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# The Global Boundary Stratotype Section and Point (GSSP) for the base of the Hauterivian Stage (Lower Cretaceous), La Charce, southeast France

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*Following votes by the Hauterivian Working Group, the Cretaceous Subcommittee and the International Commission on Stratigraphy, in December 2019 the Executive Committee of the International Union of Geological Sciences unanimously approved the proposal that the Global Stratotype Section and Point (GSSP) for the base of the Hauterivian Stage of the Lower Cretaceous be placed at the base of bed n° 189 of the La Charce section, Drôme, southeast France (Vocontian Basin). This level is marked by the first appearance of the ammonite genus *Acanthodiscus*, which defines the base of the *Acanthodiscus radiatus* ammonite Zone. Complementary data include 13 ammonite and nannofossil events, and magnetostratigraphic and carbon isotope events.*

## Introduction

A boundary and Global Stratotype Section and Point (GSSP) is defined for the base of the Hauterivian Stage of the Lower Cretaceous at La Charce (southeastern France). The definition arises from recommendations of the Hauterivian Working Group of the Subcommittee on Cretaceous Stratigraphy made during the Second International Symposium on Cretaceous Stage boundaries held in Brussels from September 8-15, 1995 and subsequent publications.

## Historical Background

Renevier (1874) introduced the Hauterivian Stage for sediments occurring in the vicinity of Hauterive, near Neuchâtel, Switzerland.

But the type area has long been regarded as unsatisfactory for defining the base of the stage because of “the condensed nature of some beds, the poor exposure and the general rarity of ammonites” (Mutterlose et al., 1996, p. 21). Thus from Kilian (1888) onward, the French scientific community has preferred to use the expanded sequences in southeast France as a standard for reference and this view is now widely accepted internationally. Of these, the La Charce section (Drôme southeast France), Vocontian Basin, is the best documented exposure across the Valanginian/Hauterivian boundary (Thieuloy, 1977; Reboulet et al., 1992; Bulot et al., 1993, 1995; Bulot, 1995; Bulot and Thieuloy, 1995; Reboulet, 1996, 2008, 2015; Reboulet and Atrops, 1999; Kujau et al., 2013). La Charce was first proposed as the Hauterivian stratotype by Thieuloy (1977) who defined the base of the stage there by the first occurrence (FO) of the ammonite genus *Acanthodiscus* (essentially following Paquier, 1900). This biostratigraphic event was then recommended at Copenhagen for defining the base of the Hauterivian (Birkelund et al., 1984).

Birkelund et al. (1984) also recommended that possible boundary stratotype sections should be investigated elsewhere in southeast France, and in southeast Spain, the Crimea and the Caucasus. Subsequently, the Hauterivian Working Group of the International Subcommittee on Cretaceous Stratigraphy was established in 1993, prior to the 2<sup>nd</sup> International Symposium on Cretaceous Stratigraphy in Brussels in 1995, in order to define the Valanginian/Hauterivian boundary. As no alternative type section had been suggested by the time of the 1995 Symposium the Hauterivian Working Group followed Thieuloy’s (1977) proposal to define the GSSP at La Charce (Mutterlose et al., 1996).

Hence from 1997 to 2010 several informal meetings organized by Luc Bulot and Stéphane Reboulet coordinated an integrated study of the La Charce section. The latter also organised numerous meetings of regional administrative boards to establish the section as a protected

site (“Espace Naturel Sensible”). It was re-measured and re-sampled for biostratigraphic, chemostratigraphic and sedimentologic studies during two field sessions (1996-1997, 2006-2007). New data have been acquired for biostratigraphy (ammonites, calcareous nanofossils, benthic foraminifers, radiolarians, dinocysts), stable isotope stratigraphy, inorganic/organic geochemistry, and cyclostratigraphy/astrochronology.

The reasons for using *Acanthodiscus* to define the Valanginian/Hauterivian boundary are:

- the genus is present in the shallow-water facies of both Tethys and the Boreal-Atlantic Subrealm;
- the boundary is correlated by a genus, not a species;
- there are no taxonomic problems in identifying the genus *Acanthodiscus*;
- this definition closely follows the traditional boundary concept.

Disadvantages in using *Acanthodiscus* for correlating the Valanginian/Hauterivian boundary include:

- its rarity in the Boreal-Atlantic Subrealm (Kemper et al., 1981; Mutterlose, 1992a);
- its absence in the Arctic Subrealm (Baraboshkin, 2004) and in the Austral region;
- in the Tethys it is also rarer in the deep-water facies than in shallow water sediments (Busnardo and Thieuloy, 1989; Thieuloy et al., 1991; Reboulet, 1996);
- the potential diachronism of its FO in the Lower Saxony Basin of the Boreal-Atlantic Subrealm. In northwest Germany Kemper et al. (1981, p. 302) reported *A. radiatus* from the middle part of the *Endoceras amblygonium* AZ (= Ammonite Zone). Consequently, the lower part of the *E. amblygonium* AZ, which was traditionally included in the Hauterivian, could be latest Valanginian (see “Correlation” section below, and McArthur et al., 2007; Mutterlose et al., 2014; Reboulet et al., 2014, p. 133).

## The GSSP for the base of the Hauterivian Stage

### Location

The GSSP is located in the La Charce commune in the Department of Drôme, about 70 km southeast of Valence and approximately 35

km south of Die (Fig. 1). It is on the Luc-en-Diois sheet of the “Carte géologique de la France” at the 1/50,000 scale (Flandrin et al., 1970) and on the topographic sheet, scale 1/25,000, Luc-en Diois, n° IGN 3615. The local French literature refers to the GSSP locality as the “Serre de l’Ane Section”, named after the mountain ridge at which the section is exposed. As this name is not familiar to an international audience, we use the internationally well established term “La Charce section”.

Hauterivian strata crop out over a large area (formation n3 on the geological map). The most accessible section is exposed about 550 m west of La Charce village (coordinates: 44°28'10.0"N 5°26'37.4"E, altitude 620 m). The lower part of the section crops out on the eastern escarpment of the Serre-de-l’Ane (between the electric line and Road D 61), then the section is exposed along the side of the road (Fig. 2). It is free from significant stratigraphic breaks and ranges from the *Neocomites peregrinus* AZ (upper Valanginian) to the *Plesiospitidiscus ligatus* AZ (upper Hauterivian). The *A. radiatus* AZ is 30.5 m thick (Reboulet, 1996).

### Protection and Access

The site is permanently protected from major changes, including road works, by the formation of an “Espace Naturel Sensible” (ENS) created and financed by the Drôme Department in collaboration with the La Charce municipality. A reception area has been developed with a car park and a picnic area allowing free access to the site via a geological information circuit. There are permanent information panels in French, with a short summary in English and Dutch, and on the circuit the Valanginian/Hauterivian boundary is symbolically marked on the ground by a metal strip on which is engraved the absolute age of the boundary.

### Description of the Section

The interval of the La Charce section (Fig. 3) which embraces the Valanginian/Hauterivian boundary is 40 m thick and is included in the “*Calcaires marneux à Hoplites*” sensu Paquier (1900). The section was subdivided into several formations by Moullade (1966) and Thieuloy (1977).

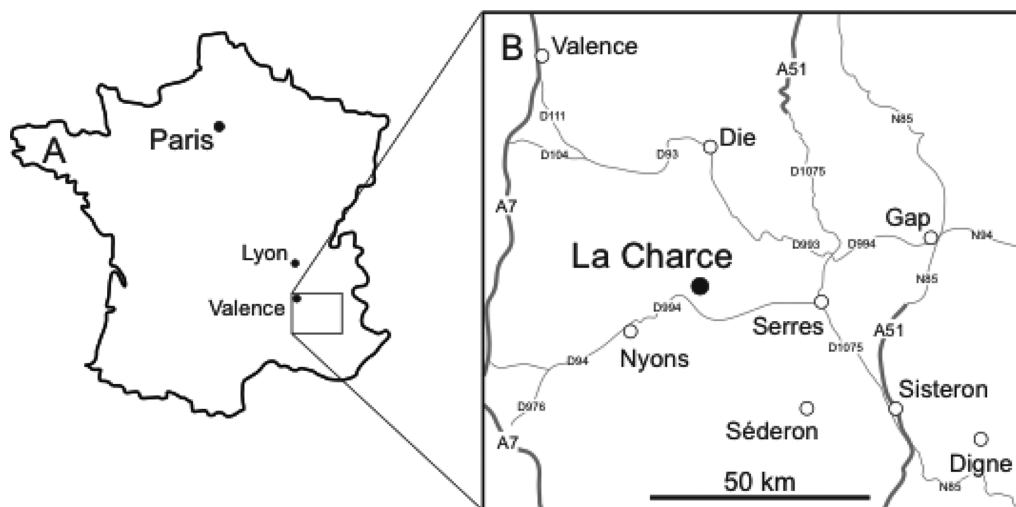
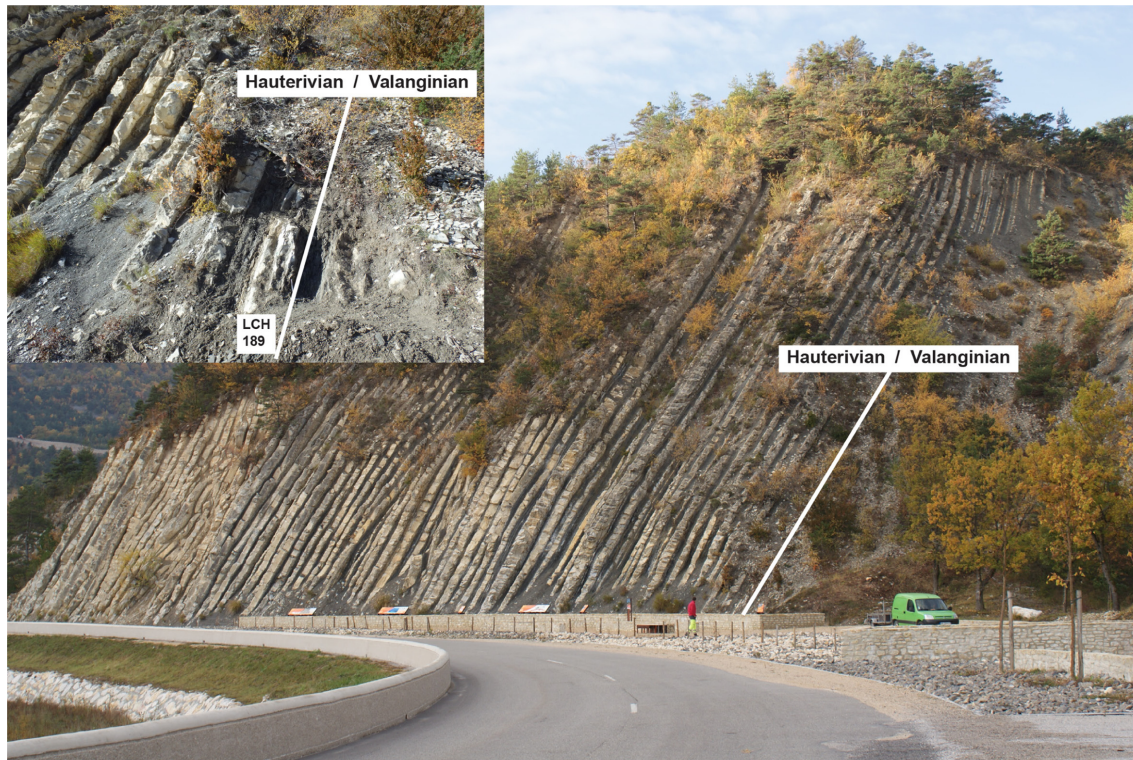


Figure 1. Location map of the La Charce section (Drôme, southeastern France).



**Figure 2.** View of the Espace Naturel Sensible (ENS) site of the La Charce section; the Great Landscape Terrace is behind the car park. The area dedicated to the Fossil Garden and the wall of Geologic Time Circuit can be seen on the left, between the road and the section (photo Reboulet). The Valanginian/Hauterivian boundary is placed at the base of bed n° 189 according to the bed numbering system of Reboulet et al. (1992).

Two different bed numbering systems exist (Reboulet, 2008): one used by Reboulet et al. (1992), Reboulet (1996, 2015) and Reboulet and Atrops (1999), the other by Bulot et al. (1993, 1995) and Bulot (1995). Both are listed in figures based on Fig. 3; columns c and d correspond to the numbering systems of Bulot and Reboulet, respectively. In order to simplify reading, only the numbering system of Reboulet et al (1992) has been used in the text as it was the first modern and complete numbering of the section. In the following ASZ stands for Ammonite Sub-zone.

The lower 8 m of the section (beds 182 to 188; *Teschenites callidiscus* ASZ) consist of irregularly spaced, medium grey argillaceous limestone layers, ranging from 0.10 to 0.50 m in thickness. They alternate with greyish marly layers, 0.50 to 1.0 m thick, rarely up to 2.00 m. The following 24 m (beds 189 to 214; *A. radiatus* AZ), are characterized by 0.20 to 0.50 m thick, light grey limestone layers alternating with darker grey marly layers almost of equivalent thickness. The limestone layers may exceed 1.0 m or more, becoming thereby very prominent. The uppermost part of the *A. radiatus* AZ, well above the boundary, is marked by a minor slump (bed 215) around 3.50 m in thickness. The transition to the overlying 4.50 m thick unit (beds 216 to 221; *Crioceratites loryi* AZ) is marked by a monotonous sequence of limestones (0.4 to 0.6 m thick) and marly layers (0.2-0.3 m thick).

According to the Dunham classification the fine grained limestones can be labelled as mudstones. They yield common ammonites, rare belemnites, and very rare brachiopods (*Pygope*), bivalves, and gastropods. Nannoconids constitute the bulk of the micrite. The marls

are rich in coccoliths and planktic foraminifera occur (Darmedru et al., 1982; Cotillon, 1984; Giraud et al., 1995). Spherical radiolarians, calcitized and/or pyritized, during diagenesis are also present. The detrital material in the limestones (> 80% CaCO<sub>3</sub>) is mostly smectite, that of the marls kaolinite, illite, chlorite and silt-sized quartz grains (Cotillon et al., 1980). The beds are heavily bioturbated, with both limestones and marls being affected. *Chondrites* and *Zoophycos* feeding burrows are common in the limestones (Gaillard, 1984; Olivero, 1996, 2003).

The alternation of marl and limestone has been interpreted to represent cyclic variations of calcareous nannofossils caused by climatic changes on the Milankovitch scale (Cotillon et al., 1980; Darmedru et al., 1982, Giraud et al., 1995). The marl-limestone alternations correspond to successions of cycles between humid climates, during which higher detrital input led to the deposit of marl beds, and semi-arid climates, during which more developed carbonate platforms led to increased export of carbonate mud toward the basin (Reboulet et al., 2003; Martinez, 2018). If this model is applied to the Hauterivian series, stable isotope data have to be handled with care (see Oehlert et al., 2012; Martinez et al., 2020).

Recent research on some outcrops of the Vocontian Basin, including La Charce, has revealed the occurrence of centimetre-thick goethite-rich horizons. One of these horizons (reddish in colour), which has already been mentioned by Beaudoin et al. (2003), occurs in the upper part of the *A. radiatus* AZ (marly layer of bed 205). It closely resembles Oxfordian, Valanginian and Aptian bentonites described from

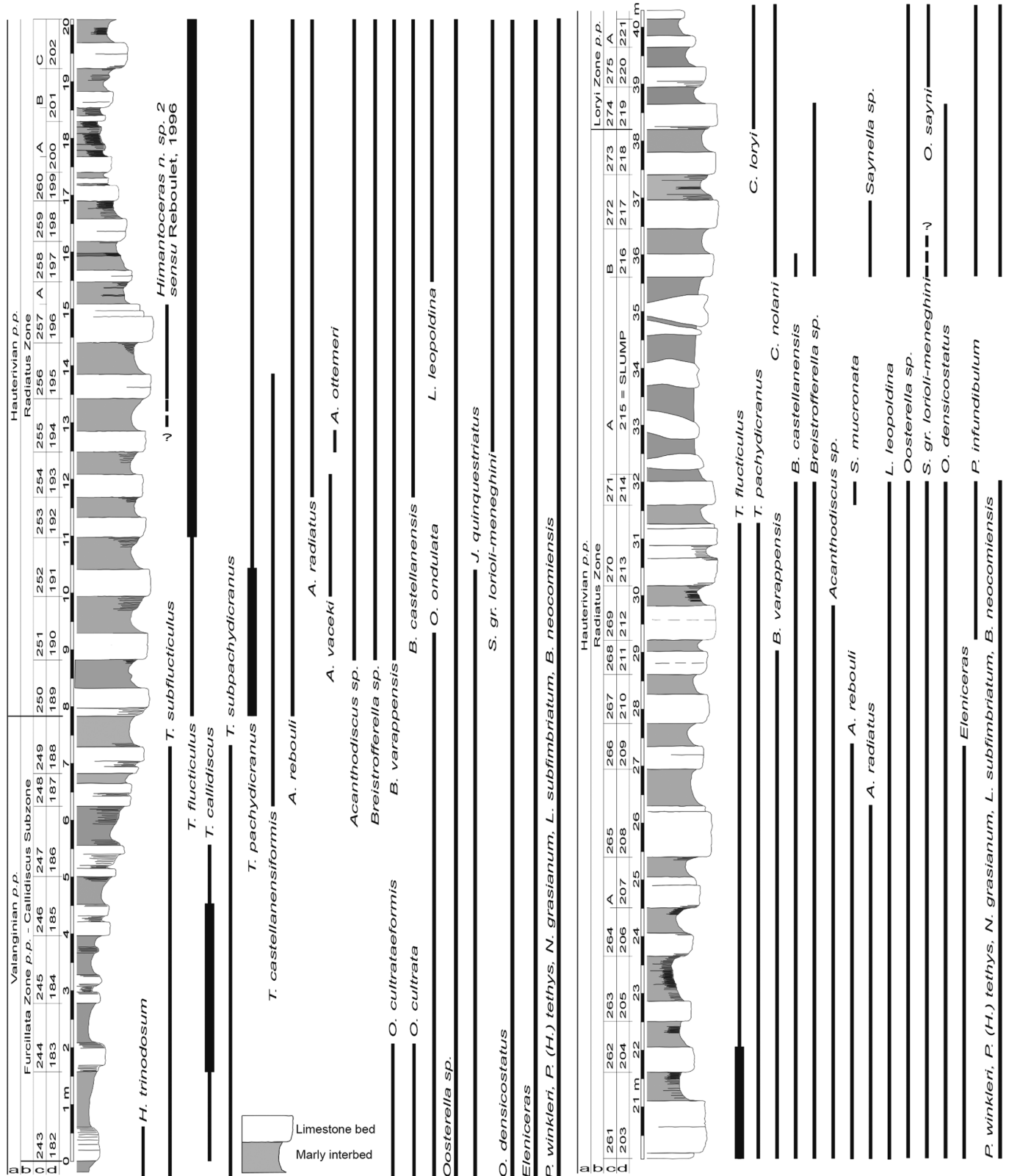


Figure 3. Lithology and ammonite distribution of the La Charce section. Columns (a) stages; (b) ammonoid zones; c = bed numbers of Bulot et al. (1993); d = bed numbers of Reboulet et al. (1992), used here (see text, part “Description of the section”).

other sections of the Vocontian Basin (Pellenard et al., 2003; Fesneau et al., 2009). Further investigations are necessary to determine the true nature of this goethite-rich horizon. Indeed, for the Valanginian ochre

layers, Fesneau et al. (2009) demonstrated the occurrence of one bentonite layer, while other horizons were derived from the meteoric weathering of pyrite.



## Biostratigraphy

Ammonites provide the primary biostratigraphic tool at La Charce. Other macrofossil groups include scarce belemnites (Janssen, 2009). There are very few brachiopods, bivalves and gastropods and these have not yet been studied in detail. Among microfossils, calcareous nanofossils and dinoflagellates provide valuable information, while foraminifera, ostracods and radiolarians are sparse.

## Ammonites

At La Charce, the late Valanginian *Teschenites callidiscus* ASZ of the *Criosarasinella furcillata* AZ and the early Hauterivian *Acanthodiscus radiatus* and *Crioceratites loryi* AZs of the Standard Zonation scheme (Reboulet et al., 2018) are characterized by abundant and well preserved ammonoid faunas. These faunas represent the most continuous and fossiliferous succession of ammonites recorded from sections of the Mediterranean–Caucasian Subrealm of the Tethyan Realm *sensu* Lehmann et al. (2015). They provide a very high resolution biostratigraphic record of the Valanginian/Hauterivian boundary interval (Fig. 3).

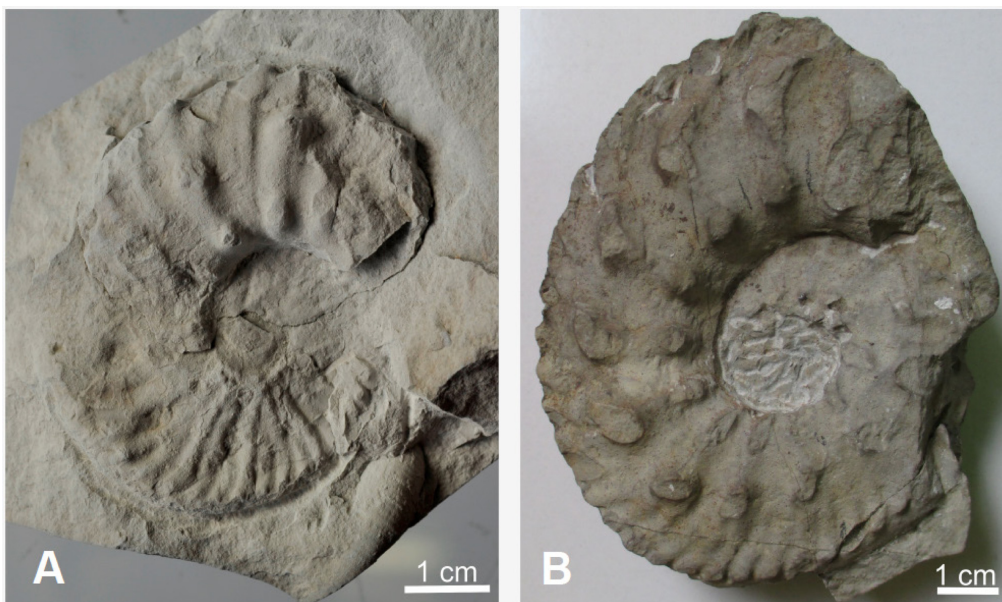
The first detailed palaeontological and biostratigraphical study across this interval was published by Thieuloy (1977). Since then extensive new bed-by-bed collections have been made by L. Bulot and S. Reboulet and the ranges and systematic palaeontology of the faunas have been monographed in detail (Reboulet et al., 1992; Bulot et al., 1993, 1995; Thieuloy and Bulot, 1993; Atrops and Reboulet, 1995; Bulot, 1995; Bulot and Thieuloy, 1995; Reboulet, 1996, 2015; Reboulet and Atrops, 1999). These studies provide a sound base for the standard Mediterranean ammonite scale accepted by the Kilian Group for the late Valanginian and early Hauterivian (Hoedemaeker et al., 2003; Reboulet et al., 2006, 2009, 2011, 2014, 2018). It should be noted that this zonal scheme has remained unchanged since its general acceptance at the Lyon Meeting of the Kilian Group in 2002 (Hoedemaeker et al., 2003). For the

formal GSSP proposal and this paper, Bulot and Reboulet have homogenized the ammonite ranges and taxonomy published in their previous studies. The result is a new log and ammonite ranges which are presented here (Fig. 3). The material consists of several thousand specimens, housed at the University of Grenoble (Thieuloy), the Musée Requien in Avignon (Bulot) and the University of Lyon (Reboulet).

As proposed by Reboulet (1996) and recommended by the Hauterivian working group at Brussels (Mutterlose et al., 1996), the FO of the genus *Acanthodiscus* is taken to mark the base of the Hauterivian. This recommendation was included in the Geologic Time Scale 2004 (Ogg et al., 2004) and adopted by the Kilian Group (Reboulet et al., 2009). At La Charce, the first *Acanthodiscus* species to appear is *Acanthodiscus rebouli* in bed 189 (Fig. 4, Reboulet, 1996; Fig. 22, p. 216). The FO of *A. radiatus*, index species of the lowermost Hauterivian AZ, lies four beds higher in the succession (bed 193, Fig. 4). *Acanthodiscus vaceki* and *Acanthodiscus ottmeri* are short-ranging species that occur in the lowermost part of the *A. radiatus* AZ. The stratigraphic distribution of these taxa does not necessarily reflect the evolution of the genus. Goguel (1940) and Reboulet (1996, 2002) suggested that *Acanthodiscus* might represent a single biological species marked by an important morphological variability illustrated by various intermediate forms occurring between the typological species of the literature. For the latter author this interpretation supports the use of the FO of the genus rather than a species to define the base of the AZ and the stage.

*Acanthodiscus* has been recorded from many areas along the northern margin of the Tethys, from the Caucasus to France (e.g., Klein, 2005). It is relatively rare in the pelagic successions of southeast France (Bulot, 1993, 1995; Reboulet, 1996), but common in the condensed sections of the Swiss Jura and the northern Provence Platform (Busnardo and Thieuloy, 1989; Thieuloy et al., 1991). On the southern margin of Tethys it has been recorded from Morocco (Wippich, 2003; Ettachfini, 2004).

Several other significant ammonite events mark or bracket the boundary at La Charce. The most significant are the successive FOs of *Breistrofferella varapensis* in bed 190 and *Breistrofferella castel-*



**Figure 4.** (A) *Acanthodiscus rebouli*, bed 189 of the La Charce section (see Reboulet, 1996, Fig. 22, p. 216). (B) *Acanthodiscus radiatus*, bed 208 of the La Charce section, *Acanthodiscus radiatus* ammonite Zone (see Reboulet, 1996, Fig. 22, p. 216; Pl. 14, Fig. 12). Both photos Reboulet.

*lanensis* in bed 193, providing a useful alternative when *Acanthodiscus* is absent. *Breistrofferella* is well represented in pelagic successions (Bulot, 1995; Reboulet, 1996). Reboulet (1996, 2002) suggested that it could be the microconch of *Acanthodiscus*. In the Mediterranean area, the palaeobiogeographic distribution of *Breistrofferella* is wider than that of *Acanthodiscus*, it also includes Spain (Company, 1987), Tunisia (Memmi, 1981), and Crimea, where it was found with *Leopoldia desmoceroides* (Baraboshkin et al., 2016). *Leopoldia* and *Saynella* are other typical earliest Hauterivian neocomitids. The former apparently evolved from *Acanthodiscus* in the lower third of the *A. radiatus* AZ (bed 197) while the latter appears at the very top of AZ (*Saynella mucronata*, bed 214). This distribution is consistent with the ranges observed on the shelf of the north Provence Platform (Bulot, 1993, 1995). It should be noted that in the Transdanubian range of Hungary, Fözy and Janssen (2009) used the occurrence of *Saynella* to help place the base of the Hauterivian stage.

Another event that marks the boundary is the FO of *Teschenites pachydicranus* and *Teschenites flucticulus* in bed 189. This event is truly evolutionary since the last occurrences (LOs) of the ancestral species *Teschenites subpachydicranus* and *Teschenites subflucticulus* have been observed in the uppermost Valanginian (bed 188). It might provide a useful marker in deep basal settings, where *Acanthodiscus* is absent. Unfortunately, except for the western Carpathians (Vašiček, 2010), there is hardly any information available on the *Teschenites* successions outside the Vocontian Basin to test the broader significance of this event. Only few biostratigraphic data are given for northern Italy (Faraoni et al., 1997). In both areas the FO of *T. flucticulus* was used to define the base of the Hauterivian stage. *Teschenites callidiscus*, a short ranging index species of the highest Valanginian ASZ, last occurs in bed 186, about 2.5 metres below the boundary.

Additional secondary markers include *Jeanthieuloyites quinquestriatus*, *Spitidiscus* gr. *lorioli-meneghinii* and *Oosterella undulata*. *Jeanthieuloyites* and *Spitidiscus* represent a phylletic lineage in the early history of the Spitidiscinae. At La Charce, the LO of *J. quinquestriatus* lies three beds (bed 191) above the base of the Hauterivian, and two beds below the FO of *Spitidiscus* in bed 194. There is no overlap between the two taxa but this might reflect their rarity around the Valanginian/Hauterivian boundary at La Charce. The early *Spitidiscus* are still in need of detailed taxonomic revision since some authors refer them to *Jeanthieuloyites* (Avram, 1995; Vašiček, 2002; Fözy and Janssen, 2009). Nevertheless, *Spitidiscus lorioli*, *Spitidiscus meneghinii*, *Spitidiscus nodosus* and *Spitidiscus rossfeldensis* form a natural group that shows intermediate characters between the true Valanginian *Jeanthieuloyites* and true *Spitidiscus* of the *C. loryi* AZ. According to Vašiček (1995), Reboulet (1996) and Busnardo et al. (2003), when *Acanthodiscus* (or *Breistrofferella*) are absent, the FO of *Spitidiscus* can be used to characterize the base of the Hauterivian, as Melliti et al. (2019) did in Tunisia. *Oosterella undulata* disappears in the *A. radiatus* AZ; its LO in La Charce is two beds above the base of the AZ (bed 190).

The remainder of the ammonite fauna is represented by long ranging species including *Olcostephanus densicostatus*, *Phyllopachyceras winkleri*, *Phylloceras* (*Hypophylloceras*) *tethys*, *Neolissoceras grasianum*, *Lytoceras subfimbriatum* and *Bochianites neocomiensis* that already appeared in the Valanginian. Conversely, *Phyllopachyceras infundibulum* first appears in the upper part of the *A. radiatus* AZ.

## Belemnites

Belemnites are rare at La Charce and no bed-by-bed collections have been made. They are more common in the Angles and Cheiron sections, about 100 km southeast of La Charce, but there are no shifts in the taxonomic composition of the belemnite assemblages across the Valanginian/Hauterivian boundary interval (Janssen, 2009).

## Calcareous Nannofossils

The calcareous nannofossils at La Charce (Fig. 5 and 6) have a low-latitude (Tethyan) affinity with common *Crucellipsis cuvillieri*, *Speetonina colligata* and *Calcicalathina oblongata*. Nannoconids, which are known to prefer low-latitude, warm surface-waters and hemipelagic settings (Thierstein, 1976; Mutterlose, 1991; Erba, 1994; Mutterlose et al., 2014), are very rare in the marl samples examined here. Taxa more commonly associated with higher latitudes such as *Sollasites* spp, *Crucibiscutum salebrosum*, *Corolithion silvaradion*, are constantly present at La Charce although in much lower numbers than at Boreal sites. This is due to the northern Tethyan position of the Vocontian Basin which acted as a gateway to the Northwest European Boreal domain.

Early zonation schemes of calcareous nannofossils for the Valanginian/Hauterivian boundary interval (Sissingh, 1977; Perch-Nielsen, 1979, 1985; Roth, 1978, 1983; Thierstein, 1973, 1976) were followed by that of Applegate and Bergen (1989), who established a CC4a calcareous NZ (= Nannofossil Zone), which covers the interval under discussion. They defined the base of the CC4a NZ by the FO of *Eiffellithus striatus* in the late Valanginian (also see Bralower et al., 1995) and the top of the CC4a NZ by the FO of *Lithraphidites bollii*. Within CC4a, the LO of *Eiffellithus windii* has been observed in the early Hauterivian *A. radiatus* AZ in France (Bergen, 1994; Gardin, 2008); see discussion below. *Eiffellithus windii* is, however, rare or absent in the Boreal Realm. Furthermore, it is a taxonomically problematic form (Mutterlose et al., 1996). The LO of *Tubodiscus verенаe* has often been recorded as a latest Valanginian event in Mediterranean sections (Bralower, 1987; Bergen, 1994; Channell et al., 1995; Erba et al., 1995). However, Gardin (in Bulot et al., 1996) recorded this species, though very rare and discontinuous in range, throughout the Hauterivian. *Tubodiscus verенаe* has not been observed in expanded sections in the Boreal Realm covering the Valanginian/Hauterivian boundary interval.

The complete and expanded Valanginian–Hauterivian sequence at La Charce shows a sequence of local events in relation to the established AZs. *Nannoconus bucheri* and *Nannoconus wassalli* occur sporadically starting from the top of the *T. callidiscus* ASZ onwards. Both species are always rare and patchy throughout the Valanginian/Hauterivian boundary interval, they become more abundant and continuous from the *C. loryi* AZ onward. *Tubodiscus verенаe* and *Tubodiscus jurape-lagicus* occur sporadically up to the upper Hauterivian *P. ligatus* AZ. The FO of *Staurolithites mitcheneri* was observed near the base of the *A. radiatus* AZ (bed 190), a form extremely rare in the Boreal Realm. *Tribrachiatius* sp. ranges from the base of the section to the *A. radiatus* AZ (bed 213). It appears to be the first record of the genus *Tribrachiatius* in Valanginian and Hauterivian strata. The LO of *E. windii* occurs in the uppermost part of the *A. radiatus* AZ (bed 213), and the FO of *Diloma galiciense* near the top of this AZ (bed 217). Both species are rare but their stratigraphical ranges are reasonably consistent.

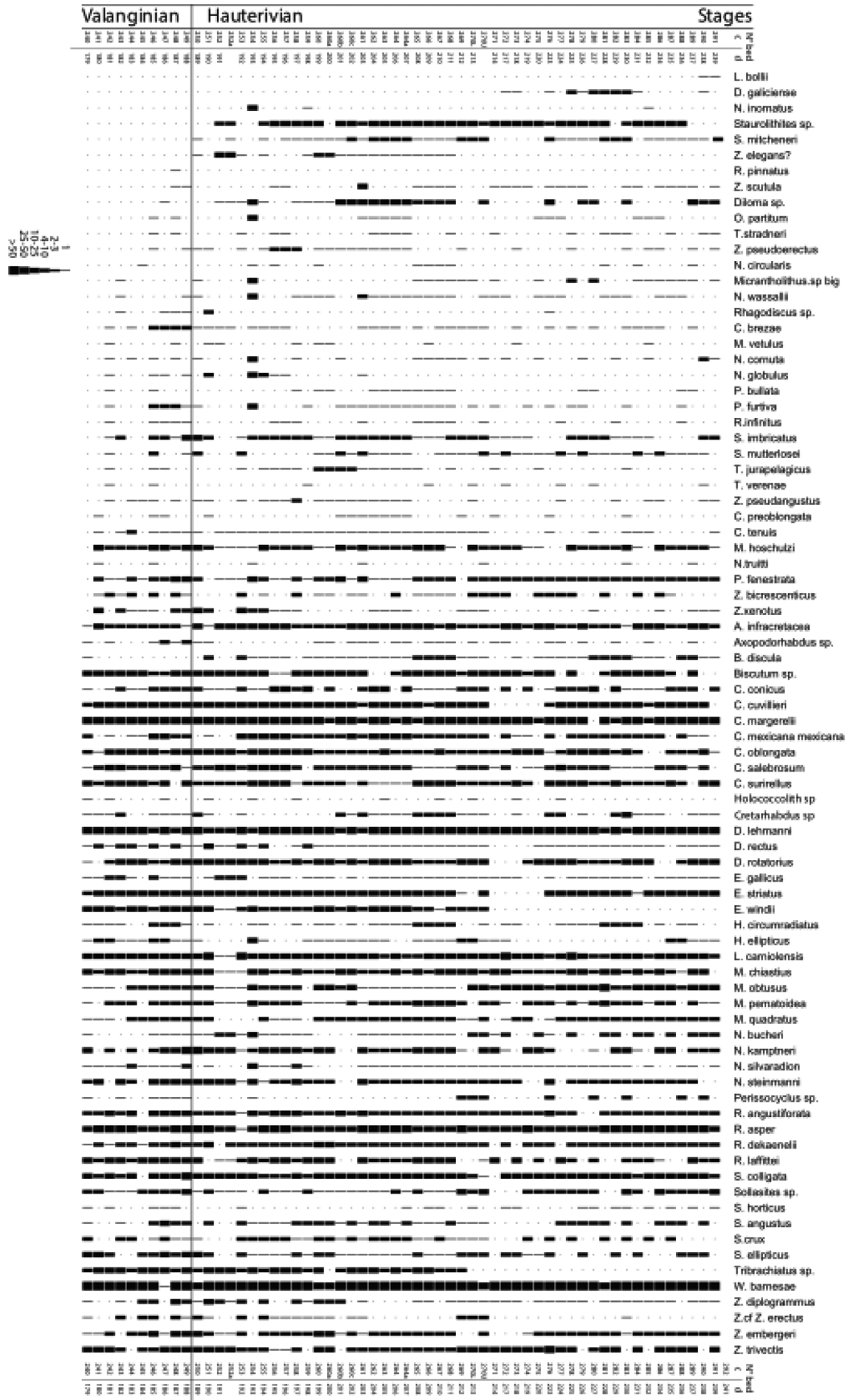
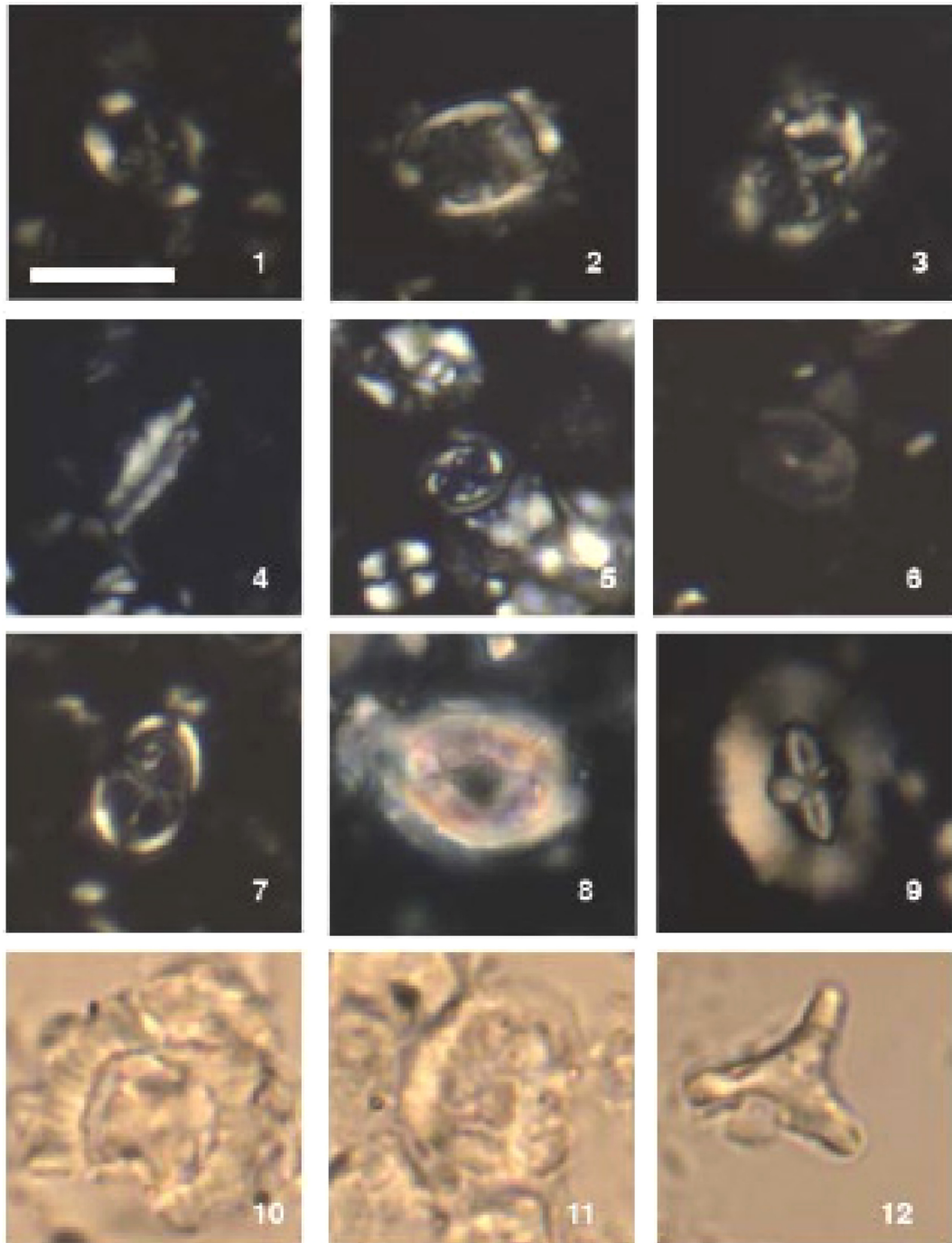


Figure 5. Stratigraphic distribution of calcareous nannofossils across the Valanginian/Hauterivian boundary at La Charce after Gardin (2008). Semiquantitative counts represent the n° of specimens found in 100 fields of view. Columns c and d = bed numbers of Bulot et al. (1993) and Reboulet et al. (1992), respectively.



**Figure 6.** Light microscope photos of important taxa of calcareous nannofossils from the Valanginian/Hauterivian boundary of La Charce (Gardin, 2008). (1) *Eiffellithus windii*, bed 190; (2-3) *Eiffellithus striatus*, bed 194; same specimen rotated); (4) *Litrathidites bollii*, bed 238; (5) *Staurolithes mitcheneri*, bed 194; (6) *Corollithion silvaradion*, bed 217; (7) *Diloma galicense*, bed 225; (8) *Tubodiscus verena*, bed 217; (9) *Crucellipsis cuvillierii*, bed 194; (10) *Nannoconus cornuta*, bed 201; (11) *Nannoconus bucheri*, bed 201; (12) *Tribrachiatius* sp., bed 190. Scale bar (Fig. 1) = 5  $\mu$ m.

The FO of *L. bollii* was observed in the *C. loryi* AZ (bed 238) although its common occurrence starts in the *Lyticoceras nodosoplicatum* AZ (bed 296). *Rhagodiscus dekaeneli* last occurs at the top of the latter AZ. The usefulness of these biostratigraphically important events (Fig. 6) needs to be tested against those of the Boreal Realm. The nannofossil event which best approximates the Valanginian/Hauterivian boundary at La Charce is the LO of *E. windii* (bed 213).

### **Foraminifera**

Benthic foraminifera have been used quite successfully in the Boreal-Arctic Subrealm for a detailed biozonation and regional correlation (e.g., Bartenstein and Bettenstaedt, 1962; Meyn and Vespermann, 1994). But this biozonation cannot be used for inter-regional correlation, because currently no precise data are available for La Charce or elsewhere in



the Vocontian Basin.

Even though species of planktic foraminifera have been recorded from the Valanginian of the Mediterranean area, the assemblages comprise very few, small-sized taxa that occur discontinuously so they are not biostratigraphically significant (Coccioni and Premoli Silva, 1994; Cecca et al., 1994; Robaszynski and Caron, 1995). Moreover, so far they have not been recorded before the Barremian in the Boreal Realm except for *Favusella hoterivica* which first appeared in the Berriasian of the Scotian Shelf (offshore Canada; Wernli et al., 1995).

### Ostracods

Ostracods are also used for biozonation and regional correlation in the Boreal-Arctic Subrealm (e.g., Bartenstein and Bettenstaedt, 1962). Here the FO of the ostracod *Protocythere triplicata* has been recorded by many authors: this event occurs in the *Astieria* beds (*Olcostephanus densicostatus* AZ of Rawson, 1995; = *Eleniceras paucinodum* AZ of Quensel, 1988) in the latest Valanginian of northwest Germany (Niedziolka, 1988). In France (Alpes-de-Haute-Provence), the FO of *P. triplicata* seems to equate to the base of the *C. furcillata* AZ (Donze, 1976; Bulot, 1992, 1995). Consequently the FO of *P. triplicata* is time transgressive having its FO in northwest Europe later than in France.

### Radiolarians

At La Charce, radiolarians occur primarily in limestone beds, whereas they are rare or absent in the marly interbeds. Diversity increases in the uppermost Valanginian *T. callidiscus* ASZ and remains high across the Valanginian/Hauterivian boundary. Lambert (1999) studied 124 samples from the La Charce section, but only 87 were productive. The abundance of radiolarians is extremely low, only 5-10 specimens per sample in average were encountered. The range chart presented by Lambert (1999) is therefore quite fragmentary and the data should be interpreted with caution.

Lambert (1999) did not identify any zones or assemblages of stratigraphic importance. Louis O'Dogherty has re-checked the relevant in detail. His data allow a zonation for the lower/upper Hauterivian boundary but not for the Valanginian/Hauterivian boundary beds.

### Dinoflagellates

Leereveld (1995, 1997) compiled the FOs and LOs of dinoflagellates for the European Hauterivian both in Tethys and in the Boreal Realm. The FO of *Muderongia staurota*, an early Hauterivian event, is a possible alternative candidate for defining the Valanginian/Hauterivian boundary. In the Mediterranean area, *M. staurota* occurs in the upper part of the *A. radiatus* AZ, in northwest Germany at the top of the *Endemoceras amblygonium* AZ. According to Leereveld (1995, 1997), this taxon appears to be cosmopolitan as it was recorded from Australia, and it is now known from the Neuquén Basin in the southern Andes (Aguirre-Urreta et al., 2005; Paolillo et al., 2018). The FO of *M. staurota* is therefore an important event, allowing direct inter-regional correlation. In the Vergons section (Alpes-de-Haute-Provence, France), Londeix (1990) reported the FO of *M. staurota* in sample H11 from the marly layer of bed 35 located in the uppermost part of the *A. radiatus* AZ. However, dinoflagellates have not been studied from La Charce.

## Chemical and Physical Stratigraphy

A range of studies across the Valanginian/Hauterivian boundary embraces carbon isotope stratigraphy, inorganic and organic geochemistry, magnetostratigraphy, cyclostratigraphy and astrochronology.

### Carbon Isotope Stratigraphy

Carbon isotope data of carbonate bulk rock samples ( $\delta^{13}\text{C}_{\text{carb}}$ ) are published for La Charce and Vergol (Montbrun-les-Bains, Drôme, France), about 30 km south of La Charce (Hennig et al., 1999; van de Schootbrugge et al., 2000; Gréselle et al., 2011; Kujau et al., 2013). A combined record from both sections shows that there are three positive excursions in the mid-Valanginian, which are attributed to the globally occurring Weissert Event. Throughout the upper Valanginian (*Olcostephanus nicklesi* ASZ and *C. furcillata* AZ) and lowermost Hauterivian (*A. radiatus* AZ) the  $\delta^{13}\text{C}_{\text{carb}}$  values decrease gradually, without any significant excursions. The Valanginian/Hauterivian boundary interval is characterized by a plateau around 1.3‰.

For the Valanginian/Hauterivian boundary at La Charce, Vergons and Angles (Alpes-de-Haute-Provence, France), the  $\delta^{13}\text{C}_{\text{BeI}}$  data range from 0 to +1‰ (McArthur et al., 2007; Bodin et al., 2015). A considerable variation of  $\delta^{13}\text{C}$  values of up to 1.5‰ has been recorded from different specimens of co-occurring belemnite rostra (e.g., Wierzbowski and Joachimski, 2009; Malkoc and Mutterlose, 2010), probably reflecting metabolic effects on the incorporation of carbon. The paleo-environmental meaning of the  $\delta^{13}\text{C}$  signal from belemnites is thus still under discussion.

### Strontium Isotope Stratigraphy

High-resolution, belemnite based Sr-isotope ( $87\text{Sr}/86\text{Sr}$ ) curves are readily available for the Vocontian Basin (McArthur et al., 2007; Bodin et al., 2015). The Sr-data have a much smaller variance than the  $\delta^{13}\text{C}$  values and are thus well suited for stratigraphic purposes and supraregional correlation (Mutterlose et al., 2014). The late Valanginian–early Hauterivian interval is characterized by increasing Sr-isotope values from 0.707361 (*S. verrucosum* AZ) to 0.707428 (*L. nodosoplicatum* AZ). Based on belemnite material from Angles and Vergol, the middle part of the Valanginian *C. furcillata* AZ has a value of 0.707376, the base of the Hauterivian of 0.707383  $\pm$  0.000005 (McArthur et al., 2004).

### Inorganic Geochemistry

Limestone beds of the marl-limestone alternations at La Charce (bed 182 to bed 222) were sampled and analysed for the trace elements Mn and Sr in bulk carbonate. Fluctuations of manganese have been interpreted as variations of sea-water chemistry related to sea-level changes (Emmanuel, 1993; Emmanuel and Renard, 1993; De Rafelis et al., 2001). The latter caused a varying quantitative input of the biogenic carbonate by the partitioning of platform and hemipelagic carbonates (Renard, 1986).

The manganese values are relatively low, fluctuating between 83 and 184 ppm. They allow to recognise four geochemical sequences (Fig. 7) similar to those described for the Angles and Vergons sections

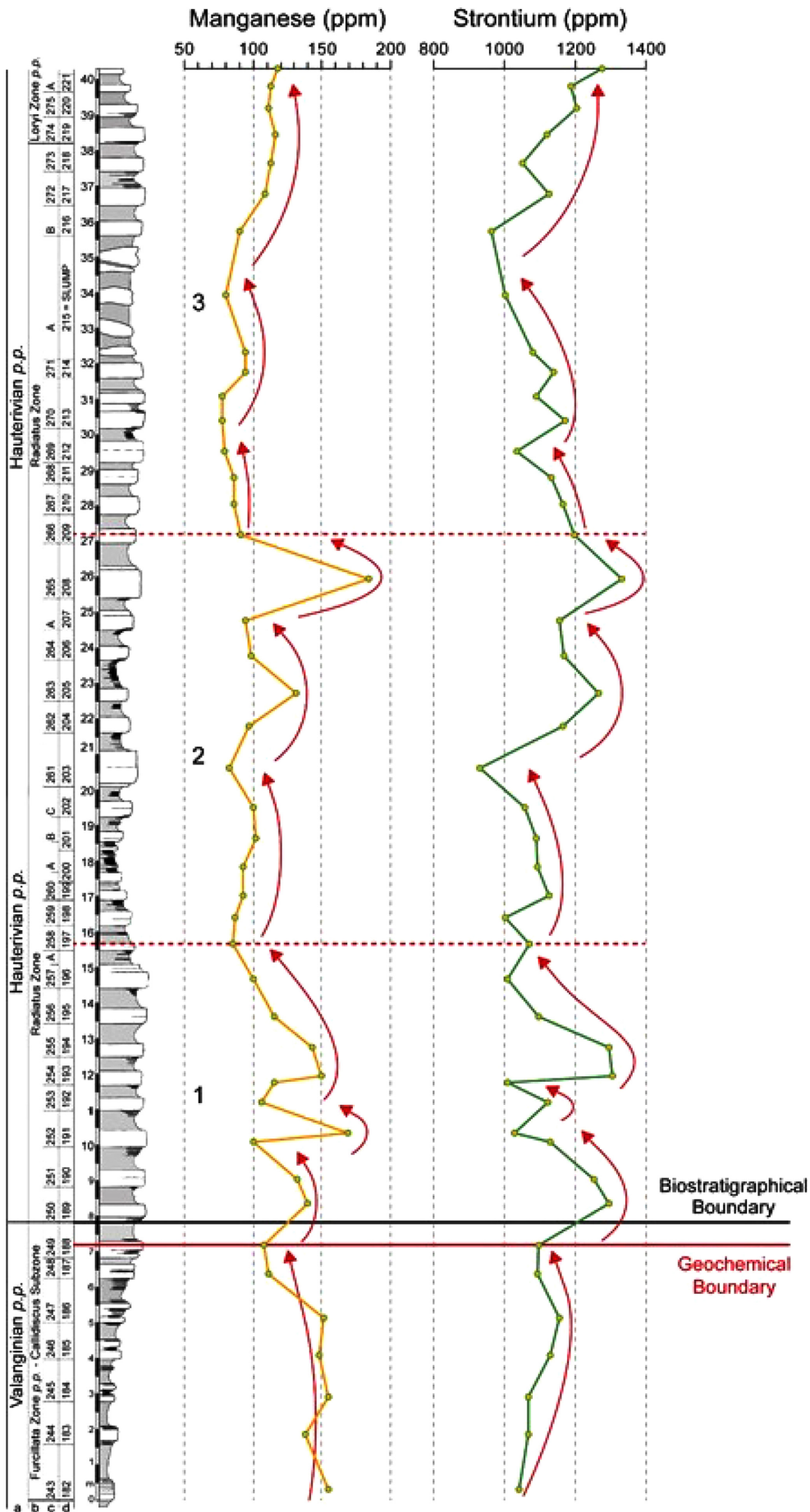


Figure 7. Manganese and strontium concentrations of bulk rock carbonates (pelagic limestones) from the La Charce section. Columns c and d = bed numbers of Bulot et al. (1993) and Rebollet et al. (1992) resp. (see "Description of the section"). A shift of the Mn and Sr values, near the biostratigraphically defined Valanginian/Hauterivian boundary, is marked by the red solid line. The two dashed red lines (beds 197, 209) indicate further geochemical sequence boundaries. 1, 2, 3 = Hauterivian geochemical sequences described by variations of manganese and strontium concentrations.

(Emmanuel, 1993). The first, lowermost sequence shows an overall decrease of values from bed 182 (168 ppm) to bed 188 (105 ppm). Bed 188 corresponds to the lower boundary of the following, second geochemical sequence (beds 188-197), which can be subdivided into three geochemical parasequences. These have highest Mn concentrations in bed 189 (140 ppm), bed 191A (169 ppm) and bed 193A (150 ppm) resp. The upper boundary of this second sequence is located in bed 197 (85 ppm). The third Mn sequence begins with low values in beds 197 to 203. The two overlying geochemical parasequences, with more positive Mn values, culminate in beds 205 (131 ppm) and 208

(184 ppm) resp. The top of sequence two is located in bed 209 (91 ppm). The third geochemical sequence is incomplete, it starts with low Mn concentrations in beds 209 to 213 (91-78 ppm). The Mn contents increase to bed 222 (118 ppm) via two parasequences (beds 213-215, beds 216-222). These results are consistent with the geochemical and chronostratigraphical framework established by Emmanuel (1993) for the Angles and Vergons sections. Beds 188, 197 and 209 of the La Charce section, with low Mn concentrations (108 ppm, 85 ppm, 91 ppm resp.), correspond to geochemical sequence boundaries.

The bulk rock carbonate Sr content is high throughout the entire

**Table 1. Inorganic and organic carbon geochemical results. CaCO<sub>3</sub> concentration and selected Rock-Eval parameters for the marly interbeds close to the Valanginian/Hauterivian boundary in La Charce**

Sample	Bed number		Elevation (m)	CaCO <sub>3</sub> (%)	TOC (%)	Tmax (°C)	S2 mg HC/g rock	IH mg HC/g TOC
	Bulot	Reboulet						
LCH 275AS	275A	221	40.0	59.9	0.41	429	0.59	143
LCH 275S	275	220	39.5	55.7	0.44	428	0.72	163
LCH 274S	274	219	38.8	58.1	0.31	426	0.36	116
LCH 273S	273	218	38.0	54.4	0.49	426	0.72	146
LCH 272S	272	217	37.2	62.4	0.20	434	0.17	85
LCH 271S	271	214	32.2	67.6	0.32	431	0.33	103
LCH 270S	270	213	31.5	67.8	0.37	430	0.56	151
LCH 269S	269	212	30.0	51.5	0.80	431	1.56	195
LCH 268S	268	211	29.1	60.3	1.06	429	3.43	323
LCH 267S	267	210	28.5	56.8	1.09	428	3.72	341
LCH 266S	266	209	27.5	62.9	0.82	429	2.00	243
LCH 265S	265	208	26.6	74.6	0.32	432	0.56	175
LCH 264AS	264A	207	25.3	52.9	0.37	429	0.78	210
LCH 264S	264	206	24.3	46.7	0.49	428	0.97	197
LCH 263S	263	205	23.3	57.7	0.27	418	0.50	185
LCH 262S	262	204	22.3	58.9	0.64	427	1.39	217
LCH 261S	261	203	21.3	66.5	0.41	430	0.63	153
LCH 260CS	260C	202	20.0	63.5	0.32	425	0.53	165
LCH 260BS	260B	201	19.0	58.9	0.45	431	0.87	193
LCH 260S	260	199	18.0	53.4	0.81	429	2.44	301
LCH 259S	259	198	16.8	69.1	0.33	423	0.81	245
LCH 258S	258	197	16.0	46.6	0.63	429	1.28	203
LCH 257S	257	196	15.3	70.1	0.33	431	0.57	172
LCH 256S	256	195	14.1	43.1	0.59	429	1.32	223
LCH 255S	255	194	13.2	55.0	0.92	429	2.97	322
LCH 254S	254	193	12.3	54.8	0.55	432	0.82	149
LCH 253S	253	192	11.5	60.2	0.33	430	0.48	145
LCH 252S	252	191	10.7	58.3	0.43	431	0.71	165
LCH 251S	251	190	9.5	51.2	0.58	436	0.80	137
LCH 250/251	250	189	8.5	69.4	0.33	429	0.54	164
LCH 249/250	249	188	7.5	52.0	0.52	430	0.92	177
LCH 248/249	248	187	6.8	72.4	0.34	431	0.58	171
LCH 247/248	247	186	6.0	77.5	0.33	434	0.40	121
LCH 246/247	246	185	4.8	54.6	0.77	432	2.30	299
LCH 245/246	245	184	3.5	57.6	1.17	431	3.53	302
LCH 244/245	244	183	2.5	62.2	0.45	430	0.78	173
LCH 243/244	243	182	1.0	64.3	0.22	431	0.45	205

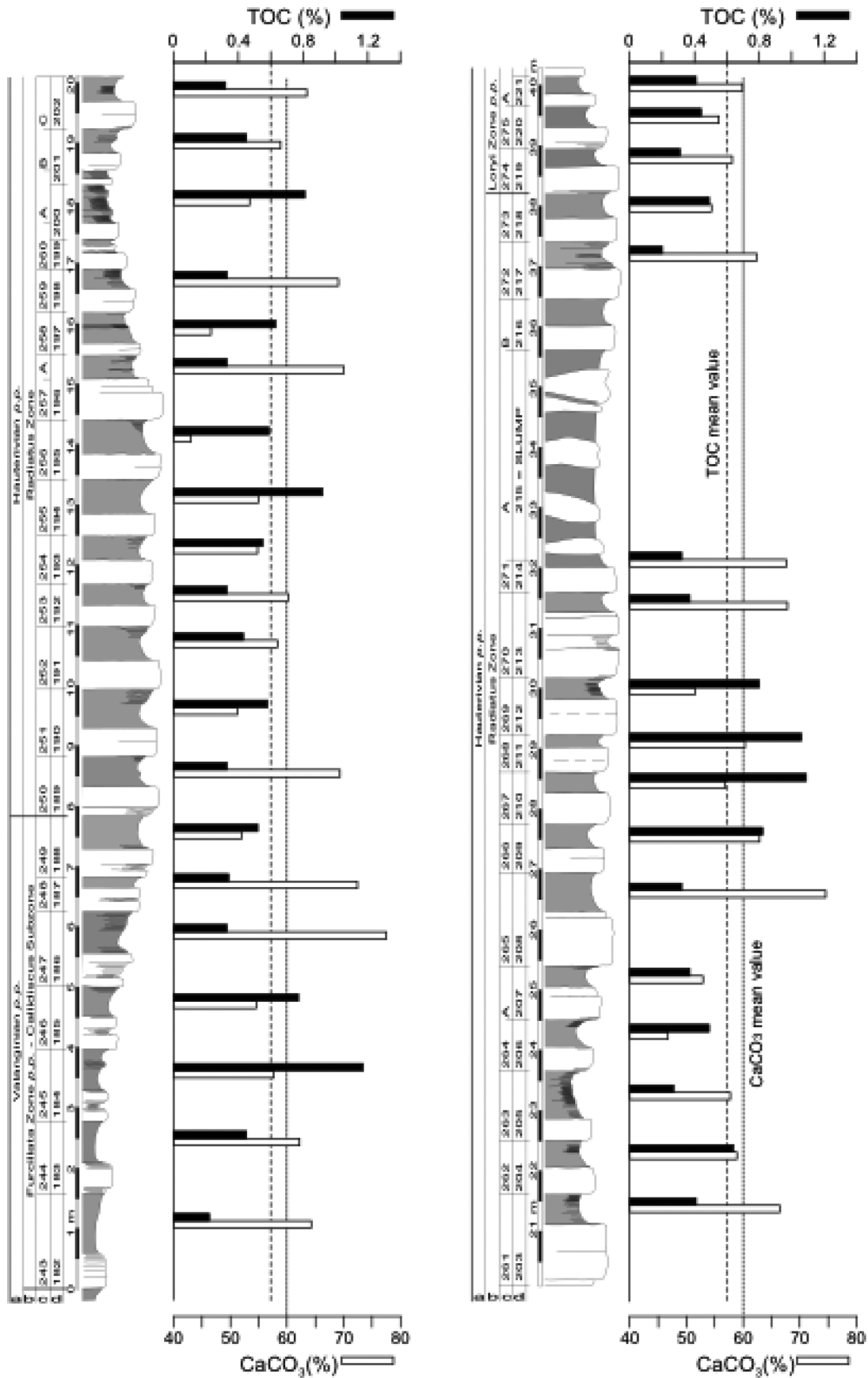


Figure 8. Vertical distribution of  $CaCO_3$  and total organic carbon (TOC) concentrations in the marly interbeds of the Valanginian/Hauterivian boundary in La Charce. The two dashed lines indicate the  $CaCO_3$  and TOC mean values. Columns c and d = bed numbers of Bulot et al. (1993) and Reboulet et al. (1992), respectively (see text, part 5).



succession (931 to 1,330 ppm). The resulting Sr curve resembles that of Mn, it presents a similar pattern with four geochemical sequences. The first, lowermost sequence ends in bed 188 (1,097 ppm). The second sequence consists of three positive parasequences with maxima of 1295, 1124 and 1304 ppm in beds 189, 192 and 193A respectively. The exact position of the upper sequence boundary is unclear, but it can be fixed between beds 196 and 198 near the corresponding Mn sequence boundary in bed 197. The third Sr sequence shows three positive parasequences, its top can be placed in bed 209. The last sequence begins with two positive parasequences.

In conclusion, the two trace elements Mn and Sr suggest no major geochemical break or event at the Valanginian/Hauterivian boundary. The Mn and Sr curves exhibit a negative shift of medium importance, which characterize a geochemical sequence boundary. This boundary lies in bed 188 just below the biostratigraphically defined Valanginian/Hauterivian boundary (bed 189, base of the *A. radiatus* AZ).

### Organic Geochemistry

Thirty-seven samples have been taken from the middle part of clayey interbeds across the Valanginian/Hauterivian boundary interval (beds 182 to 221) and analysed for their carbonate and organic carbon content (Table 1, Fig. 8). Tmax values are relatively low (~429°C in average), indicating that the organic matter has not experienced high temperature during burial and is still immature with respect to petroleum generation. Such a moderate thermal diagenesis allows organic parameters (TOC, HI) to be interpreted as a primary signal that may reflect environmental changes during deposition.

Carbonate contents range between 43% and 77.5%, with an average value around 60% (Table 1, Fig. 9). The organic carbon content fluctuates from 0.2% to 1.2%, with an average of 0.5% TOC. The negative relationship between the percentages of carbonate and organic carbon (Fig. 9, left part) indicates that dilution by the carbonate input explains the

low organic matter content (Ricken, 1993). The Valanginian–Hauterivian strata represent conditions of low organic productivity and poor preservation of organic matter. The exception is the dark-coloured marly layers, occurring in beds 184, 210 and 211, in which TOC concentration exceeds 1%.

The low amount of organic matter (samples with TOC < 0.5%), associated with HI-values, argue for deposition in fully oxic waters (Tyson, 1995). The sedimentary organic matter in these marly interbeds is probably the result of enhanced preservation of refractory organic matter, which mainly corresponds to land-derived organic matter (Type III) and the non-metabolisable fraction of marine organic matter (Type IV). However, the samples containing more than 0.5% TOC are enriched in marine organic matter (Type II), although this organic matter is oxidized (Fig. 9, right).

### Magnetostratigraphy

Sprovieri et al. (2006) suggested that the base of the Hauterivian coincides with the top of Chron M10Nn.3n in the Maiolica Formation of Central Italy, where this magnetic event is calibrated to the FO of the calcareous nannofossil *Lithraphidites bollii*. At La Charce a 50 m-long cored interval across the Valanginian/Hauterivian boundary (Ferry et al., 1989) provided a weak magnetic signal, which corresponds to the M10 magnetic anomaly.

A correlation with the Angles section, for which magnetic results on the Valanginian stage and the lowermost Hauterivian were compiled by Besse et al. (1986) and Boisseau (1987), is possible.

### Cyclostratigraphy and Astrochronology

A total of 1193 Gamma Ray Spectrometry (GRS) measurements was performed *in situ* over a 239.25 m long section at an even step of 0.2 m, using a SatisGeo GS-512. The measurements cover an interval

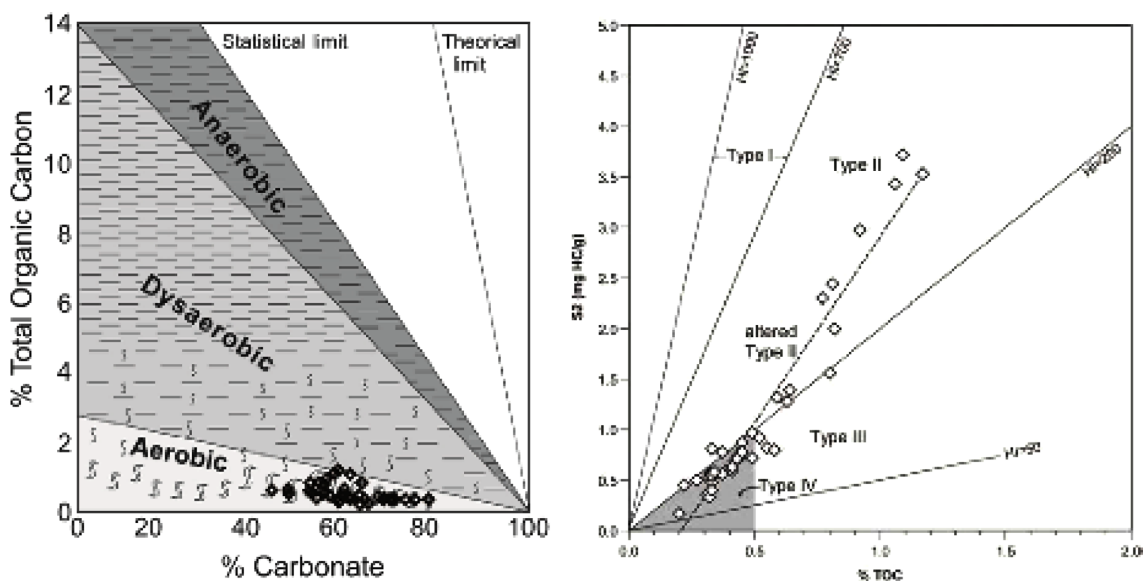


Figure 9. Left: Relationship between carbonate content and organic carbon in the marly interbeds of the Valanginian/Hauterivian boundary in La Charce with idealized bottom water oxygenation condition (after Ricken, 1993). Right: S<sub>2</sub>-TOC crossplot showing the main types of organic matter. Types I, II and III are encountered between the HI constant lines, whereas type IV is restricted to organic poor (< 0.5% TOC) samples.

ranging from the upper part of the *S. verrucosum* AZ to the lower part of the *P. ligatus* AZ. Astrochronological interpretations based on these measurements (Martinez et al., 2013, 2015) and revised by Martinez (2018) show a clear record of astronomical forcing that makes La Charce a suitable reference section for the astronomical time scale of the lower Hauterivian Substage. Astrochronology has also been studied in the Agrio Formation in the Neuquén Basin, Argentina, and anchored on U-Pb CA-ID-TIMS ages (Aguirre-Urreta et al., 2019). Correlating the base of the Hauterivian in both formations, its numerical age is calculated as 131.29 Ma. In addition, the duration of the early Hauterivian is calculated at  $2.19 \pm 0.049$  Ma, which is significantly longer than proposed in the Geological Time Scale 2016 (1.2 Ma; Ogg et al., 2016).

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## Correlation

### *Tethys–Boreal–Atlantic Subrealm*

Both ammonite and strontium isotope data provide evidence for determining the base of the Hauterivian in the Boreal-Atlantic Subrealm of the Boreal Realm.

A detailed account on the occurrence of Tethyan ammonites in the Boreal-Atlantic Subrealm was published by Rawson (1995; see also Reboulet et al., 2014). The *Olcostephanus densicostatus*, *E. amblygonium* and *Endemoceras noricum* AZs span the Valanginian/Hauterivian boundary. The type area for these AZs is the thick succession of mudrocks that characterize the Lower Cretaceous of the Lower Saxony Basin of northern Germany (Quensel, 1988; Mutterlose, 1984, 1992b).

The uppermost Valanginian *O. densicostatus* AZ was introduced by Rawson (1995) for his earlier (Rawson, 1983) *Olcostephanus* spp. AZ. It replaces the ill defined *E. paucinodum* AZ of Quensel (1988) whose index species is based on an enigmatic form. Species of *Olcostephanus* have long been recognised as the characteristic ammonites of this level (e.g., Kemper et al., 1981) and *O. densicostatus* has now been firmly identified in the Lower Saxony Basin (Bulot in Mutterlose, 1992a). It should be noted that the acme of the Tethyan migrant *Olcostephanus* in the Lower Saxony Basin has its counterpart in the uppermost beds of the *C. furcillata* AZ (*T. callidiscus* ASZ) of the Vocontian Basin (Bulot, 1993; Reboulet et al., 1992; Bulot and Thieuloy, 1995; Reboulet, 1996).

In the lowermost Hauterivian of northern Germany and northeast England (Speeton), the faunal diversity of ammonites increases and is dominated by the Tethyan derived endemic genus *Endemoceras*. In addition *Acanthodiscus* occurs in Germany (Kemper et al., 1981; Kemper, 1992; Rawson, 1995), though it did not reach England (Spath's (1924) record refers to spinose derivatives of *Endemoceras*). These findings indicate that *A. radiatus* and *A. vaceki* first occur somewhere in the middle part of the *E. amblygonium* AZ. A temporary exposure in northern Germany (Waterloo section, Hannover; Mutterlose and Wiedenroth, 2009) probably represents a similar level, though the underlying beds were not exposed. It yielded well preserved ammonites from a 7 m thick claystone succession, including *A. radiatus*, *A. vaceki*, *E. amblygonium*, *E. longinodum*, *Leopoldia* and *Distoloceras*. In La Charce, *Leopoldia* first appears in the lower part of the *A. radiatus* AZ (bed 197), only three beds above the FO of *A. radiatus* (bed 193),

and is thought to have evolved from *Acanthodiscus* in the lower third of the lower Hauterivian. These observations suggest that the lower part of the boreal *E. amblygonium* AZ corresponds either to the lowermost *A. radiatus* AZ (beds 189-192) or to the uppermost part of the *C. furcillata* AZ.

Sr-isotopy ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) is a powerful tool for dating sedimentary sequences and for correlating strata on a global scale. Published data (McArthur et al., 2007; Meissner et al., 2015) suggest Sr-values of 0.707377 for the uppermost Valanginian and 0.707381 for the lowermost Hauterivian of Tethys. In this case the base of the *E. amblygonium* AZ may correlate with the uppermost part of the *C. furcillata* AZ (McArthur et al., 2007).

Combining the ammonite and Sr isotope evidence it appears that the base of the Hauterivian in the Boreal-Atlantic Subrealm lies low in the *E. amblygonium* AZ rather than at the base of that AZ, a possibility already considered by previous workers (Thieuloy, 1977; Kemper et al., 1981; Rawson, 1983; Mutterlose et al., 2014). But we recommend that further isotope study should be made on belemnites from La Charce. Bulot et al.'s (1993) suggestion that the German *A. radiatus* are “advanced” forms of the species characteristic of the higher part of the *A. radiatus* AZ requires further investigation.

### *Other Parts of the World*

The characterisation of the base of the Hauterivian by ammonites is extremely difficult outside Europe and North Africa. For the Arctic Subrealm it was drawn provisionally by the FO of the endemic ammonite *Pavlovites polyptychoides* (Baraboshkin and Guzhikov, 2018) and the Boreal bivalve *Buchia sublaevis*, which is also recorded from the lower Hauterivian of northern Europe (Kelly, 1990).

Records of *Leopoldia* and *Acanthodiscus* from Argentina, Colombia and Mexico are based on misidentifications of Valanginian neocomitids such as *Acantholissonia*, *Karakaschiceras*, *Neohoploceras*, *Rodigheroites* and *Chacantuceras* (see Company, 1987; Young, 1988; Bulot, 1995; Reboulet, 1996; Aguirre-Urreta and Rawson, 1999, 2010; Barragán and Gonzalez Arreola, 2009; Lehmann et al., 2015 for discussions).

Aguirre-Urreta and Rawson (in Reboulet et al., 2014) proposed updated correlations between the Valanginian and Hauterivian zonation of the Neuquén Basin (Argentina) and the West Mediterranean zonal scheme (see Table 5 in Reboulet et al., 2014). The Argentine zonal scheme is based on Aguirre-Urreta and Rawson (1997) with subsequent modifications following their monographic description of many of the faunas. The modifications are summarised in Aguirre-Urreta et al. (2005) and Aguirre-Urreta and Rawson (2012). The base of the *Holcoptychites neuquensis* AZ is correlated with the base of the *A. radiatus* AZ for two main reasons: (1) early *Holcoptychites* appear very close to early *Spitidiscus* from the lowest Hauterivian in Europe (Aguirre-Urreta and Rawson, 2003); (2) rare *Oosterella* occur either side of the Valanginian/Hauterivian boundary in both areas (Aguirre-Urreta and Rawson, 2003), which is supported by astrochronology (Aguirre-Urreta et al., 2019).

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## Conclusions

The La Charce section (Drôme Department, southeastern France)

Table 2. Key features of the La Charce section, GSSP for the Valanginian/Hauterivian boundary

Requirements for a GSSP (ICS)	La Charce (southeast France)
<b>Geology</b>	
Exposure over an adequate thickness	Yes
Continuous sedimentation. No gaps or condensation close to the boundary	Yes
Rate of sedimentation	7.8 m for the late Valanginian <i>Teschenites callidiscus</i> ammonite Subzone (152 kyrs) = 5.1 cm/1000 years. 39.1 m for the early Hauterivian <i>Acanthodiscus radiatus</i> ammonite Zone (791 kyrs) = 4.9 cm/1000 years (Martinez, 2018)
Absence of synsedimentary or tectonic disturbance	There are 2 slumps well above the V/H boundary. Both intervals are covered in the Pommerol section, very close to La Charce (Martinez et al., 2015; Reboulet, 2015; Aguirre-Urreta et al., 2019)
Absence of metamorphism and strong diagenetic alteration	Both factors can be excluded
<b>Biostratigraphy</b>	
Abundance and diversity of well preserved macro- and microfossils	Abundant and diverse ammonoids and nannofloras. Sporadic occurrence of well preserved belemnites and radiolarians
Absence of vertical facies changes at/near the boundary	Uniform lithology across the boundary level
Favourable facies for long range correlations	Yes
<b>Other stratigraphic tools</b>	
Chronometry	Potential bentonite level close to the boundary. Needs further investigation
Magnetostratigraphy	Top of Chron M10Nn.3n, weak signal
Chemostratigraphy	Available, data have been published (Hennig et al., 1999, van de Schootbrugge et al., 2000; Kujau et al., 2013)
Sequence stratigraphy	Available, data have been published (Reboulet et al., 1992)
Gamma Ray spectrometry	Available, data have been published (Martinez et al., 2013; 2015)
<b>Other requirements</b>	
GSSP indicated by a permanent marker	Yes, marked by a metal strip
Physical and logistical accessibility	Open access from public car park
Free access for research	Open access
Permanent protection of the site	Substantial public support by the “Espace Naturel Sensible” (ENS) of the Council of the Drôme Department

has been accepted for the Global Boundary Stratotype Section and Point (GSSP) of the Hauterivian stage for the following reasons (see requirements for a GSSP in Table 2). The thick section is well exposed and characterised by continuous sedimentation (the first slump is located 24 metres above the Valanginian/Hauterivian boundary) without facies changes; the limestone/marl alternations are favourable for long range correlations; macrofossils (mainly ammonoids) and microfossils (mainly nannofloras) are abundant and well preserved; magnetostratigraphy (weak signal), chemostratigraphy, sequence stratigraphy and gamma ray spectrometry records have been compiled; there is already a permanent protection of the site as it belongs to an “Espace Naturel Sensible” (ENS) of the Drôme Department; a reception area has been developed allowing a free and permanent access of the site, and of course to put a permanent marker for the GSSP.

The base of the Hauterivian is defined at the base of bed number 189. This level coincides with the first occurrence (FO) of the ammonite genus *Acanthodiscus* which marks the base of the *A. radiatus* Ammonite Zone. At La Charce, the nannofossil event that best approximates the Valanginian/Hauterivian boundary is the last occurrence (LO) of *Eiffelithus windii* (bed number 213). Several other ammonite and calcareous nannofossil events are of inter-regional correlation value and provide valuable secondary markers:

Bed 217	FO of <i>Diloma galiciense</i> (calcareous nannofossil)
Bed 214	FO of <i>Saynella mucronata</i> (ammonite)
<b>Bed 213</b>	<b>LO of <i>Eiffelithus windii</i> (calcareous nannofossil)</b>
	LO of <i>Tribrachiatus</i> sp. (calcareous nannofossil)
Bed 197	FO of <i>Leopoldia leopoldina</i> (ammonite)
Bed 194	FO of <i>Spitidiscus</i> (gr. <i>lorioli-meneghini</i> ) (ammonite)
Bed 193	FO of <i>Breistrofferella castellanensis</i> (ammonite)
Bed 190	FO of <i>Breistrofferella varapensis</i> (ammonite)
	FO of <i>Staurolithites mitcheneri</i> (calcareous nannofossil)
<b>Bed 189</b>	<b>FO of <i>Acanthodiscus rebouli</i> (ammonite) [base of Hauterivian]</b>
Bed 189	FO of <i>Teschenites flucticulus</i> (ammonite)
	FO of <i>Teschenites pachydicramus</i> (ammonite)
Bed 186	LO of <i>Teschenites callidiscus</i> (ammonite)

Among inorganic markers, magnetostratigraphy is most useful. The top of Chron M10Nn.3n coincides with the base of the Hauterivian and may successfully serve as an interregional correlation event. Carbon isotopes from carbonate bulk rock samples show a plateau of around 1.3‰ across the boundary. The main geochemical breaks occur at the base and top of a marly interval (bed numbers 197-203) which lies about 8 m above the boundary.

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**Peter F. Rawson** is an Emeritus Professor at University College London and an Honorary Professor in the University of Hull. His research is focused on Late Jurassic to Early Cretaceous global biogeography, palaeogeography, sea levels and climate, and on early Cretaceous ammonite faunas from the Boreal Realm and South America (Argentina).



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## Appendix 1

Hauterivian Working group as at 2017-18

B. Aguirre-Urreta (Argentina), P. Alsen (Denmark), E. Baraboshkin (Russia), P. Bown (UK), L. Bulot (France), E. Erba (Italy), S. Gardin (France), M. Kakabadze (Georgia), S. Kelly (UK), J. Klein (Netherlands), M. Martinez (France), J. Mutterlose (Germany), I. Premoli-Silva (Italy), P. Rawson (UK) and S. Reboulet (France).

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## Appendix 2 Taxonomic index

Taxa are listed in alphabetical order.

### Dinoflagellates

*Muderongia staurota* Sarjeant 1966

### Calcareous nannofossils

*Assipetra infracretacea* (Thierstein, 1973) Roth, 1973  
*Axoporphadus* Wind & Wise, 1976  
*Braarudosphaera discula* (Bramlette & Riedel, 1969)  
*Biscutum* Black, in Black & Barnes, 1959  
*Cyclagelosphaera brezae* Applegate & Bergen 1988  
*Calcicalathina praeoblongata* Aguado in Aguado et al., 2000  
*Calcicalathina oblongata* (Worsley, 1971) Thierstein, 1971  
*Chiastozygus tenuis* Black, 1971  
*Conusphaera mexicana mexicana* Trejo, 1969  
*Cretarhabdus* Bramlette & Martini, 1964  
*Cretarhabdus conicus* Bramlette & Martini, 1964  
*Cretarhabdus surirellus* (Deflandre and Fert 1954) Reinhardt, 1970  
*Cruciellipsis cuvillieri* (Manivit, 1966) Thierstein, 1971  
*Cyclagelosphaera margerelii* Noël, 1965  
*Diazomatolithus lehmannii* Noël, 1965  
*Diadorhombus rectus* Worsley, 1971  
*Discorhabdus rotatorius* (Bukry, 1969) Thierstein, 1971  
*Diloma galiciense* Bergen, 1994  
*Diloma* Wind & Cepek 1979  
*Eiffellithus striatus* (Black, 1971a) Applegate & Bergen, 1988  
*Eiffellithus windii* Applegate and Bergen, 1988  
*Ethmorhabdus gallicus* Noël, 1965  
*Haqius circumradiatus* (Stover, 1966) Roth, 1978  
*Haqius ellipticus* (Grün in Grün & Allemann, 1975) Bown 1992 emend. Bown 2005  
*Lithraphidites carniolensis* Deflandre, 1963  
*Lithraphidites bollii* (Thierstein, 1971) Thierstein, 1973  
*Manivitella pemmatoidea* (Deflandre in Manivit, 1965) Thierstein, 1971  
*Micrantholithus hoschulzii* (Rheinhard, 1966) Thierstein, 1971  
*Micrantholithus obtusus* Stradner, 1963  
*Micrantholithus* Deflandre, 1950  
*Markalius vetulus* Bergen, 1994  
*Manivitella pemmatoidea* (Deflandre in Manivit, 1965) Thierstein, 1971  
*Microstaurus quadratus* Black, 1971  
*Microstaurus chiastius* (Worsley, 1971) Grün in Grün & Allemann 1975 emend. Bralower et al. 1989

*Nannoconus bucheri* Brönnimann, 1955  
*Nannoconus circularis* Deres & Achéritéguy, 1980  
*Nannoconus cornuta* Deres & Achéritéguy, 1980  
*Nannoconus globulus* Brönnimann, 1955  
*Nannoconus inornatus* Rutledge & Bown, 1996  
*Nannoconus kamptneri* Brönnimann, 1955  
*Nodosella silvaradion* (Filewicz et al. in Wise & Wind, 1977) Perch-Nielsen, 1984 = *Stradnerlithus silvaradius* (Filewicz et al. in Wise & Wind, 1977) Rahman & Roth, 1991  
*Nannoconus steinmannii* Kamptner, 1931  
*Nannoconus truittii* Brönnimann, 1955  
*Nannoconus wassallii* Brönnimann, 1955  
*Owenia partitum* (Varol in Al-Rifa'iy et al., 1990) Bown in Kennedy et al., 2000  
*Percivalia fenestrata* (Worsley, 1971) Wise, 1983  
*Perissocyclus* Black, 1971a  
*Pickelhaube furtiva* (Roth, 1983) Applegate et al. in Covington & Wise, 1987  
*Percivalia bullata* Bergen, 1994  
*Retecapsa angustiforata* Black, 1971  
*Rhagodiscus asper* (Stradner, 1963) Reinhardt, 1967  
*Rhagodiscus* Reinhardt, 1967.  
*Rhagodiscus dekaenelii* Bergen, 1994  
*Rotelapillus laffittei* Noël, 1973  
*Rhagodiscus infinitus* (Worsley, 1971) Applegate et al. in Covington & Wise, 1987  
*Rucinolithus pinnatus* Bergen, 1994  
*Sollasites* Black, 1967  
*Sollasites horticus* (Stradner et al. in Stradner & Adamiker, 1966) Cepek & Hay, 1969  
*Speetonia colligata* Black, 1971a  
*Staurolithites* Caratini, 1963  
*Staurolithites angustus* (Stover, 1966) Crux, 1991  
*Staurolithites mitcheneri* (Applegate & Bergen, 1988) Rutledge & Bown, 1998  
*Staurolithites imbricatus* (Gartner, 1968) Burnett, 1997  
*Staurolithites crux* (Deflandre & Fert, 1954) Caratini, 1963  
*Staurolithites mutterlosei* Crux, 1989  
*Staurolithites ellipticus* (Gartner, 1968) Lambert, 1987  
*Tegumentum stradneri* Thierstein in Roth & Thierstein, 1972  
*Tribrachiatum* Shamrai, 1963  
*Tubodiscus jurapelagicus* (Worsley, 1971) Roth, 1973  
*Tubodiscus verena* Thierstein, 1973  
*Watznaueria barnesiae* (Black, 1959) Perch-Nielsen, 1968  
*Zeugrhabdotus bicrescenticus* (Stover, 1966) Burnett in Gale et al., 1996  
*Zeugrhabdotus diplogrammus* (Deflandre in Deflandre & Fert, 1954) Burnett in Gale et al., 1996  
*Zygodiscus elegans* Gartner, 1968  
*Zeugrhabdotus embergeri* (Noël, 1958) Perch-Nielsen, 1984  
*Zeugrhabdotus erectus* (Deflandre in Deflandre and Fert, 1954) Reinhardt, 1965  
*Z. pseudoangustus* Bralower, Applegate & Wise, 1987  
*Zeugrhabdotus scutula* (Bergen, 1994) Rutledge & Bown, 1996  
*Zeugrhabdotus trivectis* Bergen, 1994  
*Zeugrhabdotus xenotus* (Stover, 1966) Burnett in Gale et al., 1996

*Foraminifera**Favusella hoterivica* (Subbotina, 1953)*Ostracods**Protocythere triplicata* (Roemer, 1841)*Ammonites**Acanthodiscus* Uhlig, 1905*Acanthodiscus ottemeri* (Neumayr & Uhlig, 1881)*Acanthodiscus radiatus* (Bruguères, 1789)*Acanthodiscus rebouli* Kilian, 1915*Acanthodiscus vaceki* (Neumayr & Uhlig, 1881)*Acantholissonia* Leanza, 1972*Bochianites* Lory, 1898*Bochianites neocomiensis* (d'Orbigny, 1842)*Breistrofferella* Thieuloy, 1971*Breistrofferella castellanensis* (d'Orbigny, 1840)*Breistrofferella varappensis* (Baumberger, 1906)*Chacantuceras* Aguirre-Urreta & Rawson, 1999*Crioceratites* Lèveillé, 1837*Crioceratites loryi* (Sarkar, 1955)*Crioceratites nolani* (Kilian, 1910)*Criosarasinella* Thieuloy, 1977*Criosarasinella furcillata* Thieuloy, 1977*Distoloceras* Hyatt in Zittel, 1900*Eleniceras* Breskovski, 1967*Eleniceras paucinodum* (Neumayr & Uhlig, 1881)*Endemoceras* Thiermann, 1964*Endemoceras amblygonium* (Neumayr & Uhlig, 1881)*Endemoceras longinodum* (Neumayr & Uhlig, 1881)*Endemoceras noricum* (Roemer, 1836)*Himantoceras* Thieuloy, 1965*Himantoceras trinodosum* Thieuloy, 1965*Himantoceras* n. sp. 2; see Reboulet, 1996*Holcoptychites* Gerth, 1921*Holcoptychites neuquensis* (Douvillé, 1910)*Jeanthieuloyites* Cooper, 1981*Jeanthieuloyites quinquestriatus* (Besairie, 1936)*Karakaschiceras* Thieuloy, 1971*Leopoldia* Mayr-Emayr, 1887*Leopoldia desmoceroides* (Karakasch, 1905)*Leopoldia leopoldina* (d'Orbigny, 1840)*Lyticoceras* Hyatt, 1900*Lyticoceras nodosoplicatum* (Kilian & Reboul, 1915)*Lyticoceras* Suess, 1865*Lyticoceras subfimbriatum* (d'Orbigny, 1841)*Neocomites* Uhlig, 1905*Neocomites peregrinus* (Rawson & Kemper, 1978)*Neohoploceras* Spath, 1939*Neolissoceras* Spath, 1923*Neolissoceras grasianum* (d'Orbigny, 1841)*Olcostephanus* Neumayr, 1875*Olcostephanus densicostatus* (Wegner, 1909)*Olcostephanus nicklesi* Wiedmann & Dieni, 1968*Olcostephanus sayni* Kilian, 1895*Oosterella* Kilian, 1911*Oosterella cultrata* (d'Orbigny, 1841)*Oosterella cultrataeformis* (Uhlig, 1882)*Oosterella undulata* Reboulet, 1996*Pavlovites* Ivanov & Aristov, 1969*Pavlovites polyptychoides* (Arisotov, 1967)*Plesiospididiscus* Breistroffer, 1947*Plesiospididiscus ligatus* (d'Orbigny, 1841)*Phylloceras* (*Hypophylloceras*) Salfeld, 1924*Phylloceras* (*Hypophylloceras*) *tethys* (d'Orbigny, 1841)*Phyllopachyceras* Spath, 1925*Phyllopachyceras infundibulum* (d'Orbigny, 1841)*Phyllopachyceras winkleri* (Uhlig, 1882)*Rodighierites* Company, 1987*Saynella* Kilian, 1910*Saynella mucronata* (Baumberger, 1906)*Saynoceras* Munier-Chalmas, 1894*Saynoceras verrucosum* (d'Orbigny, 1841)*Spitidiscus* Kilian, 1910*Spitidiscus lorioli* (Kilian, 1910)*Spitidiscus meneghinii* (De Zigno in Rodighiero, 1919)*Spitidiscus nodosus* Mandov, 1976*Spitidiscus rotula* (Sowerby, 1827)*Teschenites* Thieuloy, 1971*Teschenites callidiscus* (Thieuloy, 1971) included in *Neocomites* (*Teschenites*) by Klein (2005, p. 315)*Teschenites castellanensisformis* (Bulot, Thieuloy, Arnaud & Delanoy, 1995) included in *Neocomites* (*Teschenites*) by Klein (2005, p. 316)*Teschenites flucticulus* (Thieuloy, 1977) included in *Neocomites* (*Teschenites*) by Klein (2005, p. 317)*Teschenites pachydicranus* (Thieuloy, 1977) included in *Neocomites* (*Teschenites*) by Klein (2005, p. 318)*Teschenites subflucticulus* Reboulet, 1996 included in *Neocomites* (*Teschenites*) by Klein (2005, p. 320)*Teschenites subpachydicranus* Reboulet, 1996 included in *Neocomites* (*Teschenites*) by Klein (2005, p. 320)*Brachiopods**Pygope* Link, 1830