotman, London, pp. 62–74.

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.

Scandone, P., 1979. The origin of the Tyrrhenian Sea and the Calabrian Arc. Bollettino della Societa Geologica Italiana 98, 27–44.

Schettino, A., Turco, E., 2011. Tectonic history of the Western Tethys since the Late Triassic. GSA Bulletin 123, 89–105.

Servizio Geologico d'Italia, 2002. Geological Map of Italy 1:50000, sheet #541 'Jerzu'.

Servizio Geologico d'Italia, 2009. Geological Map of Italy 1:50000, sheet #613 'Taormina'.

Teale, C.T., 1988. Carta geologica dell'area Longobucco-Bocchigliero 1:25,000 (Ed. by Santantonio, M., Zuffa, G.G.). Litografia Artistica Cartografica, Firenze.

Teale, C.T., Young, J.R., 1987. Isolated olistoliths from the Longobucco Basin, Calabria, Southern Italy. In: Leggett, J.K., Zuffa, G.G. (Eds.), Marine clastic sedimentology. Graham and Trotman, London, pp. 75–88.

Underhill, J.R., Paterson, S., 1998. Genesis of tectonic inversion structures: seismic evidence for the development of key structures along the Purbeck–Isle of Wight disturbance. Journal of the Geological Society 155, 975–992.

Wildi, W., 1983. La chaine tello-rifaine (Algérie, Maroc, Tunisie): structure, stratigraphie et evolution du Trias au Miocène. Revue de Géologie Dynamique et de Géographie Physique 24, 201–297.

Woods, A.D., Baud, A., 2008. Anachronistic facies from a drowned Lower Triassic carbonate platform: Lower member of the Alwa Formation (Ba'id Exotic), Oman Mountains. Sedimentary Geology 209 (1), 1–14.
Young, J.R., Teale, C.T., Bown, P.R., 1986. Revision of the stratigraphy of the Longobucco Group (Liassic, Southern Italy); based on new data fr\om nannofossils and ammonites. Eclogae Geologicae Helvetiae 79, 117–135.
Zaghloul, M.N., Critelli, S., Mongelli, G., Perri, F., Perrone, V., Tucker, M., Aiello, M., Sonnino, M., Ventimiglia, C., 2010. Depositional systems, composition and geochemistry of Triassic rifted-continental margin redbeds of Internal Rif Chain, Morocco. Sedimentology 57, 312–350.