Cretaceous Research 90 (2018) 222–253

Contents lists available at ScienceDirect

Cretaceous Research

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

Late Barremian–early Aptian ammonite bioevents from the Urgonian-type series of Provence, southeast France: Regional stratigraphic correlations and implications for dating the peri-Vocontian carbonate platforms

Camille Frau [a, *], Anthony J.-B. Tendil [b], Cyprien Lanteaume [b], Jean-Pierre Masse [b], Antoine Pictet [c, 1], Luc G. Bulot [b, d], Tim L. Luber [d], Jonathan Redfern [d], Jean R. Borgomano [b], Philippe Léonide [b], François Fournier [b], Gérard Massonnat [e]

[a] Groupement d'Intérêt Paléontologique, Science et Exposition, 60 bd Georges Richard, 83000 Toulon, France
[b] Aix Marseille Université, CNRS, IRD, Collège de France, CEREGE, Marseille St-Charles, France
[c] University of Geneva, Department of Earth Sciences, 13 Rue des Maraîchers, 1205 Geneva, Switzerland
[d] University of Manchester, School of Earth and Environmental Sciences, North Africa Research Group, M13 9PL, Manchester, UK
[e] TOTAL S.A., Centre Scientifique & Technique Jean Féger, Avenue Larribau, 64018 Pau, France

ARTICLE INFO

Article history:
Received 16 December 2017
Received in revised form
8 April 2018
Accepted in revised form 11 April 2018
Available online 25 April 2018

Keywords:
Urgonian
Carbonate platform
Ammonite
OAE 1a
Cretaceous
Southeast France

ABSTRACT

This work provides a new ammonite age-calibration of the rudistid limestones of the Urgonian-type Provence carbonate platform (Southeast France) based on sampling along three ~200 km-long platform-to-basin transects and re-examination of historical collections. Ammonite key findings indicate that the first rudistid platform stage (including the *Agriopleura* and requieniid–monopleurid beds) develops and spreads northward through the *Toxancyloceras vandenheckii–Gerhardtia sartousiana* zones interval (lower upper Barremian). This stage is interrupted by the tectonically-induced deepening of the southern Provence domain during the *Imerites giraudi* Zone while the northern regions records the massive deposition of *Palorbitolina–Heteraster* beds. Recovery of the rudistid carbonate system is illustrated by the development of caprinid-bearing rudistid limestones in the North Provence domain through the *Martelites sarasini* Subzone (lower *Martelites sarasini* Zone, uppermost Barremian), which shows a bidirectional progradation toward the South Provence and Vocontian basins. The caprinid-bearing limestones terminate at a short-term exposure and are overlain by cherty–oobioclastic deposits spanning the *Pseudocrioceras waageenoides* Subzone (upper *M. sarasini* Zone) to the lower *Deshayesites forbesi* Zone. A regional-wide flooding of the study area is illustrated by the abrupt change to a marl-dominated regime occurring in the upper *D. forbesi* Zone. Compared to the previous datings, the Barremian/Aptian boundary should be relocated in the lower part of the post-caprinid, cherty–oobioclastic deposits although its precise level cannot be fixed due to the lack of a continuous ammonite record. Ammonite age-calibration of the surrounding Urgonian rudistid platform series is discussed and gives evidence of a comparable twofold demise of the peri-Vocontian rudistid biota during the uppermost Barremian. Accordingly, the link between the final demise of the peri-Vocontian rudistid biota and the onset and/or culmination of the mid-early Aptian Oceanic Anoxic Event (OAE) 1a should be reconsidered.

1. Introduction

Urgonian carbonate platforms of Barremian–Aptian age are extensively recorded in southeast France which hosts the unit-stratotype at Orgon (Alpilles Massif, Bouches-du-Rhône) as introduced by d'Orbigny (1850, 1852). At this time, the Urgonian platforms of Provence, Bas-Vivarais, Subalpine Chains and Swiss–French Jura record their maximum spatial extent and enclose the Vocontian Basin; i.e. forming a horseshoe-shaped marginal sea opened eastward to the Alpine Tethys Ocean (Arnaud, 2005a and references therein). In the existing models, the extensive growth of peri-Vocontian Urgonian carbonate platforms

* Corresponding author.
E-mail address: camille_frau@hotmail.fr (C. Frau).
[1] Present address: Musée cantonal de géologie, BFSH-2, 1015 Lausanne, Switzerland.

https://doi.org/10.1016/j.cretres.2018.04.008
0195-6671/

is first interrupted by a major shift from rudist–coral carbonate accumulation to mixed orbitolinid-dominated siliciclastic–carbonate deposition at, or close, to the putative Barremian/Aptian (B/A) boundary. This refers to the *Palorbitolina–Heteraster* guide level of the North Provence (Masse, 1976), the V4 episode of the Bas-Vivarais (Lafarge, 1978), the Lower *Orbitolina* Beds of the Subalpine regions (Arnaud et al., 1998) and the Poet Beds of Swiss–French Jura (Pictet et al., 2016). The recovery of the rudistid biota, dominated by caprinid rudists, supposedly unfolds in the lowermost Aptian but it subsequently collapses with large-scale exposure that ends the rudistid regime throughout the peri-Vocontian platforms (e.g. Masse, 1976, 1995; 2003; Masse et al., 1999; Masse & Fenerci-Masse, 2011, 2013a,b; Arnaud-Vanneau & Arnaud, 1990; Arnaud-Vanneau et al., 2005; Arnaud & Arnaud-Vanneau, 1991; Arnaud et al., 1998, 2017; Chartrousse, 1998; Clavel et al., 2002, 2007; 2013, 2014; Embry, 2005; Linder et al., 2006; Léonide et al., 2008, 2012; 2014; Bastide, 2014; Pictet et al., 2015, 2016; Huck et al., 2011, 2013; Huck & Heimhofer, 2015; Godet et al., 2016a) and eastern Switzerland as well (Föllmi et al., 1994, 2006; 2007; Wissler et al., 2002, 2003; Föllmi & Gainon, 2008; Föllmi, 2008, 2012; Stein et al., 2012a). Integrated approaches developed in the latter contributions, coupling sedimentology, palaeoenvironmental proxies and shallow-water biostratigraphy (viz. rudists, orbitolinid, dasycladaceans and charophytes), addressed the timing and causal relationships of the final demise of the Urgonian rudistid regime with the onset and/or culmination of the mid-early Aptian Oceanic Anoxic Event (OAE) 1a. Unfortunately, the lack of coeval biological markers across the B/A boundary limits the correlation of the Urgonian series with the Barremian- and Aptian-type basinal sections of the nearby Vocontian Basin. Here, various bio- (Dauphin, 2002; Herrle & Mutterlose, 2003), litho- (Bréhéret, 1995; Cotillon et al., 2000; Cotillon, 2010) and geochemical (Westermann et al., 2013) expressions of the OAE 1a have been constrained to the Mediterranean ammonite zonations; successively developed by the IUGS Lower Cretaceous Ammonite Working Group (Reboulet et al., 2011, 2014). This lack of robust biostratigraphic constrain caused a number of disputes in the literature about the calibration of shallow-water biological markers or correlation of major unconformities into the basin and their correspondence with major sea-level changes, which ultimately introduced significant confusion on the timing and predominant controlling factors of the stepwise demise of the Urgonian carbonate production.

Over the past decades, external calibration by means of chemostratigraphy (i.e. $\delta^{13}C$, $\delta^{18}O$, Sr) has emerged and imposed itself as a powerful tool of stratigraphic significance for correlating and dating carbonate units (Scholle & Arthur, 1980). The carbon signature of the Urgonian platform series of SE France and Switzerland has been, therefore, intensively investigated in order to refine platform-to-basin correlations and palaeoenvironmental interpretations (e.g. Masse et al., 1999; Raddadi, 2005; Godet et al., 2006; Föllmi et al., 2006; Huck et al., 2011, 2013; Stein et al., 2012b; Léonide et al., 2014; Huck & Heimhofer, 2015); enough to enable the authors to come to the conclusion that chemostratigraphy has the potential to provide an independent control on the controversial dating based on biological markers (Huck et al., 2013). The uppermost Barremian is characterised by a global, sharp negative excursion in $\delta^{13}C$ values in basinal sections (Kuhnt et al., 2000; Godet et al., 2006; Stein et al., 2011, 2012a; b). From this observation, several authors have characterised this time interval in the Urgonian platform successions by assuming a contemporaneous negative excursion in C-isotope signal observed at, or just below, the orbitolinid-rich episodes of the peri-Vocontian platforms (Raddadi, 2005; Arnaud-Vanneau et al., 2005; Huck et al., 2011, 2013; Léonide et al., 2014). However, such trends may result from documented subaerial exposure surfaces (Masse & Fenerci-Masse, 2011; Huck et al., 2014) and their subsequent diagenetic alteration (Allan & Matthews, 1982; Joachimski, 1994; Fouke et al., 1995; Léonide et al., 2014) which strongly affect the isotope signature of Urgonian carbonates (Godet et al., 2016b).

A limited number of works focused on the Sr-Isotope Stratigraphy (SIS), of the Urgonian platform series of SE France (Huck et al., 2011; Huck & Heimhofer, 2015) and Switzerland (Godet et al., 2011). SIS was expected to improve the existing ammonite-based age models for the Barremian–Aptian time interval (Masse & Steuber, 2007). Unfortunately, Frau et al. (accepted) highlight that SIS provide limited utility for intervals with little or no variations through time, such as the Barremian–Aptian transition. Its low resolution has led to the inconsistent stratigraphic dating of the Urgonian limestones of Provence (cf. Huck & Heimhofer, 2015). The foregoing considerations show that bio- and chemostratigraphic markers are frequently in conflict when dating the Urgonian platform series of SE France and Switzerland and do not allow to accurately pinpoint the uppermost Barremian (*Imerites giraudi–Martelites sarasini* zones interval) to earliest Aptian (*Deshayesites oglanlensis–Deshayesites forbesi* zones interval) time interval.

To address this issue, new *in situ* ammonite findings along three ~200 km-long platform-to-basin transects of the Provence platform are reported in this paper, together with a re-examination of the collection of one of us (J.-P. Masse). This allows a critical review of the ammonite age-calibration of the Urgonian-type series with respect to the standard Mediterranean ammonite zonation (Fig. 1). Our data pinpoint a late Barremian stepwise demise of the Urgonian rudistid regime throughout the peri-Vocontian carbonate platforms.

2. Current ammonite age-calibration of the Provence platform

According to the stratigraphical model developed in the past decades by Masse (1993, 1995, 2003), Masse & Fenerci-Masse (2011, 2013a,c) and Léonide et al. (2012), the Provence rudistid platform records its maximum northward progradation at the lower/upper Barremian transition and extends up into the mid-lower Aptian (*D. forbesi* Zone), from the southern (Calanques and Nerthe massifs) to the northern (Monts de Vaucluse and Rissas–Bluye Mountains) Provence where it plunges into the Vocontian Basin. Contrary to the Orgon unit-stratotype, the Monts de Vaucluse in northern Provence house complete Urgonian-type series (Masse & Fenerci-Masse, 2013a), which was historically divided into three informal lithostratigraphic units; U^1 (bioclastic), U^2 (rudistid) and U^3 (bioclastic) *sensu* Leenhardt (1883). Three distinct rudistid episodes are recognised in the North Provence rudist-bearing limestones (= U^2 *lato sensu*); these are from oldest to youngest; the (*i*) *Agriopleura* (Martigues fauna); (*ii*) requieniid–monopleurid (Orgon fauna) and (*iii*) caprinid (Rustrel fauna) rudistid faunas (see Tendil et al., accepted). The caprinid-bearing limestones (=U^2 *stricto sensu*) can be easily distinguished in the field since they usually overly the *Palorbitolina–Heteraster* guide level, traceable in the Monts de Vaucluse (Masse & Fenerci-Masse, 2011; Léonide et al., 2012) and adjacent settings of the Bas-Vivarais platform (Lafarge, 1978; Masse, 1995; Masse & Fenerci-Masse, 2011).

For the time being, only a handful of ammonite occurrences have contributed to the dating of the Urgonian-type limestones. Isolated occurrence of upper Barremian hemihoplitid and heteroceratid taxa have been documented in drowning discontinuities of the U^1 formation (Fahy, 1965; Masse, 1976; Léonide et al., 2008, 2012) or the basinward equivalent of the *Palorbitolina–Heteraster* guide level in pre-Vocontian settings (e.g. Masse, 1976; Monier,