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The Bajocian–Kimmeridgian Jurassic sedimentary cycle of eastern Sardinia: Stratigraphic, depositional and sequence interpretation of the new 'Baunei Group'

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Abstract

In eastern Sardinia, the first Jurassic sedimentary cycle (Bajocian–Kimmeridgian) develops in response to the opening of the Alpine Tethys Ocean. Starting during the Bajocian (Middle Jurassic), over a horst-and-graben system initially drowning to the northeast, at first siliciclastic sediments take place, related to continental to transitional environments. In time, they are gradually followed by marine carbonate, assigned to inner to outer ramp deposits. Afterwards, the latter, in their turn, become shallow; they are newly covered with an inner ramp lithofacies. The Kimmeridgian–Tithonian unconformity ends the cycle. Therefore, this sedimentary cycle as a whole can be interpreted as a transgressive–regressive megasequence linked to tectono-eustatic factors. All the pertaining stratigraphic units have been included within the 'Baunei Group', newly described. A comparison with the neighbouring areas, with particular regards to the Jurassic series of the Corsica, has been made, attempting to improve the reconstruction of this part of the Tethyan Ocean Western margin. ***To cite this article: L.G. Costamagna et al., C. R. Geoscience 339 (2007).***

Résumé

Le cycle sédimentaire Bajocien–Kimméridgien en Sardaigne orientale : interprétation stratigraphique, dépositionnelle et séquentielle du « groupe de Baunei », nouvellement créé. En Sardaigne orientale, le premier cycle sédimentaire jurassique se développe dans le contexte de l'ouverture de la Téthys alpine. À partir du Bajocien, sur un système de *horsts* et *grabens* en cours d'effondrement vers le nord-est, se mettent d'abord en place des sédiments continentaux, suivis par des sédiments marins carbonatés de rampe interne et externe, à leur tour recouverts par des sédiments de rampe interne. La discontinuité du Kimméridgien–Tithonien termine ce cycle sédimentaire, dont la totalité peut être interprétée comme une séquence transgressive–régressive, contrôlée par des phénomènes tectono-eustatiques. L'ensemble des formations liées à ce cycle sédimentaire constitue le « groupe de Baunei », nouvellement créé. Une comparaison a été faite avec les secteurs jurassiques les plus proches, en particulier avec celui de Corse, en essayant d'améliorer la reconstruction de ces parties de la marge occidentale de l'océan Téthys. ***Pour citer cet article : L.G. Costamagna et al., C. R. Geoscience 339 (2007).***

Keywords: Sedimentology; Stratigraphy; Carbonate ramp; Jurassic; Tethys; Sardinia

Mots clés : Sédimentologie ; Stratigraphie ; Rampe carbonatée ; Jurassique ; Téthys ; Sardaigne

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1. Introduction

A framework of the development of the Middle–Upper Jurassic sedimentary facies related to depositional environments and to the palaeogeographical setting of eastern Sardinia (Fig. 1) has been allowed by several field investigations. In this area, the entire Jurassic series is about 1000 m thick.

The Jurassic series is formed, from the bottom to the top, first by a continental to transitional unit named *Genna Selole Fm.* (Bajocian–Bathonian) [13,17,19,22], built prevalently of siliciclastics. Then, the carbonate

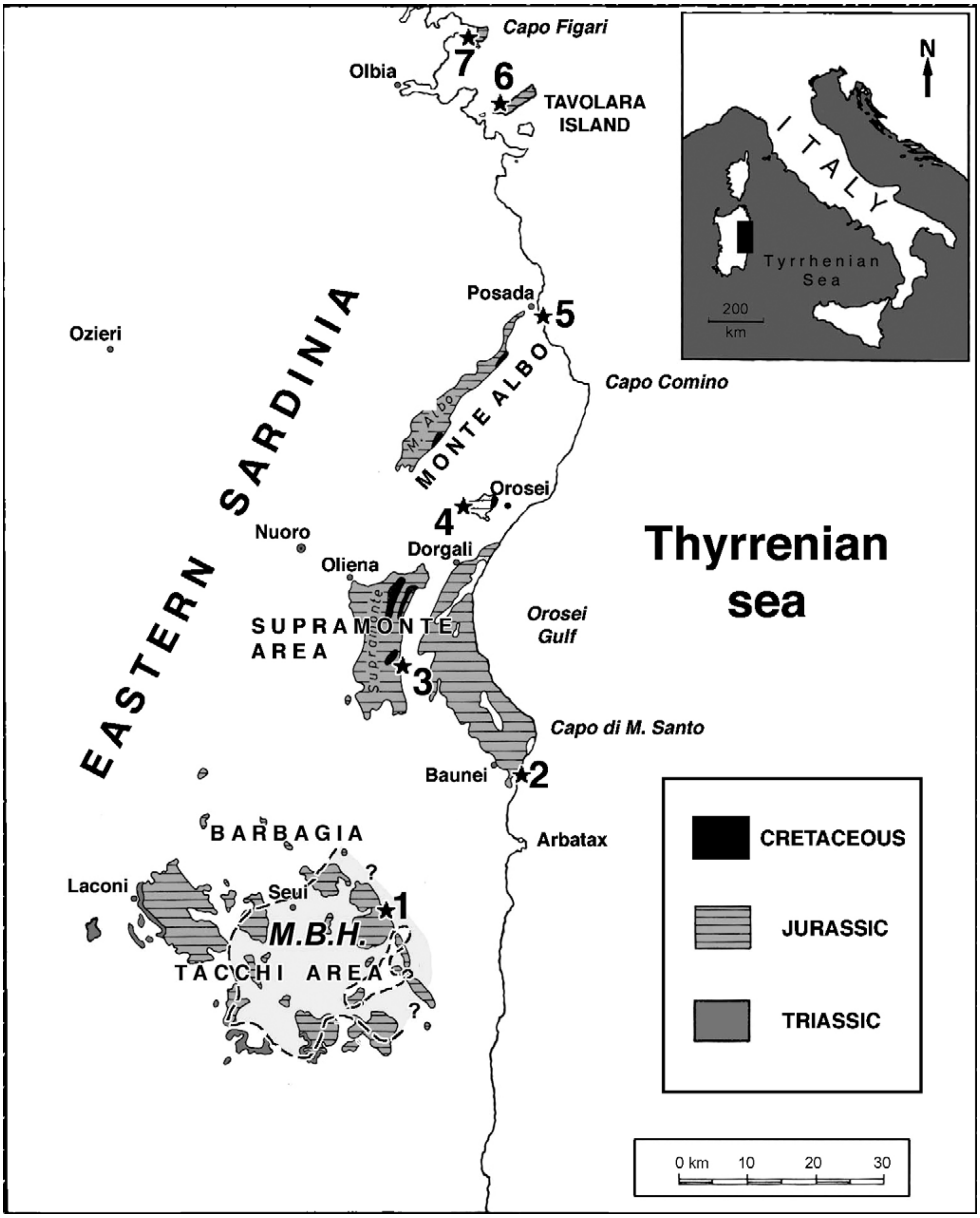

Fig. 1. Mesozoic outcrops in eastern Sardinia, rough location of the morphostructural Barbagia Palaeo-high [13] and ubication of the studied stratigraphic sections, modified from [19]: (1) Taquisara; (2) Monte Oro; (3) Genna Silana; (4) Monte Tuttavista; (5) Posada; (6) Tavolara; (7) Capo Figari; M.B.H. (shadowed area): morphostructural Barbagia palaeo-high.

Fig. 1. Affleurements jurassiques en Sardaigne orientale, position approximative du paléo-haut de la Barbagia [13] et localisation des coupes du Jurassique étudiées, d'après [19], modifié : (1) Taquisara ; (2) Monte Oro ; (3) Genna Silana ; (4) Monte Tuttavista ; (5) Posada ; (6) Tavolara ; (7) Capo Figari ; M.B.H. (zone ombrée) : paléo-haut de la Barbagia.

marine units follow: the *Dorgali Dolostone Fm.* (Bathonian-Kimmeridgian) [13,19,22], the *Monte Tului Fm.* [1,6] (Callovian–Kimmeridgian) [19], The *Monte Bardia Fm.* [1,6,19] (Oxfordian–Kimmeridgian) and the *S'Adde Fm.* [19,20] (Callovian–Kimmeridgian). Afterwards, the upper part of the *Monte Bardia Fm.* [1,6] (Tithonian–Berriasian) [19] conformably overlies a limited and brief stratigraphic gap dated Kimmeridgian–Tithonian [19 and references herein]. A first general stratigraphic and palaeoenvironmental frame pointing to a gradual deepening has been given [13,19,22].

This Jurassic series overlies unconformably the Variscan basement (more rarely the Permian or the Triassic cover), and is delimited at its top by the Berriasian unconformity [19]. In this work, we only restrict the investigations to the lower stratigraphic interval, Bajocian–Kimmeridgian in age, of the Jurassic series.

2. Stratigraphical and sedimentological frame

2.1. Genna Selole Fm.

The Genna Selole Fm. (Bajocian–Bathonian) [17,22] unconformably overlies the Variscan basement and forms the lower part of the southernmost Jurassic succession in central–eastern Sardinia (Fig. 1). It becomes thinner and disappears towards the north. In the northernmost outcrops, the Jurassic succession usually starts directly with the marine Dorgali Dolostone Fm. (Bathonian–Kimmeridgian) [19], containing, close to its base, only scattered and reworked quartz pebbles.

The Genna Selole Fm., having a maximum thickness of 50 m in the southwestern Tacchi area, consists of siliciclastics, then evolving towards the top to mixed siliciclastic/carbonate deposits. It has been subdivided vertically and laterally into three lithofacies [13]:

A) the Laconi–Gadoni lithofacies, corresponding to massive to badly stratified quartzose conglomerates and subordinated sandstone lenses. This lithofacies relates to distal alluvial fans/braided rivers environments;

B) the Nurri–Escalaplano lithofacies, made of well-stratified alternations of fine sandstones, clayey siltites and lignitiferous siltites with plant fragments and microfloristic assemblages [16,17,21]. It is linked to alluvial, palustrine and upper delta plain contexts;

C) the Ussassai–Perdasdefogu lithofacies, mainly constituted by well-stratified alternations of sandstones, marls, marly limestones and limestones with localized, thin wood coal horizons and containing a poorly preserved lagoonal fauna (bivalves, brachiopods, gastropods, ostracods; rare echinoderms, foraminifera, charophytes, sponges) [13,21,22]. This lithofacies laid down in littoral to deltaic, partially carbonate environments, and it represents the gradual passage to the following Dorgali Dolostone Fm.

The gradual thinning up then the gap of the Genna Selole Fm. towards the central Tacchi area (Fig. 1), evidenced by the isopachs course of this unit [13], imply the former development of uplifted eroded and weathered areas: in fact, here the 'Ferro dei Tacchi' pedogenetic ore [28] developed likely almost at the same times. The location of these areas has been controlled by structural and syn-depositional factors, such as the Variscan metamorphic palaeo-high of Barbagia (Fig. 1) [13]. This short-lasting emerged morphostructural high could be due to the coeval extensional tectonics developed along the European plate margin during Early and Middle Jurassic times [4,34], and inducing the Alpine Tethyan oceanic opening. These morphostructural highs were successively buried by continental sedimentation and finally overlain by the transgressive Middle Jurassic marine deposits. Extensional tectonics in the Genna Selole Fm. is also evidenced by slumps, synsedimentary faults and neptunian dykes.

2.2. Dorgali Fm.

According to [21,22], the Dorgali Dolostones Fm. (Figs. 2–4) overcomes, reaching 250–300 m of thickness in the Tacchi area. It is characterized by several different lithofacies, which, although frequently masked by the dolomitization, are all referable to inter- to subtidal environments of a carbonate shelf comprised between the tidal carbonate lagoonal coastline and the inner shelf margin [13]. Its palaeontological content (bivalves, brachiopods, gastropods) [23] is usually poorly preserved due to the dolomitization. Internal breccias may indicate a still persistent synsedimentary tectonic activity. Most frequent deposits are irregular alternations of calcarenitic (oolitic–bioclastic packstones–grainstones) cross-laminated storm layers and bioturbated calcilutites (mudstones).

This lithostratigraphic unit gradually thins irregularly towards the north, holding 150 m in some

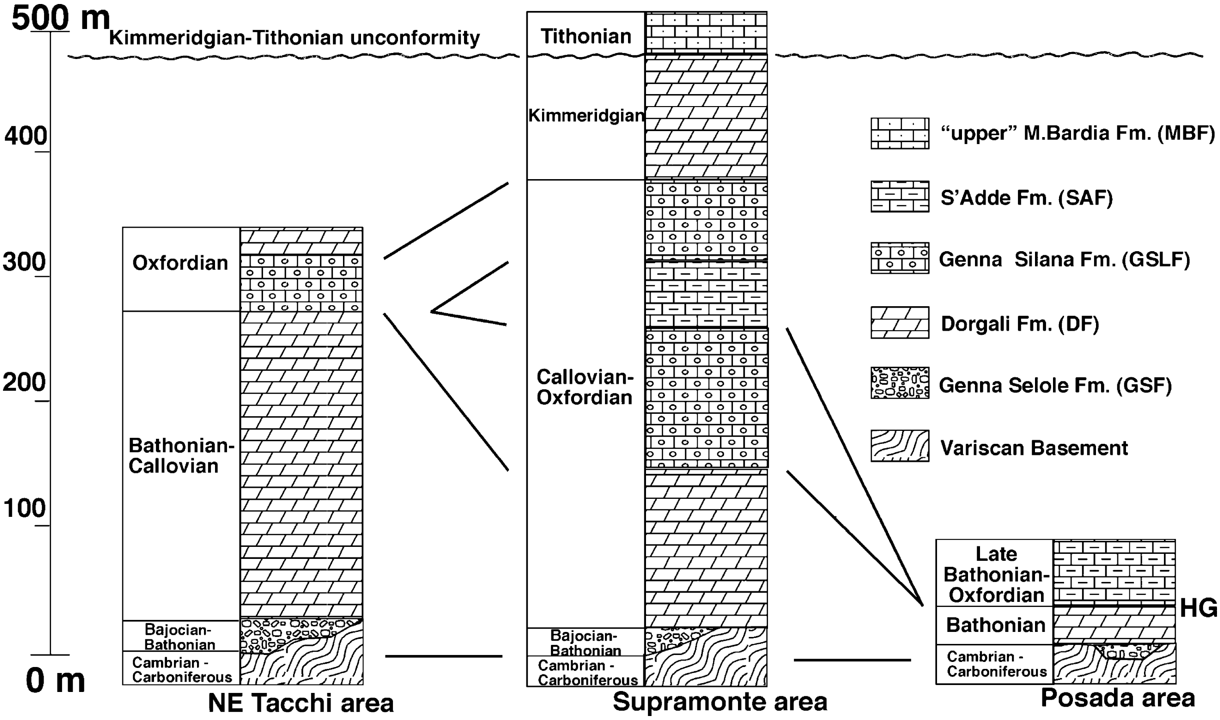

Fig. 2. Comparison and correlation of Middle–Late Jurassic stratigraphic successions of eastern Sardinia (northeastern Tacchi, Supramonte and Posada areas).

Fig. 2. Corrélation des successions stratigraphiques du Jurassique moyen–supérieur des Tacchi, du Supramonte et du secteur de Posada (Sardaigne orientale).

Supramonte localities and reducing to less than 25 m in the Posada cliff. In this last locality, this stratigraphic unit shows a very weak, discontinuous dolomitization. Nevertheless, there are also sectors, as the southern Monte Albo or the northern Oliena Supramonte, where the Dorgali Dolostone Fm. ranges again almost 300 m, and, reversely, sectors where this unit thins down, as at Genna Silana (Oliena Supramonte, 3, Fig. 1), or Monte Oro (Baunei Supramonte, 2, Fig. 1). It seems even to be missing almost completely at Punta Giradili and Genna Arramene (Baunei Supramonte). However, in these last outcrops, the typical carbonate inner platform depositional facies of the Dorgali Dolostone Fm., still developed without any dolomitization phenomena, has been observed at the base of the succession (sometimes over a few metres of possible freshwater limestones, maybe still attributable to the Genna Selole Fm.). In our opinion, the absence of dolomitization hindered a correct lithostratigraphic attribution, and in many cases, it led to referring erroneously to this lithofacies as a marginal part of the overcoming Monte Tului Fm. [1]. Therefore, we suggest modifying the previous definition of the Dorgali Dolostone Fm., formerly strictly related to dolomitization phenomena, and replace it by a simple Dorgali Fm., precisely characterized by lithofacies of lagoonal, inner to outer shelf environments. In this way, an actual gradual thinning towards the north of this newly defined Dorgali Fm. can still be evidenced.

2.3. Genna Silana Fm. – S'Adde Fm

In the Baunei Supramonte areas, after Dieni and Massari [19], the Dorgali Fm. is both overlaid and partially eteropic with the Monte Tului Fm. [1,19], the lower part of the Monte Bardia Fm. [1,19] and the S'Adde Fm. [19]. The Monte Tului Fm. (Callovian–Kimmeridgian) [19] is a calcareous, prevalently oolitic unit, with a thickness comprised between 200 and 300 m. The lower part of the Monte Bardia Fm. [1] (Oxfordian–Kimmeridgian) [19] is a calcareous, biohermal unit that can reach 150 m of thickness. The S'Adde Fm. (Callovian–Kimmeridgian) [19,20], up to 300 m thick, is formed by bioclastic calcarenites–calcilutites, containing locally chert thin layers and nodules.

Indeed, field surveys evidenced the interdigitation and the same palaeoenvironmental location of the

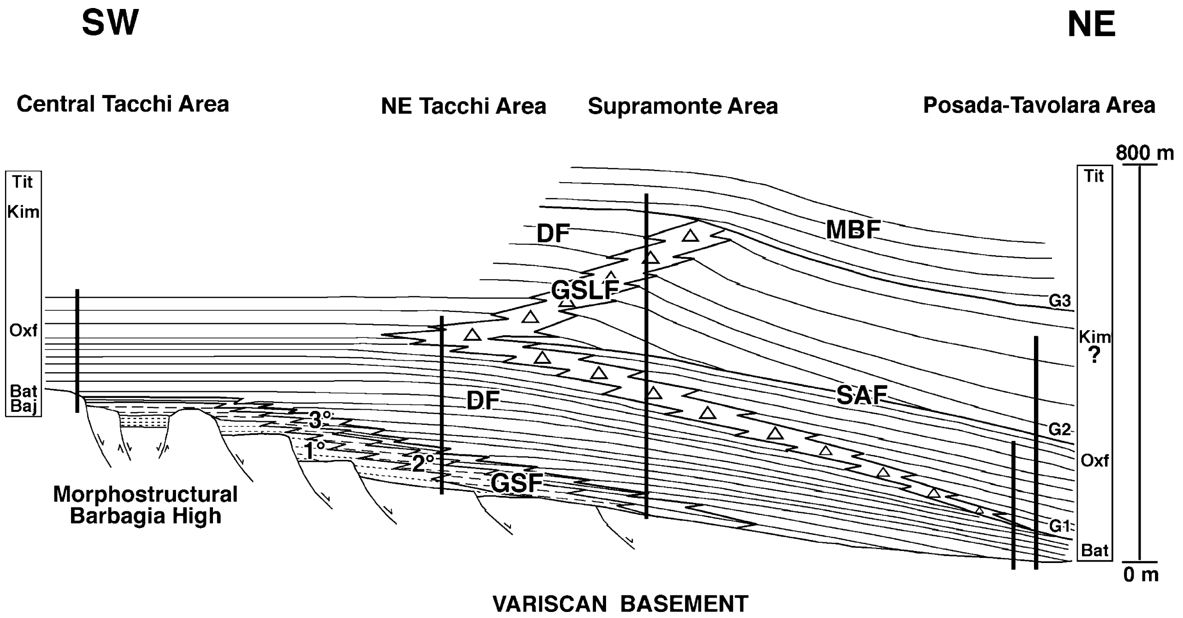

Fig. 3. Sketch of the stratigraphic–sequential evolution of the Middle–Late Jurassic carbonate ramp in eastern Sardinia (scale and distance only indicative). Legend: GSF, Genna Selole Fm. (1, Laconi–Gadoni lithofacies; 2, Nurri–Escalaplano lithofacies; 3, Usassai–Perdasdefogu lithofacies); DF: Dorgali Fm.; GSLF: Genna Silana Fm.; SAF: S'Adde Fm.; MBF: Monte Bardia Fm. G1: First stratigraphic gap, G2: second stratigraphic gap, G3: third stratigraphic gap according to [19]; Baj: Bajocian; Bat: Bathonian; Oxf: Oxfordian; Kim: Kimmeridgian; Tit: Tithonian.

Fig. 3. Essai de reconstruction de l'évolution stratigraphique séquentielle de la rampe carbonatée du Jurassique moyen–supérieur de Sardaigne orientale (échelle seulement indicative) : GSF : Formation de Genna Selole (1, lithofaciès de Laconi–Gadoni ; 2, lithofaciès de Nurri–Escalaplano ; 3, lithofaciès de Ussassai–Perdasdefogu) ; DF : formation de Dorgali ; GSLF : formation de Genna Silana ; SAF : formation de S'Adde ; MBF : formation de Monte Bardia. G1 : Première lacune stratigraphique, G2 : seconde lacune stratigraphique, G3 : troisième lacune stratigraphique [19]. Baj : Bajocien ; Bat : Bathonien ; Oxf : Oxfordien ; Kim : Kimméridgien ; Tit : Tithonien.

Monte Tului and Monte Bardia Fms.: in fact, they separate the inner (Dorgali Fm.) from the outer (S'Adde Fm.) shelf. Therefore, in our opinion, they can be considered merely as lithofacies of a single lithostratigraphic unit, and they could be merged and renamed Genna Silana Fm.

Therefore, the Genna Silana Fm. is built of oolitic bars (oolitic and oolitic–bioclastic grainstones and

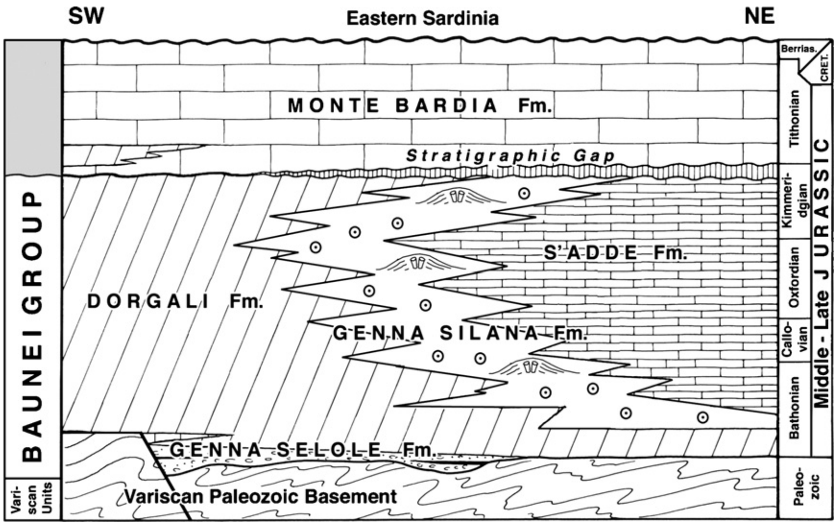

Fig. 4. General stratigraphic sketch of the Jurassic deposits of eastern Sardinia (modified from [19]).

Fig. 4. Schéma stratigraphique général des dépôts jurassiques de l'Est de la Sardaigne (d'après [19], modifié).

packstones) and lenticular coralline framestones. Upwards, the prevalence of oncolitic floatstones reveals an environmental deepening, passing to shallow outer shelf contexts. Towards the top, and partially heteropic with the previously described lithostratigraphic units, the finer S'Adde Fm. [19,20] occurs. It is related to deeper environments (outer shelf) and is only present in the northeastern parts of the island.

Consequently, in all the Jurassic outcrops of eastern Sardinia, the Dorgali Fm. is both overlaid and partially heteropic with the Genna Silana and S'Adde Fms. (Fig. 4). Moreover, the upper part of the Dorgali Fm. also overlies these units (Fig. 2–4).

A good example of this situation is shown at Genna Silana (Baunei Supramonte) – Fig. 2, centre –, where a stratigraphic section evidenced about 120 m of the Dorgali Fm., directly overlying the Variscan basement, followed by about less than 100 m of the Genna Silana Fm. Afterwards, a thin intercalation (50 m) of the S'Adde Fm. takes place, in its turn roofed first again by about 60 m of the Genna Silana Fm., and finally by less than 100 m of the Dorgali Fm. resumption (Fig. 2). Here, the Dorgali Fm. is unconformably overlain by a calcareous, inter-supratidal unit, named again by Dieni and Massari ''Monte Bardia Fm.'' [19] and assigned by them to Tithonian–Berriasian.

2.4. South–north evolution of the Jurassic series: the Tacchi, Supramonte and Posada–Tavolara stratigraphic sections

In the northeasternmost Tacchi areas (e.g., Taquisara, Tacco di Osini) [13] (Fig. 2, left), the stratigraphic sections showed that about 10 to 20 m of the Genna Selole Fm. are overlaid by 250 to 300 m of the Dorgali Fm., in its turn covered by thin remains of the Genna Silana Fm., dated Oxfordian (foraminifera, corals) [13], and reaching a maximum thickness of 40 m.

At Genna Silana, as described in the former paragraph, the Dorgali Fm. embeds the Genna Silana Fm., in its turn embedding a thin S'Adde Fm. (Fig. 2, centre).

In a general view, in the Tacchi and Baunei Supramonte area, the Genna Silana Fm. is posed conformably over the Dorgali Fm. However, according to Dieni and Massari [19], moving to the north, the transition takes place here throughout a hard-ground surface. Our field surveys evidenced that nowhere does it happen that, when the Dorgali Fm. ends up with a hard ground surface, the S'Adde Fm. directly follows the latter (Fig. 2, right).

This is clearly visible at Posada (Fig. 1) [2], where, overlying the Dorgali Fm., few tens of metres thick and crowded by an encrusted hard-ground surface, the S'Adde Fm. takes place (Fig. 2, right). This heterogeneous unit is formed first by calcarenites/calcilutites containing scattered, little, early-stage slumpings, followed by well-stratified marly limestones showing nodular structures. Upwards, calcilutites, and subordinated oolitic calcarenites layers perhaps due to storm events are found: two other hard-ground surfaces are also present here. Fine oncolitic calcarenites and calcilutites end the succession.

By means of the palaeontological content of the S'Adde Fm. [20], it should be noted that, while the first 45 m of the Posada succession are comprised between Early and Late Bathonian (calcareous algae, benthonic foraminifera, ascidians), the following 25 m represent the Late Bathonian–Oxfordian interval (brachiopods, benthonic foraminifera, echinoderms, ostracods), improving a condensed deposit linked to hard-ground episodes, typical of deeper, drowned environments. Here the thickness of the S'Adde Fm. is about 50 m. Therefore, we suggest that the sedimentation of this unit was connected with the Middle Jurassic early drowning of the eastern Sardinia Jurassic carbonate shelf.

At Tavolara Island, to the north, the Jurassic series appears quite similar to the Posada one: a Dorgali Fm. 50 to 100 m thick, formed by bioclastic to subordinately oolitic grainstones is rapidly followed by the outer shelf of well-stratified fine limestones (bioclastic wackestones/packstones) of the S'Adde Fm., less than 150 m thick.

2.5. General framing

The exposed data suggest that, in a regional perspective, the chronostratigraphic extents of the Dorgali, Genna Silana, and S'Adde Fms. are clearly superposed on each other. This could be linked to the development, evolution and shifts through time and space of the environments of the carbonate shelf, related to tectonic and eustatic phenomena. The described succession differences, in spite of the present geographic position, originate from the diverse, diachronous palaeogeographic developments (Figs. 3 and 4): in the Tacchi area (inner shelf), the southernmost outcrops, the Jurassic succession (Fig. 2, left) is only reduced to the Genna Selole Fm., followed first by the Dorgali Fm., and finally by little remnants of the Genna Silana Fm. Over these formations, on rare occasions the Dorgali Fm. restarts with a thickness of a few metres (Figs. 2–4). In this case, this last unit ends the succession. In the eastern Oliena Supramonte and in the Baunei Supramonte areas, the Jurassic succession could be interpreted as a depositional cycle, Bajocian–Kimmeridgian in age, starting and ended by the Dorgali Fm. (here, rare, isolated pockets of Genna Selole Fm. have been found along the basal unconformity); in the middle (Figs. 2–4), the Genna Silana Fm. contains a thin intercalation of S'Adde Fm. (Figs. 3 and 4). The Dorgali Fm., as defined in this work, is northwards often faintly or not dolomitized, and is thinner than in the Tacchi area (e.g., 120 m at Genna Silana).

Over the Kimmeridgian–Tithonian unconformity, an 'upper' Monte Bardia Fm. (*sensu* [1]) follows, featured by completely different lithofacies if compared to the lower Monte Bardia lithofacies of the Genna Silana Fm.

Towards the north, up to Tavolara–Capo Figari, the upper part of the Bathonian–Kimmeridgian cycle is scoured: progressively, first the upper level of the Dorgali Fm. (Monte Tuttavista, Orosei), and after that the Genna Silana Fm. (northern part of M. Albo), thin down and finally disappear, because of the erosion beneath the Kimmeridgian–Tithonian unconformity (Fig. 4). The top of the succession is represented by the S'Adde Fm.

The Posada cliff succession starts with the Dorgali Fm. and ends with the S'Adde Fm. The limited thickness of the overall Posada succession and the condensed character of its upper part improve the gradual passage, during the Middle Jurassic, from open-shelf to (incipiently) drowned-platform conditions, the latter being related to the eastwards gradual development of an active extensional tectonics due to the opening of the Alpine Tethys. By this way, on the base of the abovementioned data, the Jurassic carbonate shelf stratigraphic units of eastern Sardinia can be assembled to form together the 'Baunei Group' (Fig. 4). In fact, despite the fact that this ''Baunei Group'' would cover a very large time interval, nevertheless it is built by formations sharing significant and diagnostic lithologic properties, representing the constituting depositional elements of a single, major stratigraphic–depositional unit: the carbonate shelf of the Tethyan margin of the Sardinian sector. In a manner, the Genna Selole Fm., for its own features, its palaeogeographic meaning, and the pertinence with the Bajocian–Kimmeridgian sedimentary cycle can also be joined to the 'Baunei Group'. Besides, the latter provides of course a significant simplification in the eastern Sardinia Jurassic stratigraphy.

3. Aggradation and progradation growth patterns

In the Tacchi area, the lagoonal environment (Dorgali Fm.) is clearly characterized by aggradation patterns. Examples could be observed on the northern side of the Seui Tacco, where an aggrading series, over 250 m thick, crops out [12]. In contrast, in the central part of the studied area (Baunei Supramonte), the lagoonal, aggrading Dorgali Fm. is suddenly replaced, after less than 100-m thickness, by the oolitic calcarenites of the Genna Silana Fm., characterized by low-angle oblique–parallel to sigmoid–oblique progradation patterns towards the ENE [12]. This setting is consistent with the northeast-verging frontal accretion of the Genna Silana Fm. oolitic bars towards the outer and deeper part of the shelf. The thickness and the stratigraphic–depositional architecture of the carbonate successions in the Tacchi area, compared with those in the Supramonte area, indicates a major subsidence rate in this last zone, consistent with its palaeogeographic location during Middle–Late Jurassic times. In fact, differently to the Tacchi area, the Sardinian Jurassic carbonate succession cropping out from the Supramonte to the northern areas overlies the edge of the diverging European tectonic plate [J. Thierry's 'Late Callovian' in 18] and, particularly, the blocks of the Jurassic Sardinian divergent palaeomargin, which collapsed and were gradually drowned in front of the Alpine Tethys.

4. Palaeogeographic evolution of eastern Sardinia and relationships with the surrounding areas

4.1. Generalities

In eastern Sardinia, the Middle–Late Jurassic sedimentation is driven by the evolution of the horst–graben–half graben system created along the European Plate edge [4,5, J. Thierry's 'Late Callovian' in 18,34] by the opening of the Alpine Tethyan Ocean [13]. Eastern Sardinia was located on a morphostructural emerging high. This most likely leads to the erosion of a significant part of the previous deposits, as the former post-Variscan cover (Permian, Triassic, Liassic?), and even a part of the Variscan basement. Similar morphotectonic conditions have been quoted in the Briançonnais realm ('révolution du Lias sup.') [5,14] and, partially, in the Alpine 'Domaine intermédiaire' of Septfontaine [33].

Otherwise, in western Sardinia (probably flanking the eastern Sardinia horst), because of a major subsidence, the carbonate deposition continues almost undisturbed [8,9,11,15]: only a significant shallowing has been evidenced during the Bathonian (brackish lagoon and coastal lake environments) [9,15]. Here, this situation resembles the French Grand-Causses (palustrine transitional deposits interfingered with carbonate lagoon deposits at Bajocian times) [7,10,32].

So, in eastern Sardinia, the physiography could initially be explained as a main horst, in its turn subdivided by secondary faults into minor horst–graben–half graben structures (probably striking NNW–SSE): these minor tectonic structures gradually start smoothing and lowering the main horst to the ENE direction. The breakout of the horst takes place first in the northern part of eastern Sardinia, closer to the area where the Alpine Tethys is opening, and lately it involves its southern part. Just during the uplift of the horst, the continental sedimentation, represented by the Genna Selole Fm., develops on the slopes of the higher sectors (Tacchi area), where it underlines the base of the Middle Jurassic transgression. The Genna Selole Fm. gradually spreads out, giving place to increasingly finer deposits towards lower sectors (e.g., the Supramonte area). These last ones, far from the relieves, are also characterized by a progressively thinner continental deposition. As a fact, starting from the Supramonte and up to northeastern areas, moving away from the border of the uplifted blocks, the Genna Selole Fm. is missing: only isolated, usually thin remnants (Fig. 3) crop out here and there. Therefore, the Dorgali Fm., often containing scattered quartz clasts and pebbles, usually takes place directly over the metamorphic Variscan basement.

A progressive drowning and collapse of the tectonic blocks follows the slowing down and the stop of the horst uplift. This collapse is driven by the Tethyan discontinuities, and is more rapid in the marginal areas of eastern Sardinia: here, it induces a condensed sedimentation and hard-grounds, provoking consequently the marine facies shift and onlap towards the inner sectors, located presently to the southwest (Fig. 3).

Then, the lagoonal facies of the Dorgali Fm. moves in times from northeastern (Early Bathonian, Posada) [20] to southeastern Sardinia (Late Bathonian, Tacchi area) [21,22] (Figs. 3 and 4). At its base, moving to the southwest, the Dorgali Fm. gradually superimposes over increasingly thicker deposits of the Genna Selole Fm. (Fig. 3, 4). When the marine transgression reaches the top of the uplifted blocks (Barbagia palaeo-high, Fig. 1), the Genna Selole thickness sharply becomes much thinner and frequently disappears (Figs. 2 and 3). Here, the Dorgali Fm. directly overlies the Variscan basement, often affected by weathering processes ('Ferro dei Tacchi'). In the same way, the Dorgali Fm. gradually aggrades and thickens. Otherwise, in the outer areas, the Dorgali Fm. is covered in its turn by the outer and deeper Genna Silana and S'Adde Fms. In the outermost shelf areas (e.g., Posada) the Dorgali Fm. is followed, throughout a hard-ground surface suggesting a rapid environmental deepening (most likely due to a tectonic collapse), by the S'Adde Fm., typical of deeper, outer shelf environments.

During the progressive southwestward shift of the lagoonal Dorgali Fm., a marginal unit between the inner and the outer shelf differentiates: the Genna Silana Fm. The ooidal shoals and little bioconstructions of the Genna Silana Fm. develop where the environmental and physiographical conditions are favourable, between the outer shelf environment of the S'Adde Fm. and the inner shelf environment of the Dorgali Fm. This unit, just starting to evidence itself in the Late Bathonian–Callovian at Monte Tuttavista (perhaps at Monte Albo), reaches southeastern Sardinia (Tacchi area) not before the Oxfordian [13].

After the Oxfordian, the subsidence rate slows down and is overwhelmed by the carbonate sedimentation rate: the progradation (depositional regression) of the shelf takes place, triggering the shift and the superposition of the marginal Genna Silana Fm. and the inner shelf Dorgali Fm. towards the northwest over the outer shelf units.

4.2. *Comparison with the Jurassic successions of Corsica*

A similar gradual evolution (drowning and deepening) of the Jurassic sequences facing the Tethys towards the ENE has just been noticed in the Alpine Corsica, initially by Beauvais and Rieuf [3] and, afterwards, evidenced and developed with more details [25,30,31] (Fig. 5).

In Corsica, the Jurassic series have been differently attributed to the 'Sardo-Provençal Domain' in the West of the island, and to the 'Extra-Alpine Domain' in its eastern part [24 and references therein].

The presence of the 'Sardo-Provençal Domain' in southern Corsica, at present completely dismantled, has been stated throughout the facies and palaeontological analysis of the carbonatic pebbles coming from the Tertiary (?) Chiappa conglomerates [24]. Sedimentological analysis suggests that the debris originate from the west of Porto-Vecchio. The reconstructed

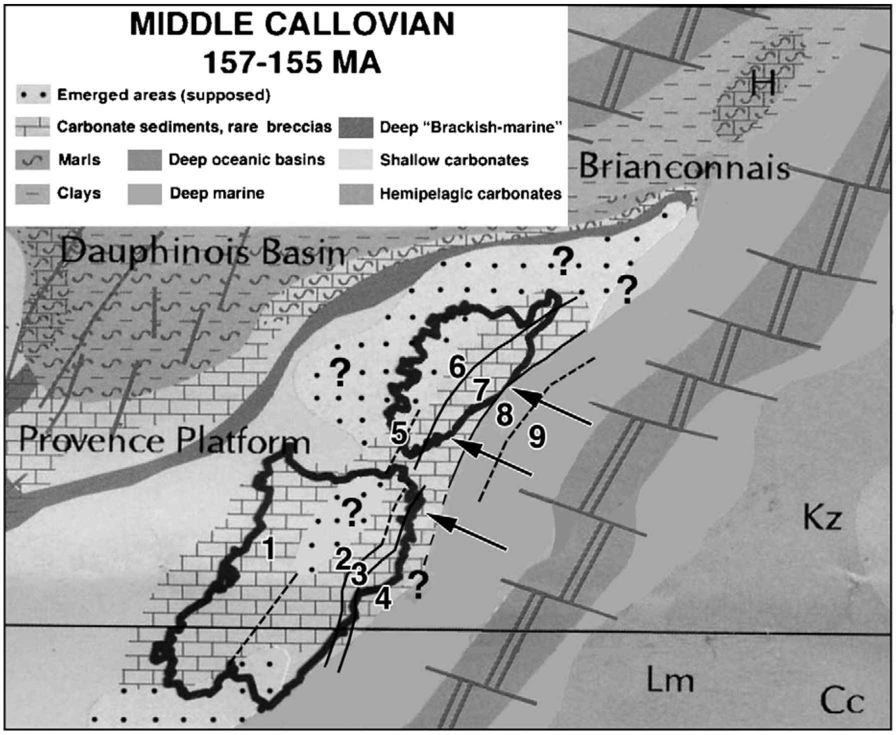

Fig. 5. Attempt of palaeogeographic reconstruction of the eastern Sardinian–Corsican Tethyan margin during Middle Callovian times (modified from Thierry and Barrier, map no. 9, Middle Callovian, in [18]: data from the present work and [12,13,24,25,30]; legend: Sardinia: (1) Nurra, Sardo-Provençal Domain; (2) Dorgali Fm. area, Extra-Alpine domain; (3) Genna Silana Fm. area, Extra-Alpine Domain; (4) S'Adde Fm. area, Extra-Alpine Domain. Corsica: (5) possible source area of the Chiappa conglomerates carbonate pebbles, Sardo-Provençal Domain; (6) Autochthonous: peritidal dolostones area, Extra-Alpine Domain; (7) margin and outer shelf supposed area, not outcropping, Extra-Alpine Domain; (8) 'Prepiemontaise' zone: Francardo breccias, nodular limestones and limestones area, Extra-Alpine Domain; (9) Balagne nappe: radiolarites area, Extra-Alpine domain. H = Hochstegen; Kz = Krizna nappe; Lm = Licicum; Cc = Choc nappe. The arrows indicate the inferred coastal line shift direction. For further details, see Thierry and Barrier in [18].

Fig. 5. Essai de reconstruction paléogéographique de la marge téthysienne du bloc Corso-Sarde pendant le Callovien moyen (d'après Thierry & Barrier, carte n° 9 (Callovien moyen) in [18], modifié) ; données du présent travail et de [12,13,24,25,30]. Sardaigne : (1) zone de la Nurra : domaine sardo-provençal ; (2) zone de dépôt de la formation de Dorgali, domaine extra-alpin ; (3) zone de dépôt de la formation de Genna Silana, domaine extra-alpin ; (4) zone de dépôt de la formation de S'Adde, domaine extra-alpin. Corse : (5) zone de possible provenance des galets carbonatés des conglomérats de la Chiappa, domaine sardo-provençal ; (6) autochtone : zone de dépôt des dolomies péritidales, domaine extra-alpin ; (7) marge et zone supposée de plate-forme externe non affleurante, domaine extra-alpin ; (8) zone « prépiémontaise » : zone de dépôt des brèches de Francardo, des calcaires noduleux et des calcaires, domaine extra-alpin ; (9) nappe de Balagne ; zone de dépôt de radiolarites, domaine extra-alpin. H = Hochstegen ; Kz = nappe de Krizna ; Lm = Licicum ; Cc = nappe de Choc. Les flèches indiquent la direction supposée de déplacement du littoral. Pour plus de détails, voir Thierry et Barrier [18].

successions, covering the Rhaetian–Santonian interval (Fig. 5, 5), revealed strict similarities with the Sardinian Nurra ones (Fig. 5, 1).

Otherwise, some of the Alpine Corsica Jurassic successions, pertaining to the 'Extra-Alpine Domain', resemble the central-eastern Sardinia ones. An isolated outcrop of this domain is also present in the southern part of the island (Conca, Malm limestones). In Corsica, the comparison of the different stratigraphic successions of the 'Autochthonous', the 'Pre-Piedmontese zone' and the 'Balagne Nappe' allowed the reconstruction of a small segment of the collapsing western margin of the Ligurian–Piemontese Ocean during Middle–Late Jurassic [30]. Here, environments comprised between the inner carbonate shelf and the deep radiolaritic basin have been evidenced. The inner carbonate shelf is represented by the 'Autochthonous' succession of Punta di Calcina: the described succession [29,30] can be compared with the central–eastern Sardinia Bathonian–Kimmeridgian one.

In the 'Autochthonous' of Corsica, the Punta di Calcina Jurassic succession is about 90 m thick. It is built of:

(1) 30 m of massive dolostones (Bathonian-Callovian);
(2) 60 m of:

(a) sparites with trocholines (Dogger–Malm boundary);
(b) micrites containing charophites;
(c) intraoosparites with dasycladaceae algae (Late Oxfordian–Kimmeridgian).

This succession is covered discordantly by Tertiary deposits [29].

Although this succession is significantly thinner with respect to the Sardinian ones, the 1, 2a and 2b intervals could be compared with the Dorgali Fm., and so referred to lagoon–inner shelf environments, while the 2c interval could be compared with the Genna Silana Fm., figuring out higher energy environments (oolitic–bioclastic bars) posed along the margin of the shelf. Reputedly, the assigned ages [29] could suggest in the Corsica area a later depositional regression of the upper part of the transgressive–regressive cycle, in the Sardinian dated Bathonian–Kimmeridgian.

Because of the shortening related to the Alpine deformations, the Tethys margin reconstructed by means of the Corsica successions is significantly larger with respect to the Sardinian one. At Middle Callovian times (Fig. 5), in Sardinia, inner shelf (2), oolitic-patch reef margin (3) and outer shelf (4) zones have been identified. In Corsica, only the inner shelf ('Autochthonous', Punta di Calcina section) (6) can be considered as corresponding to the Sardinian inner shelf zone (2). The 'Pre-Piedmontese' zone (8) and the 'Balagne Nappe' (9) are not comparable with the Sardinian environments, since they are related to deeper and more basinal environment with respect to the outer shelf areas evidenced in the Sardinia area. In Corsica, the marginal and outer shelf areas (7), whose location could be comprised between the 'Autochthonous' and the 'Pre-Piedmontese' zones, have probably been involved in the nappe building; thus they do not crop out currently. Otherwise, in central-eastern Sardinia, the Jurassic basinal zones likely lay collapsed far to west presently, along the bottom of the Tyrrhenian Sea.

5. Sequence stratigraphy chart comparison

The transgressive–regressive Sardinian Bathonian–Kimmeridgian facies cycle does not match well with the facies cycles described [26,27], for both the Tethyan and Boreal realms. In fact, in the Tethyan realm, from the Middle Bathonian to the Latest Tithonian, two complete transgressive–regressive second-order cycles (T8-R8 and T9-R9, after [27]) are evidenced, while in Sardinia, as stated above, the first complete Jurassic facies cycle is dated from Bathonian to Kimmeridgian: the M. Bardia transgression, assigned to Tithonian, follows upwards. These differences are probably due to the subsidence linked to the active extensional tectonics of the continental margin that influences the eustatic sequences.

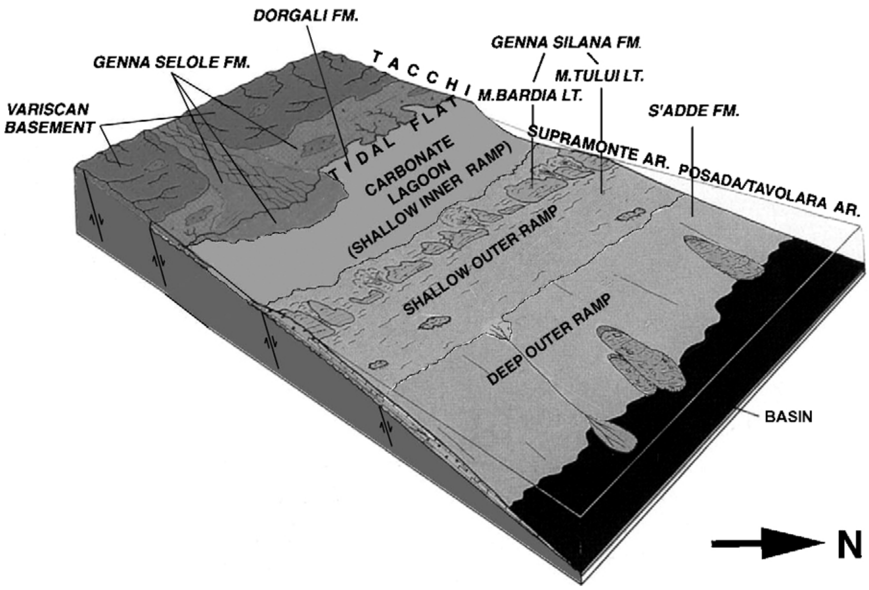

Fig. 6. Paleoenvironmental sketch of the eastern Sardinia Jurassic carbonate ramp during the Bathonian. LT = lithofacies; AR. = area.

Fig. 6. Essai de reconstitution de la rampe carbonatée jurassique de Sardaigne orientale pendant le Bathonien. LT = lithofaciès ; AR. = aire.

6. Depositional model

Based on these previously exposed features, a ramp morphology dipping from southwest to northeast for the central-eastern Sardinia Jurassic carbonate shelf can be suggested (Fig. 6). The abundance of storm deposits in the lagoon and the lack of both major reef development and steep margin features support this statement. Nevertheless, the persistence of this ramp could have been interrupted by small, scattered Variscan basement emerged highs, as suggested by the diffuse presence of coarse siliciclastics (quartz angular pebbles and grains) all along the Posada Bathonian–Oxfordian succession. The hypothesis of a distally steepened ramp could also be supported by the finding of slope and deeper ramp features (chert, weak unconformities, scattered channelized breccias bodies) in the S'Adde Fm., observed in various localities (i.e. Perdalonga, Baunei Supramonte).

After the Oxfordian, the transgression ceases and the ramp progrades towards the northeast (Fig. 3): this is attested to by:

- the clinoforms observed in the Genna Silana Fm. of the Baunei Supramonte;
- the upper level of the lagoonal Dorgali Fm. found almost everywhere (in localities where the Bathonian–Kimmeridgian cycle is complete) in north-eastern Sardinia over the Genna Silana and S'Adde Fms. (Fig. 3b), and also, to a small extent, in the northernmost Tacchi area.

Unfortunately, we could not hypothesize the evolution of the Bathonian–Kimmeridgian carbonate ramp to the north to the Oliena Supramonte, because of the erosion and the gap preceding the Kimmeridgian–Tithonian unconformity.

In this frame, as stated above, also the stratigraphic gaps evidenced by the palaeontological data (ostracods, forams, calcareous nannofossils, brachiopods, echinoderms) along the whole Bathonian–Kimmeridgian succession listed by Dieni and Massari [19,20], have now a clearer explanation (Fig. 3):

- the Bathonian–Callovian gap separating the Dorgali Fm. from the S'Adde Fm. could be linked to a sharp deepening of the outer shelf, probably associated with tectonic collapses (opening of the Tethys);
- the Callovian–Oxfordian gap could have the meaning of a starving surface (apparent cut or downlap plane) due to the inversion point between a transgressive and a regressive system;
- the Latest Kimmeridgian–Tithonian gap, the most extended towards the inner shelf, could be related to a hard lowering of the sea level, followed by a wide transgression, leading to the general deposition over all the shelf of the 'upper' Monte Bardia Fm., related to a supra- to intertidal shelf environment.

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