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New Insights into the Platform-to-basin Anatomy of the Urgonian Bas-Vivarais Domain (Lower Cretaceous; SE France)

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Authors' contributions

This work was carried out in collaboration among all authors. Author CF designed the study, performed field collection, and wrote the first draft of the manuscript. Authors AJBT and CL managed the literature searches, the visualization, as well as writing-reviewing and final editing. All authors read and approved the final manuscript.

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ABSTRACT

This paper offers a new contribution to our ongoing harmonization efforts concerning the chronostratigraphic model of the southern France Urgonian-type carbonate platforms, which surrounded the Vocontian Basin during the Early Cretaceous. A multi-stratigraphic approach on the classical sections of the Ardèche River gorges and the Saint-Remèze Plateau have been used for reconstructing the evolution of the Bas-Vivarais Urgonian domain along an inner-to-outer platform profile; the latter being nearly perpendicular to the eastern Vocontian platform margin. In our

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transect, the installation and first developments of the Urgonian platform domain occured during the early Barremian *Taveraidiscus hugii* and *Kotetishvilia nicklesi* ammonite zones. This first platform stage was interrupted at a brief emersion episode that lasted through the *Nicklesia pulchella* ammonite zone, and resulted in the deposition of a sedimentary wedge with limited gradual downward, basinward shift in inner platform facies. This was followed by the regional deposition of shallow-water communities dominated by corals, echinoids, and orbitolinids, which passes basinward into open-marine, ammonite-bearing marly deposits in the Saint-Remèze Plateau outcrops. This change in facies was previously referred to as the Serre de Tourre Beds (STB), and dated to the *Kotetishvilia compressissima* and *Moutoniceras moutonianum* ammonite zones. The STB are further identified to as the local sedimentary expression of the Mid-Barremian Event recording a brief warming climate pulse testified by the presence of *Offneria simplex*, a caprinid rudist of Caribbean origin. Above, there is a regional recovery of inner platform Urgonian facies during the early late Barremian showing a striking progradational basinward trend. The latter, and its subsequent developments are in need of investigations. Taken together, the general evolution of the Urgonian Bas-Vivarais domain shows strong similarities with the sedimentary context of the nearby Subalpine Urgonian platform during the early Barremian. The finding of common sedimentary signals is more difficult with the Provence platform domain at that time.

Keywords: Chronostratigraphy; barremian; cretaceous; platform-to-basin profile; bas-vivarais; France.

1. INTRODUCTION

The Cretaceous outcrops in the Ardèche River gorges of the Bas-Vivarais domain in southern France provide a unique opportunity to observed the depositional geometries of Urgonian-type, Barremian aged carbonate bodies along km-long cliffs passing laterally into outer platform settings in the nearby Saint-Remèze Plateau [1-4]. Various sections have been documented from old monographs [5], seminal theses [2,4,6-8], geological map notices [9-11], field-trip books [12], and research articles [1,3,13-31].

Over the past decades, three main contrasting chronostratigraphic models have been proposed to explain the evolution of the Bas-Vivarais Urgonian platform; namely those of Lafarge [2,15], Bastide [8], and Clavel et al. [23] then updated by Granier et al. [31]. Many of the differences found in these models are rooted in conflicting biostratigraphic scheme either based on ammonite- and/or orbitolinid-age calibration. The aims of the present contribution are to (*i*) compile the litho-, and biostratigraphic markers from the classical sections of the Bas-Vivarais domain, to (*ii*) build a comprehensive and updated inner-to-outer platform profile of the study area, and finally, to (*iii*) continue the ongoing harmonization efforts that are ongoing on the chronostratigraphic model of the southern France Urgonian carbonate platforms.

2. GEOLOGICAL SETTINGS

The main area of interest, i.e., the Bas-Vivarais domain, is located in the southeastern part of the Ardèche region (Fig. 1A). It is bounded by the Palaeozoic basement and the early Mesozoic cover of the Massif Central to the west, and by the Pliocene-Pleistocene fluvial deposits of the Rhône River valley to the east. These geographical boundaries correspond to NNE-SSW fault systems (Cévennes and Nîmes faults) involved in the sinistral displacement of the Provence block relative to the Languedoc one, in the range of 45–50 km [26].

According to the existing data, the Bas-Vivarais deposits formed an epicontinental carbonate belt bordering the Massif Central and opened eastward to the deep-water settings of the Vocontian Basin during the Early Cretaceous (Fig. 1B–C). The rudist-rich platform carbonates – the so-called Urgonian facies – develop over a thick pile of Berriasian to lower Barremian hemipelagites exceeding 1500-2000 meters in thickness [3]. The most proximal settings that cropped out on the west side of the Alès fault are now eroded. This explains the lack of true coastal environment in the sedimentary record of the study area. Our study focuses on the installation of the rudist-rich platform carbonates and its development during the early to early late Barremian time interval.

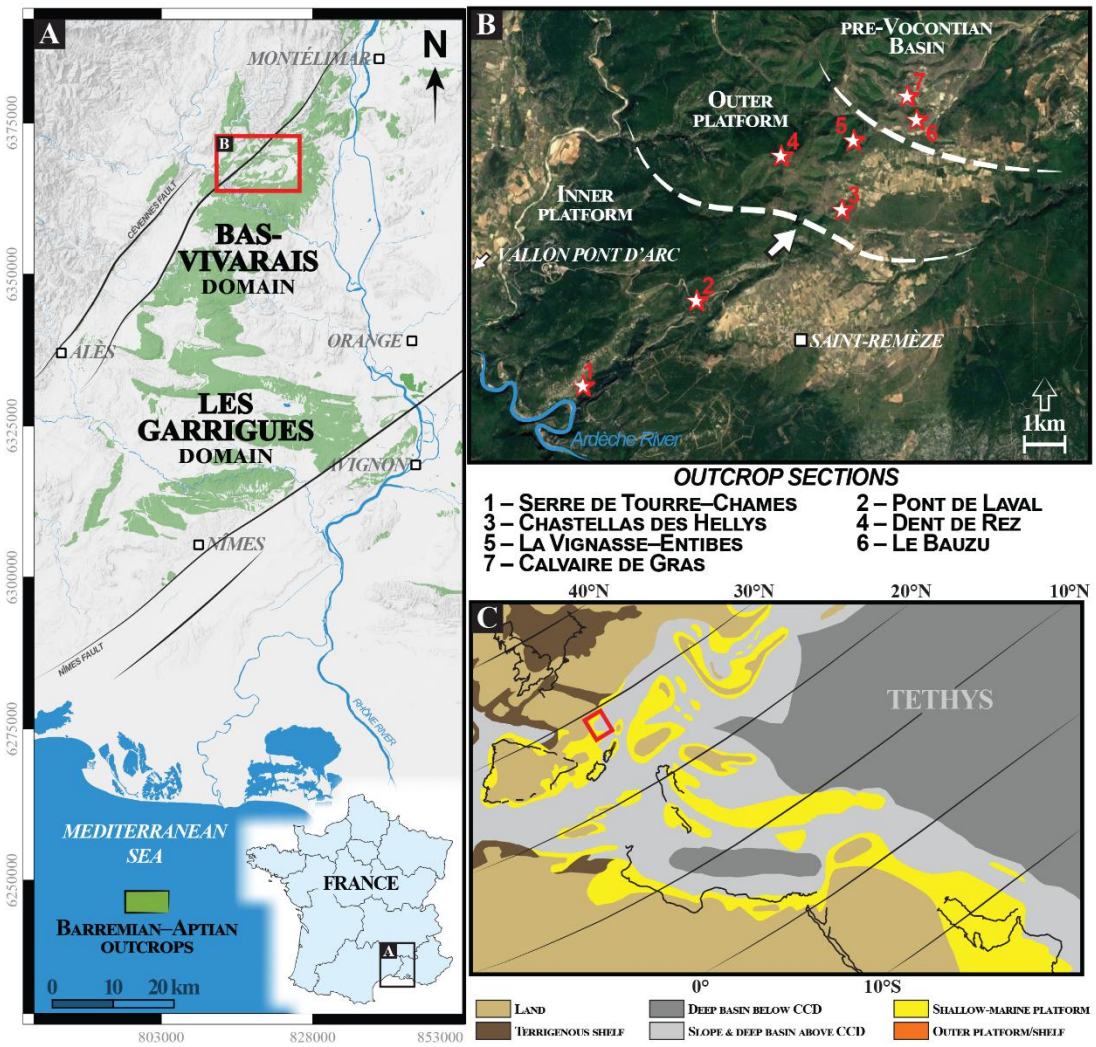

Fig. 1. (A) Simplified geological map displaying the Barremian–Aptian deposits (light green color) outcropping between the Cévennes and Nîmes fault systems in Languedoc, SE France, and locations of the area of interest (red square); (B) Google Earth aerial view of the study area showing the position of studied sections along an inner-to-outer platform profile; (C) Barremian–Aptian palaeogeography of the western Tethys with location of the study area (red square)

Modified after [29]

3. MATERIALS AND METHODS

3.1 Field Database

Seven classical sections of the Ardèche River gorges (Chames–Serre de Tourre) and the Saint-Remèze Plateau (Pont de Laval, Chastellas des Hellys, Dent de Rez, La Vignasse–Entibes, Le Bauzu, and Calvaire de Gras) have been considered in investigating the evolution of the Bas-Vivarais domain along an inner-to-outer platform profile (Fig. 1B). The northern sections (Calvaire de Gras, Le Bauzu) are dominated by ammonite-bearing, basinal facies marking the transition with the deeper settings of the Vocontian Basin *sensu stricto* located further east [2,3,9]. They are referred to as pre-Vocontian as defined by [29].

3.2 Sedimentology

The working approach used for sedimentological characterization involves an outcrop-based carbonate facies description. Thin-section examination has been undertaken for the Chames–Serre de Tourre and Pont de Laval sections based on the sampling of [8]. Sedimentological characterisation and

interpretation of the depositional environments follow our previous contributions of the Urgonian-type platform deposits [28-29,32-33]. The colour chart and symbols presented in Fig. 2 are used consistently throughout the figures. A new stratigraphic sequences terminology is herein proposed for the lower Barremian (Fig. 2): LB refers to "Lower Barremian" and the associated letters (*d* and S) relate to "discontinuity" and "Sequence"; the affiliated numbers correspond to the chronological order of appearance. A detailed description of key stratigraphic discontinuities is provided below.

Of interest is the previous recognition of a switch in facies during the deposition of Urgonian-type rudistid strata marked by a brief change toward shallow-water communities dominated by corals, echinoids, and orbitolinids [2,6]. This switch in facies was previously referred to as the Serre de Tourre Beds (STB); a name derived from the outcrop of the Ardèche River gorges. The acronym is used throughout the text.

3.3 Biostratigraphy

3.3.1 Ammonites

The ammonite record is used for calibrating the sections. It is patchy in the Ardèche River gorges but some age-diagnostic ammonite taxa were reported by [18,21,23], then revised by [28,31]. The record is much more complete in the sections of the Saint-Remèze Plateau. Most of this material was identified by R. Busnardo *in* Lafarge [2]. Since illustration of his material was lacking, we re-examined the Lafarge/Busnardo collection deposited at the University of Claude Bernard–Lyon I. This is completed by the re-examination of [31], and our own collection on the field. Key taxa are therein illustrated in front of the litho-logs. The current Standard Mediterranean Ammonite Scale of the Lower Cretaceous stages is followed [34].

To the difference of the Vocontian basinal settings, the ammonite record of the Bas-Vivarais platform domain occurs sporadically in restricted stratigraphic interval associated with drowning/deepening events of the platform domain. This enables us to define seven successive ammonite bioevents of regional significance covering the early to early late Barremian period (Fig. 3A). The same methodology was previously applied in the upper Barremian rock interval of Provence, Languedoc and SE Vercors area, and six more ammonite bioevents have been recognized [28,33]. It is worth noting that those ammonite bioevents commonly contain the taxa that marks the base of the zones in the nearby Vocontian basinal settings. The link between relative sea-level variations and ammonite faunal turnovers is evident, and it already has proved to be a powerful tool for platform-to-basin correlations in the French Barremian [28,31-33].

3.3.2 Rudists

Where the ammonites are lacking, the shallow-marine faunal associations including rudists and dasycladale algae can provide additional markers to be used for dating and correlating the Urgonian carbonate sequences in southern France. Using previous contributions [30], two successive rudist faunas occur in the lower Barremian of Languedoc; namely the Serre de Tourre (*Agriopleura*-dominated with requieniids) and Pont de Laval (*Offneria simplex*-dominated) faunas (Fig. 3B). The core of the Serre de Tourre fauna is dated to the *Kotetishvilia nicklesi* ammonite zone [28], while the Pont de Laval one is assigned to the *Moutoniceras moutonianum* ammonite zone [17,28].

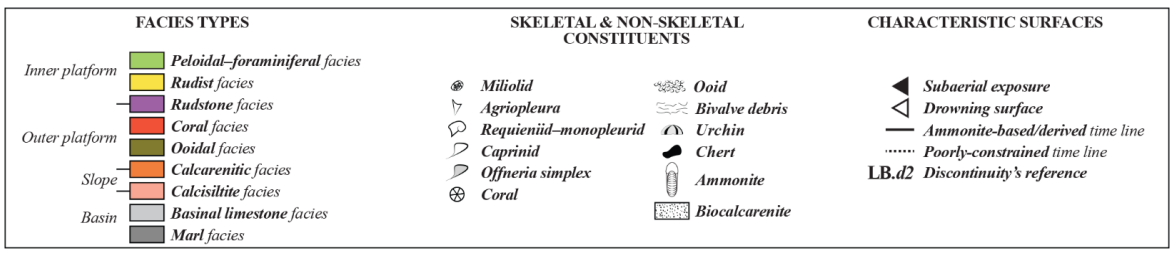

Fig. 2. Facies types, biological–sedimentological symbols and stratigraphic nomenclature used throughout the present contribution
Modified after [29]

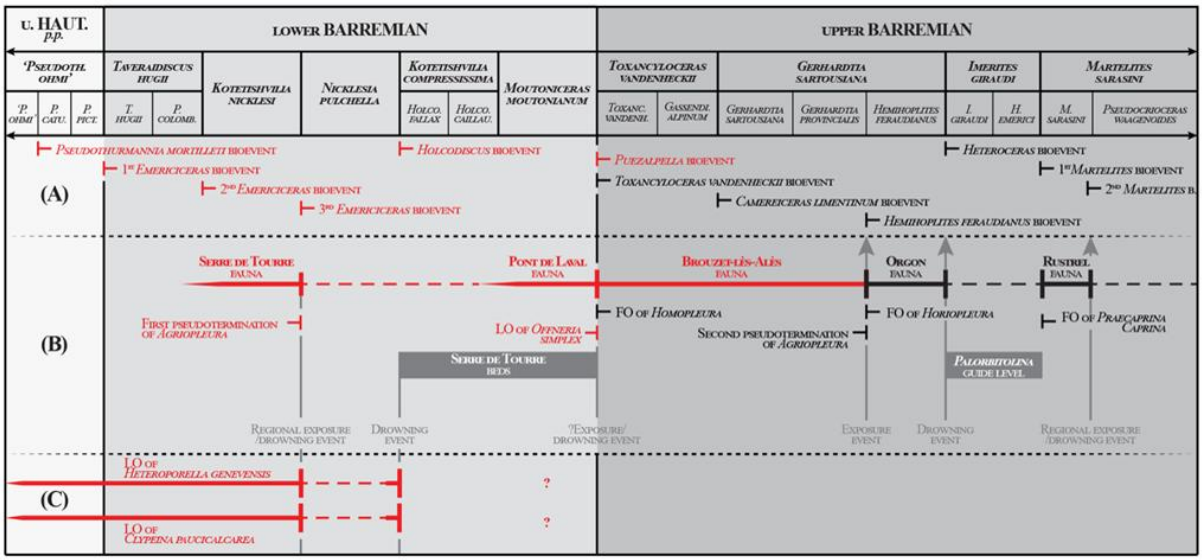

Fig. 3. Synoptic Hauterivian–Barremian *pro parte* stratigraphy with (A) ammonite bioevents (B) French-named rudist faunas, (C) and dasycladale algae bioevents from southeastern France (after [28,3033], This work) and the main environmental changes.

Ammonite scale after [34]. Biomarkers of interest for this work are in red

These faunas add to the three ones locally recognised in the upper Barremian of Provence and Languedoc by [30], namely, from bottom to top, the Brouzet-lès-Alès, Orgon, and Rustrel faunas (Fig. 3B). The last two faunas and their related deposits are not addressed in this contribution although they have an outstanding record in the Ardèche River gorges [25].

We herein acknowledge the recognition of two pseudotermination events of the Radiolitidae *Agriopleura* atop of the beds of the Serre de Tourre and Brouzet-lès-Alès faunas (Fig. 3B). The first event remains poorly investigated to date while the second one marks the supra-regional extinction of the genus – i.e., the '*Agriopleura* Event' – at the scale of the eastern European rudist province. This extinction is thought to have resulted from a combination of cooling, anoxia, platform exposure and change in the trophic factor, leading to the selective removal of these elevator rudists [35-36].

3.3.3 Dasycladale algae

Dasycladale algae are common components of Urgonian-type, shallow-water carbonates of SE France [37-40]. They often occur as long-ranging taxa through the Berriasian to lower Aptian, but some burst of speciation or extinction events have been acknowledged as powerful correlative events [41]. In the lower Barremian, Masse and collaborators [27,37-39] used the concomitant extinction of the dasycladale algae duo *Clypeina paucicalcarea* and *Heteroporella genevensis* as a key peri-Vocontian platform bioevent not younger than the *Nicklesia pulchella*–*Kotetishvilia compressissima* ammonite zone boundary. This extinction event is either observed at an emersive discontinuity in inner platform domain of Languedoc [23,28,42] and W–NW Vercors [23], or at a drowning discontinuity in outer platform domain of Languedoc [21,31], SE Vercors [27,43] and Provence [27,37]. A diachronicity in extinction has been then documented along the inner-to-outer platform profile of SE Vercors by [33]. These authors documented a stepped concomitant extinction, first atop the *Kotetishvilia nicklesi* ammonite zone, and then atop the *Nicklesia pulchella* ammonite zone from proximal to distal (Fig. 3C). It has indeed been documented that the inner-platform discontinuity is associated with hiatus development spanning the *Nicklesia pulchella* ammonite zone, while there is a deposition of a sedimentary wedge in direction of the basin during the same time span [33].

It should be noted that rare occurrences of both *Heteroporella genevensis* and *Clypeina paucicalcarea* have been reported above *Nicklesia pulchella* ammonite zone dated deposits by [31,44-46], but not younger than the *Moutoniceras moutonianum* Zone. This is mostly based on reworked orbitolinid-rich calciturbidites

calibrated by ammonites from the deeper facies of the Vocontian trough (l'Estellon section). These occurrences remain, unfortunately, unfigured (i.e., *Heteroporella genevensis* of sample 72 from l'Estellon in [45-46], while some others are from beds of uncertain ammonite-age calibration (*Clypeina paucicalcarea* of sample 92.3 from l'Estellon). Reports of *Clypeina paucicalcarea* from the *Moutoniceras moutonianum* Zone of La Béguère, Vercors also remain unfigured to our knowledge [23,31], while those from the Serre de Bleyton [47] comes from reworked, turbidite fan deposits of late early to late Barremian age [48]. As a result, the presence of this dasycladale algae duo above *Nicklesia pulchella* ammonite zone dated deposits is far from clear. In any case, this dasycladales are useful biomarkers, easy to identify, and prone to discriminate lower Barremian strata from upper Barremian ones [45-46] (Fig. 3C).

4. MULTI-STRATIGRAPHIC DESCRIPTION OF THE SECTIONS

4.1 Chames–Serre de Tourre

4.1.1 Localisation and data

The Ruisseau du Tiourre valley is located 4.5 km southeast of the so-called Vallon-Pont-d'Arc locality, and runs perpendicularly to the Ardèche River gorges. The north side of the valley (i.e., Chames outcrop) exposes the installation of Urgonian cliffed biocalcarenites over a thick pile of hemipelagites. The south side of the valley (i.e., Serre de Tourre outcrop) exposes the overlying Urgonian rudistid limestones forming two massive cliffs separated by the STB [2]. The STB crop out along the local road D290 in the vicinity of the Serre de Tourre Belvedere. A composite succession of the Ardèche River gorges has been drawn by [23] using the two sides of the valley (Fig. 4A). Most of the Chames–Serre de Tourre succession was sampled for thin sections by [8] and re-examined thereafter (Fig. 4B).

4.1.2 Sedimentology

Above the hemipelagites, the Chames–Serre de Tourre composite section has been divided into four main lithological units [2], as follows:

- ST.I unit (140m) consists of cliff-forming, massive biocalcarenites, with few oolitic horizons at its base. These biocalcarenites are exposed along the Chames cliff panorama and form low- to high-angle clinoforms showing basinward progradation in direction to the northeast (Fig. 5A and 5B).
- ST.II unit (90 m) forms the basement of the Serre de Tourre cliff (Fig. 5C). It starts with an episode of dolomitised massive lenticular coral beds which seemingly truncate the topset of the underlying clinoforms. It then consists of peloidal-foraminiferal and rudistid units including the Serre de Tourre rudist fauna dominated by dense aggregate of the Radiolitidae *Agriopleura marticensis*.
- ST.III unit (48 m) corresponds to the STB. Its characteristics are detailed below.
- ST.IV unit forms a second cliff atop the Serre de Tourre hill (Fig. 5C). It consists of massive coral–rudist accumulation units with sporadic intercalations of oolitic–bioclastic calcarenites or chaetetids-bearing marly limestones. Rudists belong to the Brouzet-lès-Alès fauna.

Above the *Agriopleura*-rich rudist limestones of the ST.II unit (Fig. 5E–F), the STB can be subdivided into four sub-units (Fig. 5D) according to [2]:

- ST.IIIa sub-unit (7 m) consists of oobioclastic calcarenites. Bedding is massive or obliquely laminated. It contains diverse reworked corals (chaetetids, scleractinians), orbitolinids, bryozoans, oysters, gastropods and rare bivalve (? rudist) fragments.
- ST.IIIb sub-unit (10 m) consists of whitish echinoderm oobioclastic limestones.
- ST.IIIc sub-unit (7 m) is formed by fossiliferous bioclastic marls including oysters, bryozoans, echinoids, reworked chaetetid corals, and lenses of biomicrite limestones made of chaetetids and scleractinians.
- ST.IIId sub-unit (20 m) consists of coral–rudist limestones, including rare occurrence of the Caprinidae rudist *Offneria simplex*. This level includes the Pont de Laval rudist fauna.

4.1.3 Biostratigraphy

The dating of the Chames–Serre de Tourre section has been much debated in the past decades (see summary in Fig. 4), till the findings of ammonites [21,23].

These authors reported two ammonite spot occurrences in pre-Urgonian hemipelagites – i.e. below the ST.I unit – at Chames, and two others above, and within the STB at Serre de Tourre. These ammonites have been re-examined by [28] and [31]. Here we interpret them as four successive ammonite bioevents (Fig. 4).

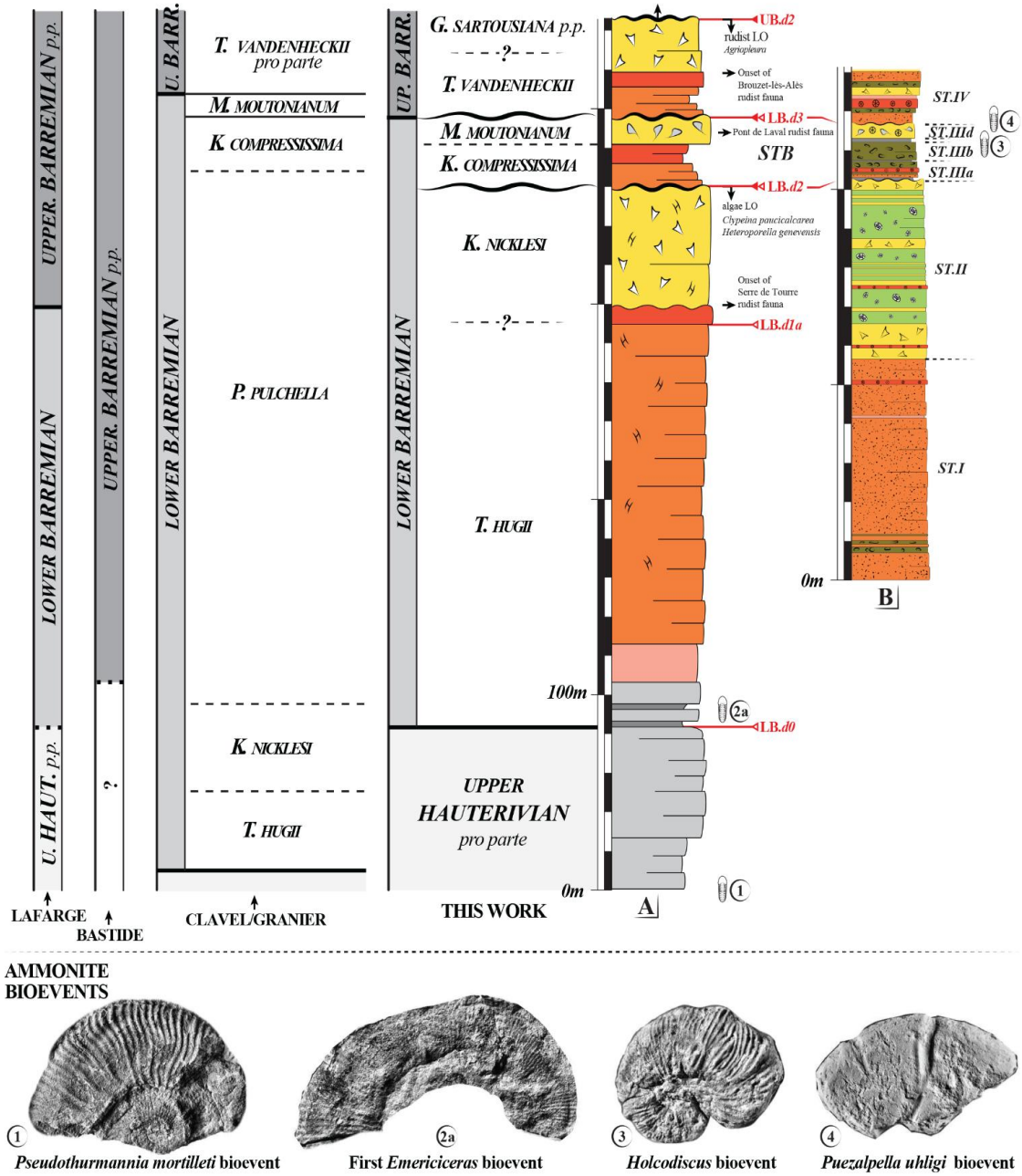

Fig. 4. Lithostratigraphic, sedimentologic and biostratigraphic interpretations of the Serre de Tourre–Chames section (A) after [23] and (B) after thin-section re-examination of [8]. Acronyms in black and red refer, respectively, to the depositional sequences of [2] and remarkable surfaces described in the present contribution

Age assignments are derived from remarkable surfaces of regional significance dated by means of ammonite bioevents figured below (after [23], not to scale). Comparison with previous dating of [2,8,23,31] are added

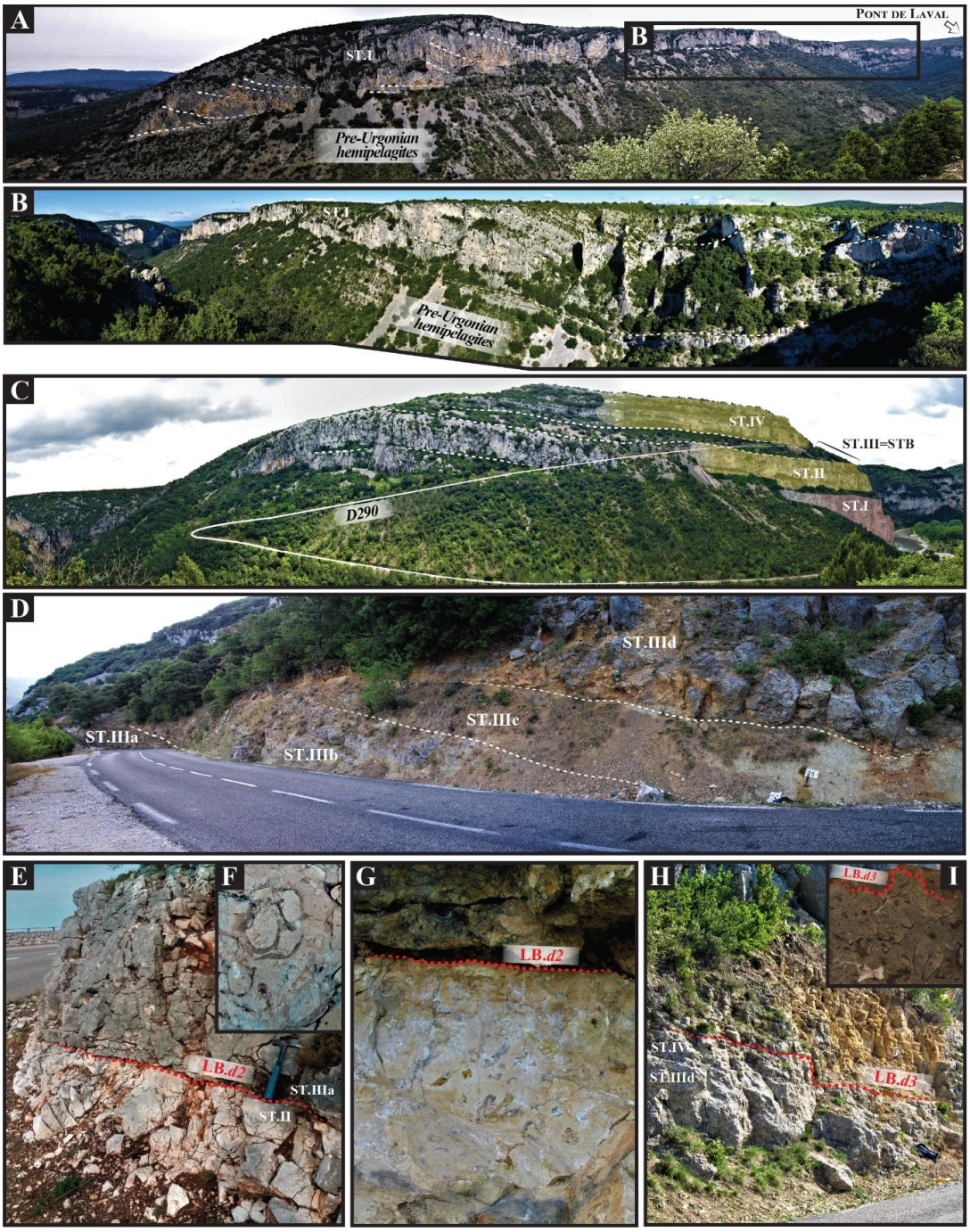

Fig. 5. Field photographs of the Chames–Serre de Tourre composite section: (A) and (B) Panoramas of the Chames cliff showing low- to high-angle clinoforms with a basinward progradation over pre-Urgonian hemipelagites, (C) Panorama of the Serre de Tourre hill with two cliff-forming platform unit separated by the STB, (D) close-up view of the STB off the local road D290, (E) Close-up view of the LB.*d2* discontinuity atop (F) Agriopleura-rich rudist limestones (Serre de Tourre fauna) of the ST.II unit, (G) Details of the LB.*d2* discontinuity showing a fringe of dissolution of rudist shells infilled in by bioclastic marls on ~ 10 cm depth, (H) Close-up view and (I) polished slab of the LB.*d3* discontinuity atop the ST.IIId sub-unit of the STB

Acronyms in black and red refer, respectively, to the depositional sequences of [2] and remarkable surfaces described in the present contribution

- The *Pseudothurmannia mortilleti* bioevent – Crioceratitidae ammonites of the group of *Pseudothurmannia mortilleti* occur in a restricted set of beds in pre-Urgonian hemipelagites at Chames [23]. The species marks a subzone in the middle part of the uppermost Hauterivian *Pseudothurmannia ohmi* Zone, and it is associated with the so-called Faraoni anoxic event [49].
- The First *Emericiceras* bioevent – A poorly preserved individual tentatively assigned to the Crioceratitidae *Emericiceras emerici* have been found in a marlstone horizon cropping out in the upper part of the pre-Urgonian hemipelagites at Chames [23]. The species has its acme in the basal Barremian beds of the *Taveraidiscus hugii* Zone in the nearby Vocontian basinal settings [50]. This dating implies a slight upward relocation of the base of the Barremian with respect to the account of [23].
- The *Holcodiscus* bioevent – The ST.III-c sub-unit of the STB yields poorly preserved holcodiscid ammonites tentatively assigned to *Holcodiscus diversecostatus sensu* [23] or *Holcodiscus* sp. *sensu* [31], together with *Astieridiscus menglonensis sensu* [23] or *Astieridiscus sensu* [31]. Such association is typical of the *Kotetishvilia compressissima* Zone in the nearby Vocontian basinal settings [50].
- The *Puezalpella* bioevent – The lower part of the ST.IV unit yields few fragments of the Barremitidae *Puezalpella uhligi* and the Desmoceratidae *Silesites vulpes* according to [23,31]. The species *Puezalpella uhligi* has its acme at the base of the *Toxancyloceras vandenheckii* Zone in the nearby Vocontian basinal settings [50]. The underlying Pont de Laval rudist beds (ST.IIId unit) thus belongs to the *Moutoniceras moutonianum* Zone in agreement with the previous dating of [17,28].

4.1.4 Main discontinuities

Three main discontinuities have been identified in the rock succession (Fig. 4):

- The marlstone horizon found atop the pre-Urgonian hemipelagites is characterised by a discrete firmground at its base. This firmground marks a minor deepening event here referred to as the LB.*d0* discontinuity.
- The episode of massive lenticular coral beds (base of the ST.II unit) lies on a covered discontinuity that truncates the topset of the underlying clinoforms (ST.I unit). This discontinuity is not yet well characterised due to poor outcropping conditions, but it is here referred to as the LB.*d1a* discontinuity pending more material to be collected.
- The ST.II unit terminates at a distinctive irregular hardground which has been reported by most of the previous authors [6-8,14,26]. It is here referred to as the LB.*d2* discontinuity (Fig. 5E). This discontinuity was repeatedly interpreted as drowning surface since it marks a switch from rudistid platform carbonates toward echinodermic calcarenites [8]. However, evidence of extensive dissolution of rudist shells infilled in by bioclastic marls on ~ 10 cm depth is documented (Fig. 5G). In line with the observations made by [28], the LB.*d2* discontinuity, therefore, amalgamates a short-termed emersion followed by a drowning event. The concomitant extinction of the dasycladale algae duo *Clypeina paucicalcarea* and *Heteroporella genevensis* at this discontinuity indicates the topmost *Nicklesia nicklesi* Zone.
- The last discontinuity corresponds to the irregular hardground occurring atop the ST.IIId sub-unit of the STB (Fig. 5H). It is here referred to as LB.*d3* discontinuity and has been overlooked by most of the authors, to the exception of [17]. Field observations documents a centimetric fringe of dissolution of corals and rudist shells, later infilled in by glauconitic and bioclastic calcarenites, or reworked by extensive burrowing (Fig. 5I). This surface is a clear drowning event occurring at, or near the base of the *Toxancyloceras vandenheckii* Zone according to ammonite occurrences [23,28,31], but evidence of a brief emersion prior to it is convincing.

4.2 Pont de Laval

4.2.1 Localisation and data

The Pont de Laval section is a classical Ardèche locality cropping out on the north side of the Ruisseau du Laval valley off the local road D4, located 2 km northwest of Saint-Remèze. The section is the closest to that of Chames–Serre de Tourre, but the two areas are separated by a N–S oriented fault [9].

4.2.2 Sedimentology

The Pont de Laval exposes the installation of Urgonian platform carbonates over Hauterivian–lower Barremian hemipelagites (Fig. 6). The section has been divided into nine lithological units [2], as follows:

- PL.I unit (55 m) consists of alternating basinal limestones and marls. Limestone beds are centimetric to decametric, with a wavy bedding, and become dominant at the top of the unit.
- PL.II unit (20 m) starts with a bioclastic marly horizon grading upward into thick fine-grained calcisiltite beds.
- PL.III unit (30 m) includes three sequences starting with a marlstone horizon and passing upward into limestone-dominated basinal beds and thin marly interbeds.
- PL.IV unit (50 m) includes alternating metric beds made of basinal limestones and marls. The top is marked by two thick marly limestone beds rich in brachiopods.
- PL.V unit (15 m) includes two metric marly horizons separated by basinal marly limestone beds (= *Vire des Mouniers* of [21]). This unit can be easily followed in the landscape since it marks two greener vegetation lines colonized by *Quercus* trees (Fig. 7A).
- PL.VI unit (50 m) is composed of massive to obliquely laminated, fine- to coarse-grained biocalcarenites. Chert nodules sporadically occur.
- PL.VII unit (65 m) is marked by the installation of coral beds over massive, fine-grained calcarenites grading upward into peloidal-foraminiferal and Agriopleura–requieniid-bearing rudist accumulations typical of the Serre de Tourre fauna (Fig. 7B–C). This unit is topped by a prominent hardground showing bioclastic infilling in rudist shells down to a fringe of several centimeters (Fig. 7D–E).
- PL.VIII unit (65 m) is a distal inner platform variation of the STB. Its characteristics are detailed below.
- PL.IX unit starts with obliquely laminated oolitic beds which become massive at the top. Reworked corals occur. This series continues up to 88 m and become enriched in corals at the top. Then rudist-bearing bearing beds with the Brouzet-lès-Alès fauna appear in the succession but the section is interrupted by faulting.

As for the Chames–Serre de Tourre section, the STB can be subdivided into four sub-units (Fig. 8A–G):

- PL.VIIIa sub-unit (25 m) consists of an alternation of obliquely laminated thin calcarenite beds and argillaceous interbeds, including echinoid and bryozoan remains (Fig. 8B).
- PL.VIIIb sub-unit (6 m) is made of a thick oolitic interval above a marly horizon at its base.
- PL.VIIIc sub-unit (20 m) is composed of coral–rudist limestones, bounded by two coral–sponge–echinoid glauconitic marlstone horizons (3.3 m and 7 m, respectively). The Caprinidae *Offneria simplex* occurs here [17], and it is the principal component of the eponymous Pont de Laval rudist fauna, together with undetermined requieniids (Fig. 8C).
- PL.VIIId sub-unit (14 m) is also formed by blueish oobioclastic limestones with flat, rounded and branched corals (Fig. 8D–E).

4.2.3 Biostratigraphy

Three main ammonite spot occurrences have been reported in the pre-Urgonian hemipelagites of the Pont de Laval section [2,16,24]. The corresponding specimens were illustrated by [21,23], later re-examined by [28]. They belong to the three following ammonite bioevents (Fig. 6):

- The bottom of the PL.I unit yields diverse *Pseudothurmannia* species in a bundle of beds, along with the Pulchellidae *Arnaudiella* sp. and the Desmoceratidae *Abrytusites* cf. *neumayri*. These ammonite accumulations correspond to the local expression of the Faraoni event pertaining to the uppermost Hauterivian *Pseudothurmannia mortilleti* bioevent defined above.
- The top of the PL.I unit contains several ammonite-bearing levels in a marlstone interval. It yields the Crioceratitidae *Emericiceras emerici*, the Acrioceratidae *Acrioceras* sp., the Protancyloceratidae *Karsteniceras* sp. and diverse Desmoceratidae. This association pertains to the First *Emericiceras* bioevent defined above, dating the base of the *Taveraidiscus hugii* Zone.
- The PL.V unit yields the Crioceratitidae *Emericiceras* sp. gr. *koechlini* (= E. sp. B in [16,21]), the Desmoceratidae

Cassidoiceras spp. and the Phylloceratidae *Phylloceras* sp. in the lower marly horizon and an undetermined Hamulinidae in the upper horizon. The presence of individuals of the group of *Emericiceras koechlini* pinpoints the base of the *Kotetishvilia nicklesi* Zone by comparison with the Vocontian basinal settings [50]. This is a second horizon with *Emericiceras*, here labelled to as the Second *Emericiceras* bioevent.

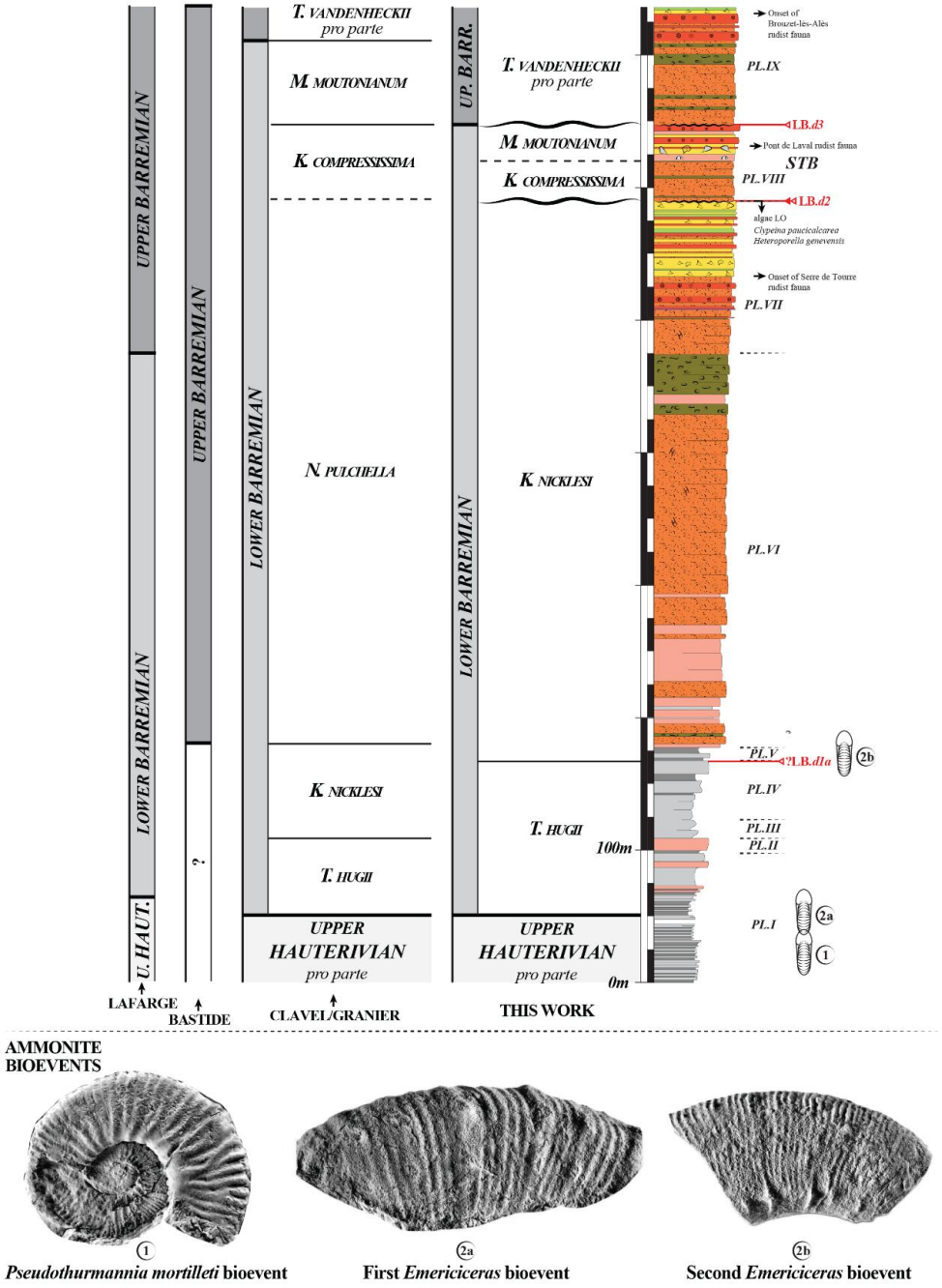

Fig. 6. Lithostratigraphic, sedimentologic and biostratigraphic interpretations of the Pont de Laval composite section after thin-section re-examination of [8]. Acronyms in black and red refer, respectively, to the depositional sequences of [2] and remarkable surfaces described in the present contribution

Age assignments are derived from remarkable surfaces of regional significance dated by means of ammonite bioevents figured below (after [23], not to scale). Comparison with previous dating of [2, 8, 23, 31] are added

Fig. 7. Field photographs of the Pont de Laval section: (A) Panorama of the lower section showing the PL.I to PL.VI units. (B) Close-up view of the LB.*d2* discontinuity atop (C) *Agriopleura*-rich rudist limestones (Serre de Tourre fauna) of the PL.VII unit, (D) and (E) Details of the prominent hardground of the LB.*d2* discontinuity showing bioclastic infilling in rudist shells down to a fringe of several centimetres

Acronyms in black and red refer, respectively, to the depositional sequences of [2] and remarkable surfaces described in the present contribution

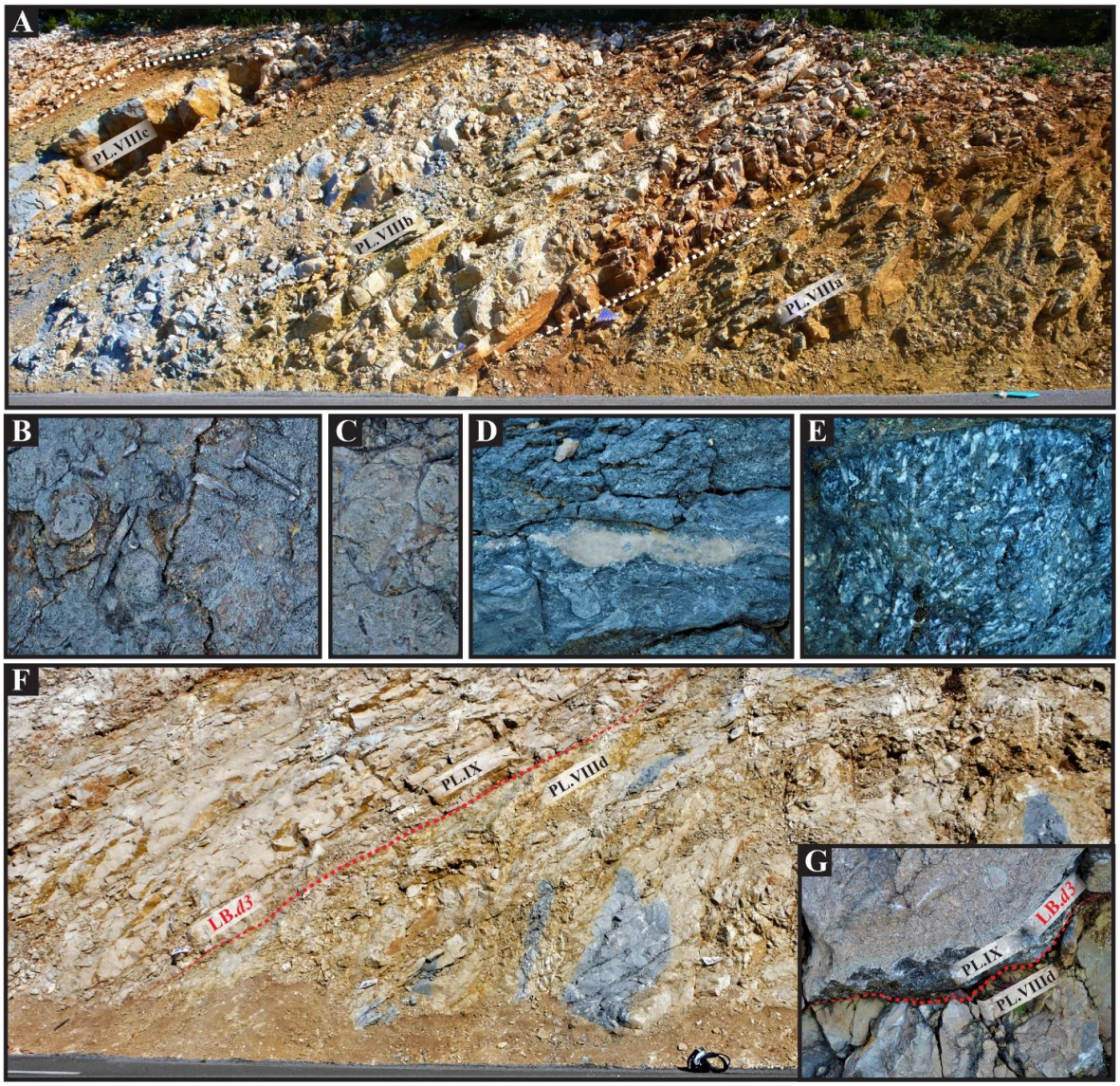

Fig. 8. Field photographs of the Pont de Laval section: (A) Panorama of the upper section showing the first three units of the STB, (B) Close-up view of echinoid and bryozoan remains from obliquely laminated calcarenites of the PL.VIIIa sub-unit, (C) In situ requieniid rudist from the *Offneria simplex* beds of the PL.VIIIc sub-unit, (D) Platy and (E) branched corals from the PL.VIIId sub-unit, (F) Panorama of the LB.*d3* discontinuity atop the STB (PL.VIIId sub-unit), and (G) close-up view of the same discontinuity showing the change from coral-rich oobioclastic to coarse-grained calcarenite sediments

Acronyms in black and red refer, respectively, to the depositional sequences of [2] and remarkable surfaces described in the present contribution

4.2.4 Main discontinuities

Three main discontinuities have been identified in the rock succession and calibrated by ammonites (Fig. 6):

- The lowest discontinuity is a discrete deepening surface found atop the PL.IV unit. This discontinuity forms a landscape marker overlain by the PL.V-related marls (*Vire des Mouniers*) including the Second *Emericiceras* bioevent, being dated to the base of the *Nicklesia nicklesi* Zone. These marls occur just below the PL.VI biocalcarenites suggesting a delayed shift in the installation of the Urgonian facies *sensu lato* between the Chames–Serre de Tourre and Pont de Laval sections. It is

here hypothesized that this discontinuity correlates to the LB.*d1a* discontinuity of the Chames–Serre de Tourre section as it falls close to the putative base of the *Kotetishvilia nicklesi* Zone.

- A second discontinuity is represented by the prominent hardground found atop the PL.VII rudistid unit containing the Serre de Tourre rudist fauna. As for the Chames–Serre de Tourre section, this hardground amalgamates a short-termed emersion followed by a drowning event associated with the LB.*d2* discontinuity. Indeed, Fig. 8D–E illustrates bioclastic infilling in dissolved rudist shells on a fringe of few centimeters.
- The last discontinuity is a distinct erosive hardground found atop the PL.VIII unit (Fig. 8F). It is recorded at the same position to the LB.*d3* discontinuity of the Chames–Serre de Tourre section, but here only evidence of a drowning is evidenced by the change from coral-rich oobioclastic to coarse-grained calcarenite sediments with no trace of dissolution (Fig. 8G).

4.3 Chastellas des Hellys

4.3.1 Localisation and data

The Chastellas des Hellys section was measured and sampled by [2]. It lies in the hill contiguous to the Les Hellys town.

4.3.2 Sedimentology

The succession is about 190 m in thickness, lying above poorly-outcropping Hauterivian aged marly limestones [2]. It has been divided into five main lithological units by the author as follows (Fig. 9A):

- CH.I unit (~ 10 m) is made of a regular bed alternation made of marly limestones and fine-grained calcisiltites.
- CH.II (~ 50 m) and CH.III units (~ 30 m) consist of fine-, then coarse-grained bioclastic to oobioclastic calcarenites, made of obliquely laminated stratifications.
- CH.IV (~ 30 m) is a cliff-forming unit made of chaetetid coral massive limestone beds (Fig. 10A). It is topped by a discontinuity with a siliceous smear (Fig. 10B–C).
- CH.V unit (~ 30 m) starts with a thin horizon made of russet colored, fine-grained calcisiltites, then overlain by bioclastic limestone with large-sized scleractinian corals. This is overlain by a slope composed of obliquely laminated stratifications of oobioclastic limestone beds.
- CH.VI unit (~ 25m) still contains obliquely laminated bioclastic calcarenites, passing upward into more massive coral-limestone beds with chaetetids.
- CH.VII unit (~ 15 m) marks the installation of coarse-grained, echinodermic calcarenites. We found the occurrence of dense aggregate of *Agriopleura* rudists at the top of this unit, that were overlooked so far.

4.3.3 Biostratigraphy

The Chastellas des Hellys section is in a basinward position to Pont de Laval, but lateral continuity of outcrop is affected by local faulting and poor outcropping conditions along the Serre de Barrès hill (Fig. 10A). None ammonite has been yet found here [2]. The only published dating marker is the dasycladale algae *Heteroporella genevensis* from the CH.III unit [2]. The species pinpoints an age not older than the *Nicklesi pulchella* Zone.

Here we further report the finding of dense aggregate of *Agriopleura* rudists atop the CH.VIII unit. Those rudists likely pinpoint the onset of the Brouzet-lès-Alès fauna, marking the basal upper Barremian *Toxancyloceras vandenheckii* Zone. This conforms to correlation of the CH.VII unit of Chastellas des Hellys with the PL.IX unit of Pont de Laval suggested by [2].

4.3.4 Main discontinuities

According to [2], the discontinuity atop the CH.IV unit correlates to the LB.*d2* discontinuity of Pont de Laval (top-PLVIII unit). However, there is no evidence of any exposure-related episode here as the lithology reflects a drowning event evidenced by a change from chaetetid coral limestones (CH.IV unit) to bioclastic-dominated calcarenites (CH.V unit). Furthermore, it is unclear whether the CH.IV unit pinches out in direction to Pont de Laval section at the base of the STB (base of PL.VIII unit) or not, as suggested by [28], on p. 38/41.

4.4 Dent de Rez

4.4.1 Localisation and data

The Dent de Rez hill (or Retz *in litt*.) is the highest peak of the Saint-Remèze Plateau and is

located 1.5 km north-eastward of the Chastellas des Hellys section. The section was measured and sampled by [2].

4.4.2 Sedimentology

Above Hauterivian aged marly limestones with *Pseudothurmannia* ammonites, the Dent de Rez section is about 110 m in thickness, and it has been divided into five main lithological units [2], as follows (Fig. 9B):

- DR.I unit (~ 35 m) is made of a regular alternation made of marly limestones and limestones beds.
- DR.II unit (~ 40 m) consists of cliffed fine- to coarse-grained, echinodermic bioclastic calcarenites with obliquely laminated stratifications, and becoming enriched in oolites in the top. This forms the basement of the Dent de Rez cliff (Fig. 10D).
- DR.III unit (~ 10 m) starts with thin beds of bioclastic calcarenites followed by a bed alternation made of marls and marly limestones, becoming irregularly bedded at the top. This forms a distinct overgrown marly horizon in the landscape splitting the Dent de Rez cliff series into two cliffed units (DR.II and DR.IV units – Fig. 10E).
- DR.IV unit (~ 25 m) consists of cliffed fine- to coarse-grained, echinodermic bioclastic calcarenites similar to that of the DR.II unit described above. The unit forms the Dent de Rez hilltop (Fig. 10F).

4.4.3 Biostratigraphy

The species *Emericiceras emerici* was reported in marly limestones laterally equivalent to the DR.I unit [2]. This species is a marker of the First *Emericiceras* bioevent indicative of the basal Barremian *Taveraidiscus hugii* Zone.

The DR.III marlstones have yield no ammonite [2], but we took *in situ* photographs of large-sized *Emericiceras* atop the DR.II unit (Fig. 9). The occurrence of such large-sized *Emericiceras* is regionally documented in the *Nicklesia pulchella* Zone of the Languedoc [51-52]. It thus corresponds to another horizon with *Emericiceras* ammonites, here labelled to as the Third *Emericiceras* bioevent.

According to [2], the DR.III marlstone horizon contains the “bloom” of the planktonic foraminifera Gavelinella barremiana. This bioevent has no major interest in biostratigraphy, but it can be followed up to the nearby La Vignasse–Entibes section and thus provides interesting element to be used for local correlation. Those *Gavelinella barremiana*-bearing marlstones presumably pinch out at the base of the CH.III unit of Chastellas des Hellys [2]. This cannot be confirmed on the field due to lack of outcrop continuity. Nevertheless, it allows interesting correlations to be drawn, and a matter of discussion (see §5.2).

4.4.4 Main discontinuities

A discontinuity has been identified in the rock succession atop the DR.II unit. It corresponds to a drowning of the echinodermic bioclastic calcarenites covered by the *Gavelinella barremiana*-bearing marlstones (DR.III unit). It has no known equivalent in the previously described sections, and it is thus referred to as the LB.*d1b* discontinuity (Fig. 9B).

The bioclastic calcarenites of the lower DR.IV unit have a distinctive wavy base, that erodes the top of the underlying DR.III marls (Fig. 10G). This likely illustrates a basinward downlapping of the DR.IV unit rather than a regional discontinuity.

4.5 La Vignasse–Entibes

4.5.1 Localisation and data

The La Vignasse–Entibes section was measured and sampled for foraminifera and ammonites by [2], and then re-examined by [24,20,23,31].

4.5.2 Sedimentology

The La Vignasse–Entibes section is about 210 m in thickness, and it has been divided into five main lithological units [2], as follows (Fig. 9C):

- VIG.I unit (~ 18 m) is made of a regular alternation made of marly limestones and limestones beds. This correlates and complements the DR.I unit of the Dent de Rez section.
- VIG.II unit (~ 20 m) consists of a pile of fine-grained oobioclastic calcarenites, with massive and obliquely laminated stratifications. It compares well to the DR.II unit of the Dent de Rez section, although it is reduced in thickness.
- VIG.III unit (~ 10 m) correlates to the DR.III unit of the Dent de Rez section which corresponds to the lateral equivalent of the

Gavelinella barremiana-bearing marlstones.

- VIG.IV unit (~ 58 m) correlates to the DR.IV unit of the Dent de Rez section and forms a second oobioclastic unit. It is more complete and thicker than at the Dent de Rez (Fig. 10F). It is topped by a distinct irregular oxide-bearing hardground [2].
- VIG.V unit (~ 10 m) forms a discrete marlstone horizon atop the VIG.IV oobioclastic calcarenites. This unit significantly thicken eastward (Fig. 10F).
- VIG.VI unit (~ 40 m) mostly consists of massive-bedded fine-grained calcisiltites enriched in chert nodules in the top. Two calcarenite horizon occur in its lower part.
- VIG.VII unit (~ 15 m) is made of echinodermic bioclastic calcarenites with obliquely laminated stratifications.

4.5.3 Biostratigraphy

[31] provided a revision of the ammonite record from the La Vignasse–Entibes area. However, these authors worked on a composite litho-log mixing both the La Vignasse–Entibes and Calvaire de Gras sections *sensu* [2]. This does not help to understand their ammonite-age calibration because the succession drastically changes in thickness along the ~ 2 kilometers separating these two localities [2]. In fact, ammonites are rare in the La Vignasse–Entibes section, exception made of the uppermost Hauterivian *Pseudothurmannia*-bearing beds from the bottom of the section (Fig. 9).

Few ammonites were reported from marlstones equivalent to the VIG.V unit at 1 km east of La Vignasse–Entibes. These marlstones yield two *Holcodiscus* species and diverse Barremitidae indicative of the *Holcodiscus* bioevent (= base of *Kotetishvilia compressissima* Zone). Since the underlying VIG.IV unit is a lateral equivalent of the DR.II unit of Dent de Rez, we confirm the assignment of these two units to the *Nicklesia pulchella* Zone in agreement with the record of the concomitant extinction of the dasycladale algae duo *Clypeina paucicalcarea* and *Heteroporella genevensis* atop these units [2,23,31].

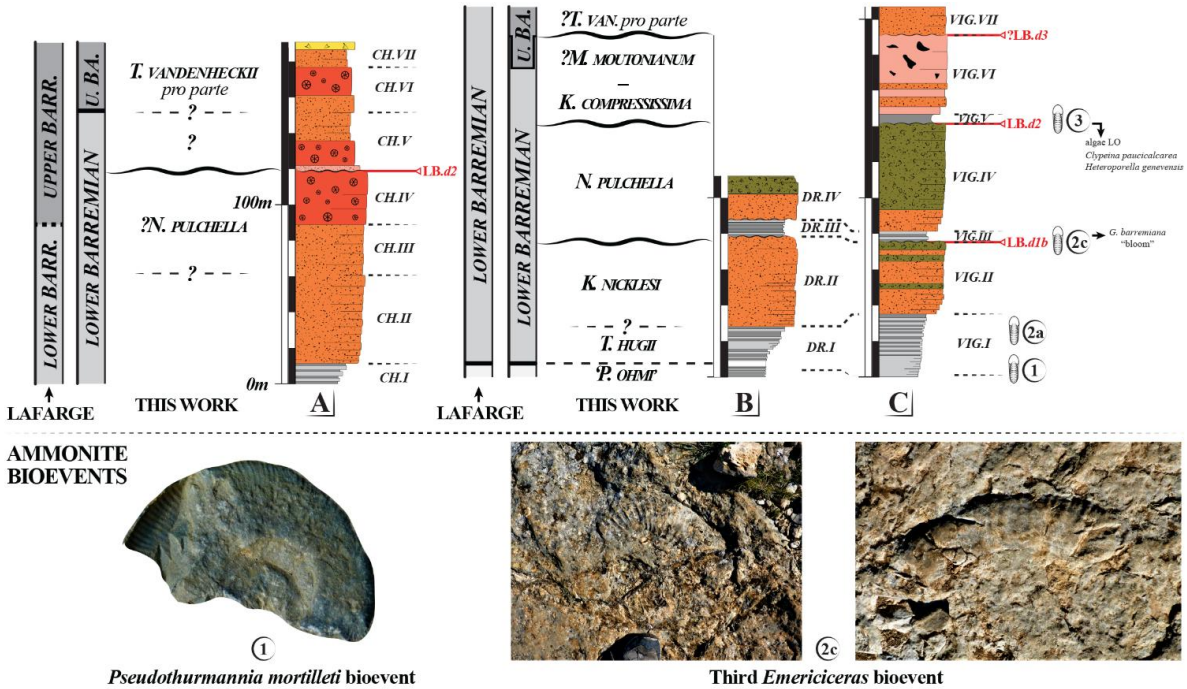

Fig. 9. Lithostratigraphic, sedimentologic and biostratigraphic interpretations of (A) Chastellas des Hellys, (B) Dent de Rez, and (C) La Vignasse–Entibes sections. Acronyms in black and red refer, respectively, to the depositional sequences of [2] and remarkable surfaces described in the present contribution

Age assignments are derived from remarkable surfaces of regional significance dated by means of ammonite bioevents figured below (This work, not to scale). Comparison with previous dating of [2] is added

Fig. 10. Field photographs of the Chastellas des Hellys, Dent de Rez, and La Vignasses–Entibes sections: (A) Panorama of the Chastellas des Hellys section showing all the units of [2], (B) Close-up view of the putative LB.*d2* discontinuity atop the coral-rich CH.IV unit, (C) Close-up view of siliceous smear at the putative LB.*d2* discontinuity *sensu* [2], (D) Panorama of the Dent de Rez sections, with DR.I to DR.IV units, over Hauterivian–lowermost Barremian hemipelagites, (E) Close-up view of the *Gavelinella barremiana*-bearing marlstones (DR.III unit) over the LB.*d1b* discontinuity. Note the thinning out of the unit in direction of the platform, (F) Close-up view of the echinodermic bioclastic calcarenites of the DR.IV unit at the hilltop of the Dent de Rez section, (G) Close-up view of the wavy base at the base of the DR.IV unit eroding the underlying DR.III marls. (F) Panorama of the Chastellas des Hellys section showing the post-VIG.III units of [2]

Acronyms in black and red refer, respectively, to the depositional sequences of [2] and remarkable surfaces described in the present contribution

4.5.4 Main discontinuities

Three main discontinuities have been identified in the rock succession.

The lower and middle discontinuities are deepening surfaces found atop the VIG.II and VIG.IV units, then capped by marlstone units (VIG.III and VIG.V units). Physical tracking of these surfaces and their dating indicate a correlation with the LB.*d1b* and LB.*d2* discontinuities, respectively.

The upper discontinuity occurs atop the VIG.VI unit and marks a change from cherty calcisiltite to echinodermic bioclastic sediments. The surface is poorly constrained, but it postdates *Kotetishvilia compressissima* Zone dated deposits (VIG.V unit). It is here hypothesised a correlation with the LB.*d3* discontinuity as it marks the regional recovery of post-STB Urgonian limestones.

4.6 Calvaire de Gras

4.6.1 Localisation and data

The Calvaire de Gras (or Mas de Gras *in litt*.) section was measured and sampled for ammonites and foraminifera by [2]. It lies in the foothill housing the catholic calvary of Gras at the hilltop, located ~ 300 m westward of the nominative town.

4.6.2 Sedimentology

The Calvaire de Gras section is about 105 m in thickness and starts above upper Hauterivian dated basinal deposits. Continuity with Barremian deposits remains unclear either due to faulting or vegetation [2]. The succession has been divided into five main lithological units by the latter author, as follows (Fig. 11A):

- CG.I unit (~ 20 m) consists of a regular alternation of marl and marly limestone beds. Marly interbeds disappear upward and the unit terminates at a distinct limestone-dominated horizon with rich ammonite accumulations at its top (Fig. 12A).
- The three next units (CG.II, III, and IV; ~ 25, 20, and 25 m, respectively) consists of similar sequences starting with thin-bedded marly limestones, grading upward into thick-bedded limestones and marly interbeds.
- CG.V unit (~ 15 m) can be divided into two part (i) a thin marly ledge that yields a pyritic ammonite fauna, and (ii) thick-bedded basinal limestones.

4.6.3 Biostratigraphy

Above *Pseudothurmannia*-bearing limestones including the *Pseudothurmannia mortilleti* bioevent (Fig. 11), the CG.I unit is topped by massive beds including lower Barremian holcodiscid ammonites, and possibly the index species *Nicklesia pulchella* (= [31], on pl. 32, Fig. C, D; pl. 33, Fig. B). Laterally, these levels yield large-sized *Emericiceras emerici* at their top [2]. This is typical of condensed *Nicklesia pulchella* Zone aged deposits of the Languedoc [51-52], here referred to as the Third *Emericiceras* bioevent. Above, the rich ammonite faunas from the CG.II to CG.IV units were revised by [31]. These includes the Pulchellidae *Kotetishvilia compressissima* (= [31], on pl. 32, Fig. C, D; pl. 33, Fig. G), *Nicklesia didayana* (= [31], on pl. 32, Fig. G; pl. 33, Fig. D, F) and *Heinzia communis* (= [31], on pl. 33, Fig. E), the Holcodiscidae *Holcodiscus perezianus* (= [31], on pl. 32, Fig. E, F) and *Amohaldites* aff. *camelinus* (= [31], on pl. 32, Fig. H), the Ancyloceratidae *Moutoniceras moutonianum* (= [31], on pl. 33, Fig. C), and the Acrioceratidae *Dissimilites dissimilis* (= [31], on pl. 33, Fig. A). These ammonites pinpoint the full *Kotetishvilia compressissima* Zone (including the *Holcodiscus* bioevent at its base – Fig. 11), and the *Moutoniceras moutonianum* Zone [31]. Note that the pyritic fauna of the CG.V unit contains few more taxa indicative of the *Moutoniceras moutonianum* Zone, notably the Leptoceratoididae *Karsteniceras cirtae*, the Holcodiscidae *Metahoplites* sp. and the Pulchellidae *Heinzia caicedi* (data based on [2]).

4.6.4 Main discontinuities

There is no clear discontinuity in this section, exception made of the ammonite-rich accumulation surface atop the CG.I unit that may represent a condensation of *Nicklesia pulchella* dated deposits.

4.7 Le Bauzu

4.7.1 Localisation and data

The Bauzu section was measured and sampled for ammonites and foraminifera by [2]. It lies in the foothill south of Gras, off the local road D262. It complements the upper part of the Calvaire de Gras section described above.

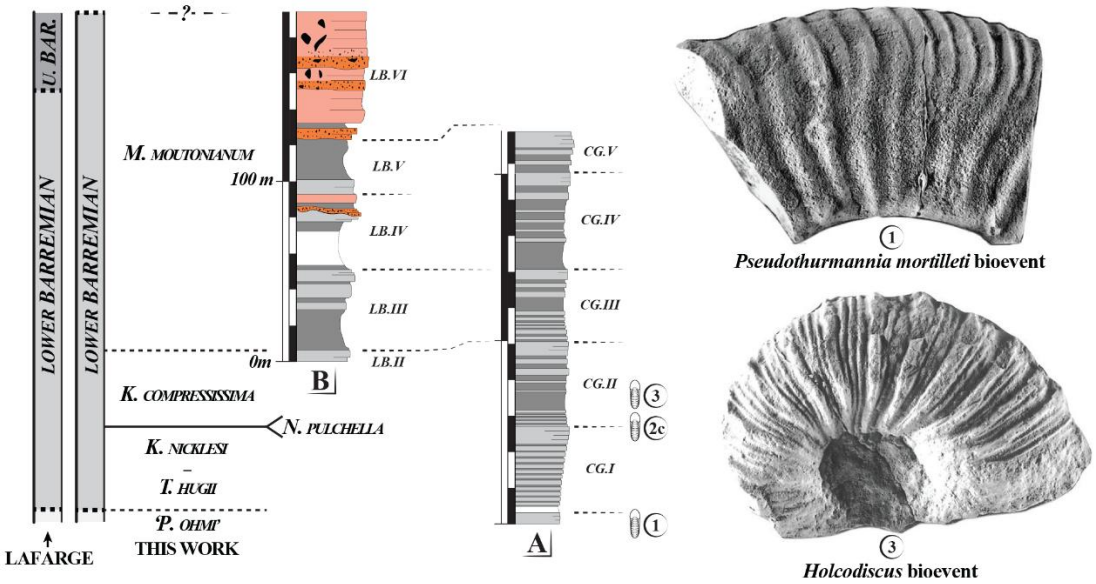

Fig. 11. Lithostratigraphic, sedimentologic and biostratigraphic interpretations of (A) Calvaire de Gras, and (B) Le Bauzu. Acronyms in black refer to the depositional sequences of [2]

Age assignments are derived from ammonite bioevents figured below (after [31, not to scale). Comparison with previous dating of [2] is added

Fig. 12. Field photographs of the Calvaire de Gras and Le Bauzu sections: (A) Panorama of the Calvaire de Gras section showing all the units of [2], and the basinward thickening of the marly VIG.V unit, (B) Panorama of the Le Bauzu sections with LB.II to LB.VI units, over the oobioclastic limestones of the lateral equivalent of the VIG.IV unit of La Vignasse–Entives.

Acronyms in black and red refer, respectively, to the depositional sequences of [2] and remarkable surfaces described in the present contribution

4.7.2 Sedimentology

The Le Bauzu section is about 95 m in thickness. It starts at a local marker bed (CG4 of [2]) correlating to the upper CG.II unit of the Calvaire de Gras section. The succession has been divided into four main lithological units by the author as follows (Fig. 11B):

- LB.III and LB.IV units (~ 20 and 24 m, respectively) consists of two similar sequences starting with thin-bedded marly limestones and grading upward into thick-bedded limestones and marly interbeds. The thick-bedded limestones atop the unit LB.III correlates to the top-CGIII unit. The top of the LB.IV unit is marked by a set of fine-grained, irregular oobiocalcarenite beds that can be either disappearing or laterally contiguous to marls. It may correspond to a turbiditic episode.
- LB.V unit (~ 15 m) corresponds to a marly ledge that yields a pyritic ammonite fauna.
- LB.VI unit (~ 15 m) consists of a cliff-forming limestones (Fig. 12B), starting with obliquely laminated biocalcarenites, grading upward into cherty calcisiltites, then into fine-grained calcarenites. Two other calcarenite tongue with stratified cherts occur in the unit.

4.7.3 Biostratigraphy

Ammonites occur as a rarity. To date, only the base of the LB.III unit yields unfigured taxa of the *Moutoniceras moutonianum* Zone, while the LB.V unit contains pyritic forms of low biostratigraphic interest although they provide correlation with the CG.V unit of Calvaire de Gras [2], herein dated to the *Moutoniceras moutonianum* Zone. The overlying cherty calcisiltites (LB.VI unit) are maintained in *Moutoniceras moutonianum* Zone, contrasting with the younger age (*Toxancyloceras vandenheckii* Zone) proposed by [23,31].

4.7.3 Main discontinuities

There is no clear discontinuity in this section.

5. RESULTS AND DISCUSSION

5.1 Platform-to-basin Stratigraphic Model of the Bas-Vivarais Domain

The identification and physical tracking of key stratigraphic surfaces calibrated to biological bioevents enable us to define regional-scale depositional sequences for the Bas-Vivarais domain. In Fig. 13, a stratigraphic model of the Bas-Vivarais domain is presented along a SW–NE-oriented transect (~12 km long), which is nearly perpendicular to the local platform margin. The main observations are discussed below. The LB.*d2* discontinuity, followed by the deposition of the STB, is used as datum (flattening surface). This allows direct comparison with the model previously established here by [2,15]. We further discuss and clarify some age discrepancies found with [8,23,31].

5.1.1 Installation of the Urgonian platform facies

The installation of the Urgonian platform facies *sensu lato* (thereafter sequence LB–S1a) is marked by the spreading of grain-supported, echinoderm-dominated biocalcarenite clinoforms over hemipelagites in the Ardèche River outcrops. This is beautifully illustrated along the Chames panorama. The underlying record of the First *Emericiceras* ammonite bioevent, atop the LB.*d0* discontinuity, pinpoints the lowermost Barremian *Taveraidiscus hugii* Zone. Basinward, the onset of Urgonian biocalcarenites is delayed up to the *Kotetishvilia nicklesi* Zone in the nearby Pont de Laval section. This is supported by the underlying record of the Second *Emericiceras* ammonite bioevent atop the LB.*d1a* discontinuity. These observations are broadly similar with those of [2].

Minor differences are found with the most recent ammonite-age calibration of [23]. Those authors likely have underestimated the strong progradational trend of the sequence LB–S1a between the Chames–Serre de Tourre and Pont de Laval sections as a consequence of taxonomic imprecision of pre-Urgonian *Emericiceras* bioevents and their biostratigraphic significance.

Stronger discrepancies are observed with the Bastide's model for the Ardèche River outcrops [8], in which Urgonian platform facies settled during the lower upper Barremian (*Toxancyloceras vandenheckii* Zone) while most of the lower Barremian deposits are supposedly lacking. This biostratigraphic scheme is inherited from the Grenoble University's conceptual platform model of the nearby Vercors Massif, which proved to be based on imperfect ammonite-, and orbitolinid-age calibration [23,31,45], and unrealistic regional field

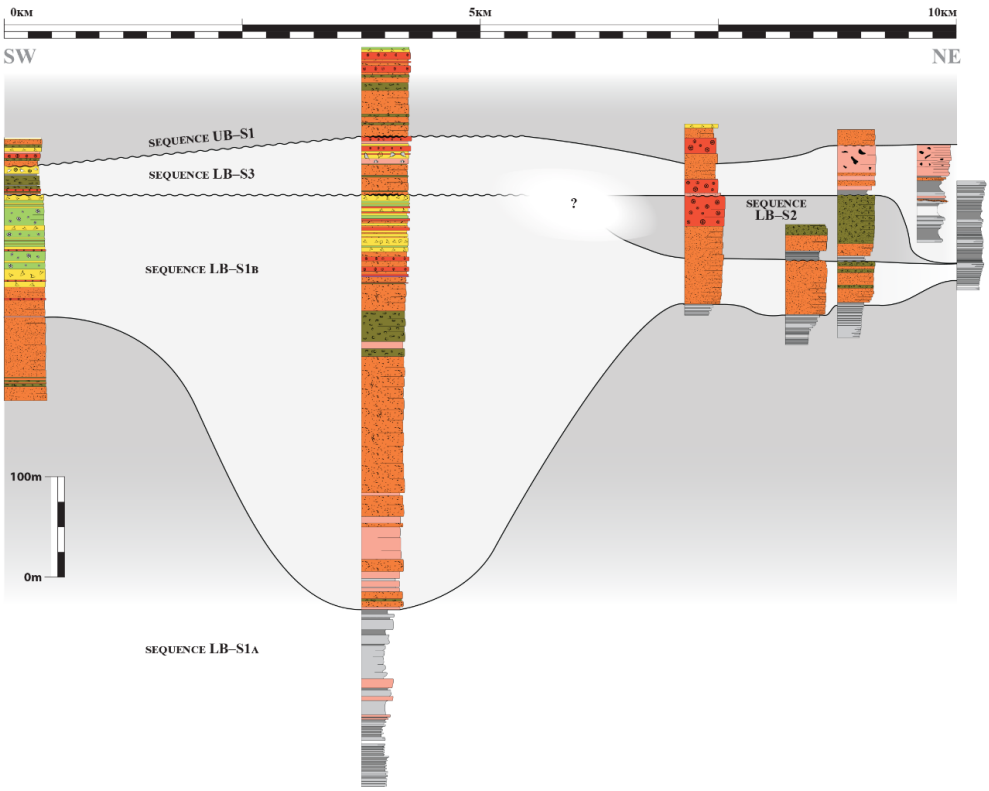

Fig. 13. Platform-to-basin correlations of the Urgonian Bas-Vivarais domain. The LB.*d2* discontinuity is used as datum (flattening surface) in this cross section.

Dashed lines illustrate the schematic stratal patterns of the different sequences therein defined

correlations [33]. This model has been applied in the Bas-Vivarais domain without any re-examination of the ammonite markers from the Ardèche River outcrops documenting a continuous hemipelagic sedimentation through the Hauterivian and lower Barremian stages [1-4,9-11,16,20-24,28,31]. When such works are considered, it becomes apparent that the stratigraphic conclusions of [8] are somewhat flawed.

5.1.2 Lateral variations of the Serre de Tourre rudist beds

At Chames–Serre de Tourre, the LB–S1a biocalcarenites are overlain by an episode of massive lenticular coral beds which seemingly truncate the topset of the underlying clinoforms, and mark the transition with the overlying Urgonian platform facies *sensu stricto*. These latter facies correspond to extensive, layered, peloid- and foraminifera-rich units separating rudistid beds. Rudist association is dominated by *Agriopleura* spp. and undetermined requieniid rudists, which typifies the Serre de Tourre fauna (thereafter sequence LB–S1b). Northward, the same sequence is dominated by dense aggregates of large-sized rudists and/or corals, either branched or colonial, at Pont de Laval. Further north, the rudists are replaced by oobioclastic limestones (CH.II unit of Chastellas des Hellys; DR.II and VIG.II units of Dent du Rez and La Vignasse–Entibes). Lack of field observations between Pont de Laval and Chastellas des Hellys sections does not currently allow to map out the transition between inner and outer platform domains which is usually represented by mud- to grain-supported chaetetid-bearing beds in such context [29].

Toward the basin (Le Bauzu, Calvaire de Gras, and beyond), these oobioclastic limestones grade downward into marls and marly limestones. The change from inner platform rudistid environments of low-energy subtidal significance, to mixed, high-energy deposits consisting of coral- and oobioclastic limestones, and then basinal marly limestones conforms well to the ecological framework of peri-Vocontian Urgonian homoclinal ramps observed during the early Barremian in SE France [53].

These lateral variations are not congruent with the model of [2]. The statement was made by the author that the chaetetid-bearing beds of Chastellas des Hellys (CH.IV unit) correlate to the massive-bedded fine-grained calcisiltites at the top of the La Vignasse–Entibes section (VIG.VI unit). This imperfect correlation is guided by conflated positioning of the lower/upper Barremian boundary using orbitolinids.

5.1.3 Significance of the LB.d2 discontinuity and its basinward expression

At Chames–Serre de Tourre and Pont de Laval, the growth of the Serre de Tourre rudistid beds (sequence LB–S1b), and their basinward equivalent deposits, is topped by a distinct discontinuity, here referred to as LB.*d2*. This discontinuity amalgamates a short-termed emersion followed by a drowning episode leading to the deposition of the STB. Evidences of emersion are confirmed in the Ardèche River outcrops (Serre de Tourre–Chames and Pont de Laval), and it is further evidenced by a distinctive negative isotopic excursion at Pont de Laval [8].

The LB.d2 discontinuity is dated to the top-*Kotetishvilia nicklesi* Zone in the Ardèche River outcrops. This is based on the record of the concomitant extinction of the dasycladale algae duo *Clypeina paucicalcarea* and *Heteroporella genevensis* at this discontinuity [28,33]. Following [28], the hiatus associated with the LB.*d2* discontinuity spans the *Nicklesia pulchella* Zone. It is estimate to have lasted 0.25 Myr according to the absolute age calibration of the Barremian Stage in the current Geological Time Scale.

Basinward, this time span is represented by the chaetetid-bearing unit (thereafter sequence LB–S2) of Chastellas des Hellys (CH.IV unit), which passes basinward into oobioclastic limestones at Dent de Rez (DR.IV unit) and La Vignasse–Entibes (VIG.IV unit). These deposits indeed belong to the during the *Nicklesia pulchella* Zone because they underlain *Kotetishvilia nicklesi* Zone dated deposits, and overlain by *Kotetishvilia compressissima* Zone dated deposits at La Vignasse–Entibes. The sequence LB–S2 has no record landward, and quickly pinch out basinward where it is represented by condensed *Nicklesia pulchella* Zone dated limestones (Calvaire de Gras). Since these deposits are concomitant to the LB.*d2* exposure event of the platform, we came to the conclusion that the sequence LB–S2 forms a sedimentary wedge, with a limited gradual downward, basinward shift in inner platform facies. This is typical of low slope angle, distally steepened ramp of Urgonian-type [54]. This further met former hypothesis of [2-3,15] suggesting the presence of a “bioclastic shoal” in the mid-ramp settings of the Saint-Remèze Plateau, albeit of different interpretation.

5.1.4 Age, lateral variations and significance of the STB

The STB in the Ardèche River outcrops is first formed by oobioclastic limestones capped by fossiliferous bioclastic marls (thereafter sequence LB–S3a), and then by a coral–rudist bed containing the caprinid rudist *Offneria simplex* (thereafter sequence LB–S3b). Thanks to its singular lithology, the STB forms a regional landmark traceable between two cliff-forming platform units through the gorges (LB–S1b below, and sequence UB–S1 above – see below). Two ammonite bioevents, above (*Puezalpella*) and within (*Holcodiscus*) the STB, allow to date these beds to the *Kotetishvilia compressissima* and *Moutoniceras moutonianum* zones. This is rather similar to the observations made at Pont de Laval section, but here the sequences LB–S3a and LB–S3b of the STB are thicker and dominated by mixed, high-energy deposits consisting of oobioclastic and coral–rudist limestones. Basinward, the two sequences are reduced and change to oobioclastic limestones at Chastellas des Hellys, and cherty limestones further east at La Vignasse–Entibes and Le Bauzu. Then, the STB thicken in direction of Calvaire de Gras forming an open-marine, ammonite-bearing marly-limestone interval overlain by cherty calcisiltites. This is confirmed by the ammonite record of the *Kotetishvilia compressissima* and *Moutoniceras moutonianum* zones.

By its age, the STB has recently been interpreted by [29] as a local expression of the Mid-Barremian Event; the latter refers to palaeoceanographic disturbances of late early Barremian age documented in both Tethyan and Boreal hemipelagic and deep pelagic settings associated with intermittent black shales deposition and major turnover in the radiolarian, planktonic foraminifera, and calcareous nannofossil assemblages [55]. In the Boreal Realm, the black shales of the Mid-Barremian Event (Hauptblätterton) are associated with drastic changes in the calcareous nannofossil abundance pattern, diversity and size suggesting

a change toward a warm and arid climate phase in the high latitudes [56]. The record of the caprinid rudist *Offneria simplex* in the STB gives credit to a short-lasted warning climate mode since the species is widespread in intertropical settings [53].

5.1.5 Recovery of the Urgonian platform facies

The STB is topped by a major discontinuity – here referred to as the LB.*d3* – which is clearly a drowning event, although evidence of local emersion cannot be ruled out (see §5.2.3). This drowning is dated to the base of the *Toxancyloceras vandenheckii* Zone, and marks the rapid recovery of the inner platform Urgonian facies at Chames–Serre de Tourre and Pont de Laval (thereafter sequence UB–S1). Basinward, it thickens and mainly changes as thick oobioclastic limestones. This sequence outlines the beginning of a new rudistid platform stage during the early late Barremian, and its overall progradation in direction of the basin. The significant width of each depositional environments supports a near homoclinal ramp morphology as observed for the sequence LB–S1b.

5.2 Limitations of Platform-to-basin Correlations in the Bas-Vivarais Domain

Lack of key biostratigraphic markers and poor outcropping continuity between sections actually hinder correlations in our model. The most important limitations are discussed below.

5.2.1 Landward termination of the sedimentary wedge (sequence LB–S2)

Field observations are almost continuous between Serre de Tourre–Chames and Pont de Laval, as well as between Dent de Rez, La Vignasse–Entibes and Calvaire de Gras. That is not the case around Chastellas des Hellys due to faulting and poor outcropping conditions. The succession of age-diagnostic biomarkers is, moreover, incomplete in this section, and the correlations were mostly tied to the observations of our predecessors [2,15]. As a result, the correlation of the chaetetid-bearing CH.IV unit of Chastellas des Hellys to the oobioclastic limestones of Dent de Rez and La Vignasse–Entibes (DR.IV unit and VIG.IV unit, respectively) is tentative (Fig. 13). One of the reasons that guided us is the pinching out of the *Gavelinella barremiana*-bearing marlstones into the base of the DR.IV unit as suggested by [2]. Though uncertain, this correlation corroborates the limited gradual downward, basinward shift of facies during the deposition of the sedimentary wedge (sequence LB–S2).

5.2.2 Laterality of STB (sequence LB–S3a/b)

Analogy of the facies succession is evident between Serre de Tourre–Chames and Pont de Laval (Fig. 13). Correlations are more difficult between Pont de Laval and Chastellas des Hellys due to the rapid facies changes in direction of the basin. The lack of systematic field logging along the Serre de Barrès hill (that linking the two sections) actually prevents the mapping of facies transitions. New investigations are needed to better understand the basinward variation of the STB deposits, and decipher their link with palaeoceanographic disturbances of the Mid-Barremian Event.

5.2.3 Significance of the LB.*d3* discontinuity

The LB.*d3* discontinuity found atop the *Offneria simplex* beds (sequence LB–S3b) is correlated for the first time at the regional scale (Fig. 13). It clearly corresponds to a major drowning leading to the gradual installation and progradation of a new platform stage. The presence of a fringe of dissolution with polyphased infills below the LB.*d3* discontinuity at Serre de Tourre–Chames may, however, point to local subaerial processes, resulting from a brief emersion prior to drowning (Fig. 5l). Such evidence is absent basinward, or has been overlooked by us. Pending new investigations, the evidence of emersion is thus of limited spatial extension, with no clear incidence on the geometry of deposits basinward.

A same pattern was also noted atop the *Offneria simplex* beds of SE Vercors [17], and used as one of the main sequence boundaries in the Grenoble University's conceptual platform model of the Vercors Massif [57]. It worth noting that the *Offneria simplex* communities settled in low energy, muddy sediments off the marginal inner platform domain, in close proximity to coral build-ups [17,53]. Those caprinid rudists further correspond to constratal sediment dwellers [40], favouring zones of sediment by-passing, frequently at the tops of shoaling cycles [58]. Those zones are sensitive environments to open-marine hydrodynamics and relative sea level changes. Hypothesis can be made that the

specific emersion atop the *Offneria simplex* beds of the Bas-Vivarais and SE Vercors best reflects a local ending of a shoaling cycle than a regional emersion episode.

5.3 Regional Comparison and Implications

The Bas-Vivarais domain is located in the eastern margin of the horse-shaped Vocontian Basin, which is itself bordered by the Subalpine platform domain to the North, and by the Provence one to the South [59]. Some clues for comparison with the Bas-Vivarais platform evolution are given below.

5.3.1 Provence domain

In southern France, the Provence platform series, outcropping in the Les Calanques and La Nerthe massifs, is formed by thick pile of lower Cretaceous shallow-marine carbonates spanning the late Berriasian to the late Barremian [37]. The lower Barremian part of this series remains inadequately studied. This is mostly due to vertical outcropping conditions and massive dolomitisation affecting the series [60-61]. Comparison with the Bas-Vivarais domain thus remains difficult.

Further north, the Provence platform domain shows strong progradation up to the La Fare, but the calibration and anatomy of the early Barremian aged platform series remain little studied since the seminal work of [37]. We can only mention the presence of an anomalic bioclastic facies forming a topographic high in the early Barremian, then overlain by prograding gravel or rudist–coral facies [62]. Such a configuration may coincide with the deposition of a sedimentary wedge in the Saint-Remèze mid-ramp platform sections (sequence LB–S2), but new investigations are needed.

5.3.2 Subalpine domain

The finding of common sedimentary signals is more evident with the nearby Subalpine platform, and especially with the Gresse-en-Vercors-to-Glandasse transect cropping out along the eastern margin of the Vercors Massif [33]. Here, the onset of the Urgonian platform facies, above hemipelagic deposits is similarly marked by prograding bioclastic clinoforms in direction to the basin during the earliest Barremian. These clinoforms are truncated by Serre de Tourre-type, *Agriopleura*-rich platform deposits in the proximal settings of Gresse-en-Vercors, and pass downward into coral, bioclastic, and finally hemipelagic deposits in direction to the basin. These deposits fully correlate to the sequence LB–S1a and LB–S1b of the Bas-Vivarais domain described above.

As in the Bas-Vivarais, the Serre de Tourre-type platform deposits are interrupted at a discontinuity dated to the top-*Kotetishvilia nicklesi* Zone, which compares to the LB.*d2* discontinuity of the Ardèche river outcrops. Although it lacks evidence of subaerial exposure at Gresse-en-Vercors – certainly due to the relative distality of the settings [33] – this discontinuity is represented basinward by the so-called La Montagnette prograding bioclastic sedimentary wedge dated to the *Nicklesia pulchella* Zone. This is the same configuration that we identified in the Saint-Remèze mid-ramp platform sections (sequence LB–S2). In both domains, this sedimentary wedge contains the delayed extinction of the calcareous algae duo *Clypeina paucicalcarea* and *Heteroporella genevensis*.

The overlying deposits mark a regional-wide switch represented southward by *Offneria simplex* caprinid rudist beds [17], belonging to the Pont de Laval fauna. Best outcropping conditions are found in the Cirque d'Archiane, in the southeastern Vercors. It has been established that this rock interval passes basinward to the Fontaine Colombette marls dated to the *Kotetishvilia compressissima* to *Moutoniceras moutonianum* Zone by ammonites [33]. This compares to the STB (sequence LB–S3) of the Bas-Vivarais domain, and suggests, *de facto*, that the Mid-Barremian Event has a widespread record in the SE France Urgonian platform ecosystems. As for the LB.*d3* discontinuity of the Bas-Vivarais domain, the *Offneria simplex* beds are regionally overlain by a new prograding platform stage, which contains the onset of a late Barremian rudist fauna in the Vercors [33]. All these observations testify of a very similar sedimentary context during the first evolution stages of the Urgonian system along the eastern and northern Vocontian margins (Fig. 14).

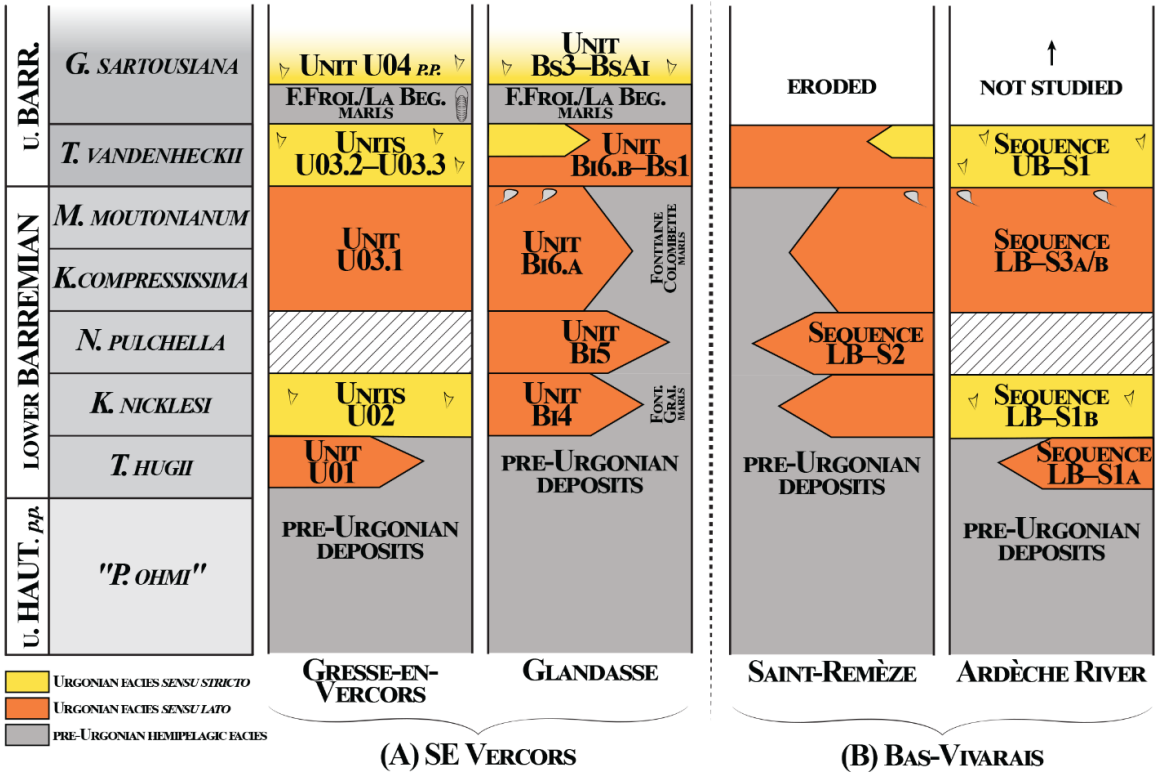

Fig. 14. Synoptic Urgonian platform evolution during the latest Hauterivian to early late Barremian between the (A) SE Vercors and (B) Bas-Vivarais

Note the record of a sedimentary wedge during the Nicklesia pulchella ammonite zone (after [34])
Symbols are described in Fig. 2

6. CONCLUSIONS

This paper is an update of the sedimentary succession and dating of the Urgonian Bas-Vivarais domain during the Barremian pro parte. It further provides a revised inner-to-outer platform profile of the study area. The installation and first developments of the Urgonian platform domain is clearly dated to the lowermost Barremian by ammonites (Taveraidiscus hugii and Kotetishvilia nicklesi ammonite zones). This first platform stage is interrupted at a brief emersion episode that lasted through the Nicklesia pulchella ammonite zone, and resulted in the deposition of a sedimentary wedge in direction of the basin with limited gradual downward, basinward shift in inner platform facies. This is regionally followed by the deposition of the Serre de Tourre Beds which illustrate major palaeoenvironmental disturbances associated with the Mid-Barremian Event, spanning the Kotetishvilia compressissima and Moutoniceras moutonianum ammonite zones. Then, there is a regional recovery of inner platform Urgonian facies during the early late Barremian showing a striking progradational basinward trend. All taken together, the general evolution of the Urgonian Bas-Vivarais domain show strong similarities with the sedimentary context of the nearby Subalpine platform. The finding of common sedimentary signals is more difficult with lower Barremian aged rock interval of southern Provence platform domain which remains inadequately studied so far.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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