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 Subcommission 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 no 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 (southeast France). The definition arises from recommendations of the Hauterivian Working Group of the Subcommission 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 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 Subcommission on Cretaceous Stratigraphy was established in 1993, prior to the 2nd 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 organized 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 nannofossils, 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 *Endemoceras 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 *Neoconites 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).
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* ASZ), 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% CaCO₃) 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 nanofossils 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 Charse, 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 2. View of the Espace Naturel Sensible (ENS) site of the La Charse 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).
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, 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. Breistroferella is well represented in pelagic successions (Bulot, 1993; Rebulot, 1996). Rebulot (1996, 2002) suggested that it could be the microconch of Acanthodiscus. In the Mediterranean area, the palaeobiogeographic distribution of Breistroferella 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, Fözý 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 flucticus in bed 189. This event is truly evolutionary since the last occurrences (LOs) of the ancestral species Teschenites subpachydicranus and Teschenites subflucticus have been observed in the uppermost Valanginian (bed 188). It might provide a useful marker in deep basinal 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. flucticus was used to define the base of the Hauterivian stage. Teschenites callidiscus, a short ranging index species of the highest Valangian ASZ, last occurs in bed 186, about 2.5 metres below the boundary.

Additional secondary markers include Jeantieuloyites quinquestriatus, Spitidiscus gr. loriolimeneghini and Oosterella ondulata. Jeantieuloyites and Spitidiscus represent a phylogenetic lineage in the early history of the Spitiidiscinae. 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 Valangian/Hauterivian boundary at La Charce. The early Spitidiscus are still in need of detailed taxonomic revision since some authors refer them to Jeantieuloyities (Avram, 1995; Vašiček, 2002; Fözý and Janssen, 2009). Nevertheless, Spitidiscus lorioli, Spitidiscus meneghini, Spitidiscus nodosus and Spitidiscus rossfeldensis form a natural group that shows intermediate characters between the true Valangian Jeantieuloyites and true Spitidiscus of the C. ioryi AZ. According to Vašiček (1995), Rebulot (1996) and Busnardo et al. (2003), when Acanthodiscus (or Breistroferella) 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 ondulata 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 Olocostephanus denicostatus, Phyllopachyceras winkleri, Phylloceras (Hypophylloceras) tethys, Neolissoceras grasianum, Lytoceras subfimbriatum and Bochianites neocomiensis that already appeared in the Valangian. 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 Valangian/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 Crucibiscutum sulliana, Spectruma colligata and Calcicallathina 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, Corollithion 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 Valangian/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 AZ by the FO of Eiffellithus striatus in the late Valangian (also see Bralower et al., 1995) and the top of the CC4a AZ by the FO of Lithurahdites 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 verenea has often been recorded as a latest Valangian 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 verenea has not been observed in expanded sections in the Boreal Realm covering the Valangian/Hauterivian boundary interval.

The complete and expanded Valangian–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 Valangian/Hauterivian boundary interval, they become more abundant and continuous from the C. ioryi AZ onward. Tubodiscus verenea and Tubodiscus jurapalicus occur sporadically up to the upper Hauterivian P. ligatus AZ. The FO of Staurolichenites mitcheneri was observed near the base of the A. radiatus AZ (bed 190), a form extremely rare in the Boreal Realm. Tribrachiatus 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 Tribrachiatus in Valangian 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 galliciense 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.
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 nanofossil 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 Bettengaet, 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 (Cocchi and Premoli Silva, 1994; Cecca et al., 1994; Rosaszyński and Caron, 1995). Moreover, so far they have not been recorded before the Barremian in the Boreal Realm except for *Favusella hotevrica* 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 Bettenstædt, 1962). Here the FO of the ostracod *Protoxythera tripli cata* has been recorded by many authors: this event occurs in the *Astieria* beds (*Oleostephanus 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. tripli cata* seems to equate to the base of the *C. furcillata* AZ (Donze, 1976; Bulot, 1992, 1995). Consequently the FO of *P. tripli cata* 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 *Eudemoceras ambygonium* 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-Urieta 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 (δ¹³C) 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; Kuja 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 (*Oleostephanus nicklesi* ASZ and *C. furcillata* AZ) the δ¹³C 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 δ¹³C data range from 0 to +1‰ (McArthur et al., 2007; Bodin et al., 2015). A considerable variation of δ¹³C values of up to 1.5‰ has been recorded from different specimens of co-occurring belemnite rostra (e.g., Wierzboski and Joachimski, 2009; Malkoc and Mutterlose, 2010), probably reflecting metabolic effects on the incorporation of carbon. The paleoenvironmental meaning of the δ¹³C signal from belemnites is thus still under discussion.

### Strontium Isotope Stratigraphy

High-resolution, belemnite based Sr-isotope (87Sr/86Sr) 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 δ¹³C 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 ±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 magnesium 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 Reboulet 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 chro-nostratigraphical 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, 91ppm 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$_3$ concentration and selected Rock-Eval parameters for the marly interbeds close to the Valanginian/Hauterivian boundary in La Charce

<table>
<thead>
<tr>
<th>Sample</th>
<th>Bed number</th>
<th>Bed number</th>
<th>Elevation (m)</th>
<th>CaCO$_3$ (%)</th>
<th>TOC (%)</th>
<th>Tmax (°C)</th>
<th>S2</th>
<th>IH</th>
<th>mg HC/g rock</th>
<th>mg HC/g TOC</th>
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<td>LCH 275AS</td>
<td>275A</td>
<td>221</td>
<td>40.0</td>
<td>59.9</td>
<td>0.41</td>
<td>429</td>
<td>0.59</td>
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<td>0.72</td>
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<td>LCH 260CS</td>
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<td>63.5</td>
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<tr>
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<td>16.0</td>
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<td>14.1</td>
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<tr>
<td>LCH 249/250</td>
<td>249</td>
<td>188</td>
<td>7.5</td>
<td>52.0</td>
<td>0.52</td>
<td>430</td>
<td>0.92</td>
<td>177</td>
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<tr>
<td>LCH 248/249</td>
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<td>187</td>
<td>6.8</td>
<td>72.4</td>
<td>0.34</td>
<td>431</td>
<td>0.58</td>
<td>171</td>
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<tr>
<td>LCH 247/248</td>
<td>247</td>
<td>186</td>
<td>6.0</td>
<td>77.5</td>
<td>0.33</td>
<td>434</td>
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<td>185</td>
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<td>54.6</td>
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<td>184</td>
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<td>57.6</td>
<td>1.17</td>
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<td>244</td>
<td>183</td>
<td>2.5</td>
<td>62.2</td>
<td>0.45</td>
<td>430</td>
<td>0.78</td>
<td>173</td>
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<td>243</td>
<td>182</td>
<td>1.0</td>
<td>64.3</td>
<td>0.22</td>
<td>431</td>
<td>0.45</td>
<td>205</td>
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</table>
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
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) *O. densicostatus* sp. AZ. It replaces the ill defined *E. pauninodum* 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 *Olostephanus* in the Lower Saxony Basin has its counterpart in the lower Hauterivian of 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. vaccki*, *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. fuscillata* AZ.

Sr-isotopy (87Sr/86Sr) 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. fuscillata* 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 isotopic 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 neoconchitids such as *Acantholissonia*, *Karakaschiceras*, *Neohoplaceras*, *Rodighieroites* 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 *Holocystites neuquensis* AZ is correlated with the base of the *A. radiatus* AZ for two main reasons: (1) early *Holocystites* appear very close to early spitzidiscus 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).

Conclusions

The La Charce section (Drôme Department, southeastern France)
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 *Eiffellithus 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 *Diloma galiciense* (calcareous nannofossil) |
| Bed 214 | FO of *Saynella mucronata* (ammonite) |
| Bed 213 | LO of *Eiffellithus windii* (calcareous nannofossil) |
| Bed 197 | FO of *Leopoldia leopoldina* (ammonite) |
| Bed 214 | FO of *Spitidiscus* (gr. *loriol-omeneghinii*) (ammonite) |
| Bed 213 | FO of *Breistrofferella castellanensis* (ammonite) |
| Bed 190 | FO of *Breistrofferella varapensis* (ammonite) |
| Bed 189 | FO of *Staurolithites mitcheneri* (calcareous nannofossil) |
| Bed 213 | FO of *Teschenites callidiscus* (ammonite) |
| Bed 186 | FO of *Teschenites pachydicranus* (ammonite) |
| Bed 186 | FO of *Teschenites callidiscus* (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.

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

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

Preparation and conservation of the GSSP site has been supported by the CGL2004-0694/BTE (MEC-CSIC) Project and grants from the 2006 and 2007 Geocorservation Projects, respectively coordinated at the Madrid and Torino universities. We are very grateful to the Council of the Drôme Department for financial support/investment. Sincere thanks are also extended to the municipality of La Chance and other numerous partners for their help and contribution. We thank members of the Hauterivian Working Group (see Appendix 1) for their suggestions and comments. We are particularly grateful to B. Aguirre-Urreta, E. Baraboshkin, N. Janssen, I. Jarvis, M. Kakabadze, S. Kelly, J. Klein, L. O’Dogherti, M. R. Petrizzo and I. Premoli-Silva for their contributions and comments on earlier versions of the proposal. We also acknowledge support by the International Subcommission on Cretaceous Stratigraphy (http://cretaceous.stratigraphy.org/).

References


on the 1st International Workshop of the IUGS Lower Cretaceous Ammonite Working Group, the “Kilian Group” (Lyon, 11 July 2002).


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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), P. Rawson (UK) and S. Reboulet (France).

Appendix 2 Taxonomic index

Taxa are listed in alphabetical order.

Dinoflagellates
Muderongia staurota Sarjeant 1966

Calcareaous nannofossils
Assipetra infracretacea (Thierstein, 1973) Roth, 1973
Axoparhabdus Wind & Wise, 1976
Braarudosphaera discisa (Brånde & Riedel, 1969)
Biscutum Black, in Black & Barnes, 1959
Cyclagelosphaera margerelii Noël, 1965
Cyclagelosphaera brezae Applegate & Bergen, 1988
Diadorhombus rectus (Wind & Wise, 1977) Roth & Thierstein, 1972
Discorhabdus rotatorius (Bukry, 1969) Thierstein, 1971
Diloma galiciense Bergen, 1994
Diloma Wind & Cepek 1979
Effelithus striatus (Black, 1971a) Applegate & Bergen, 1988
Effelithus windii Applegate and Bergen, 1988
Ethmorhabdus gallicus Noël, 1965
Haquias circumradiatus (Stover, 1966) Roth, 1978
Lithraphidites carniolensis Deflandre, 1963
Lithraphidites bolii (Thierstein, 1971) Thierstein, 1973
Manivitella pemmatoida (Deflandre in Manivit, 1965) Thierstein, 1971
Micrantholithus hochsulzii (Rheinhard, 1966) Thierstein, 1971
Micrantholithus obtusus Stradner, 1963
Micrantholithus Deflandre, 1950
Markalis vetulus Bergen, 1994
Manivitella pemmatoida (Deflandre in Manivit, 1965) Thierstein, 1971
Microstaurus quadriatus Black, 1971

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
Nannoconus Steinmanni Kamptner, 1931
Nannoconus truitii Brönnimann, 1955
Nannoconus wassallii Brönnimann, 1955
Owelia partitum (Varol in Al-Rifaiy et al., 1990) Bown in Kennedy et al., 2000
Perissocyclus Black, 1971a
Picklehaube 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 reinhardtii, 1967
Rhagodiscus dekaenelii Bergen, 1994
Rotelapillus laffittei Noël, 1973
Rhagodiscus infratus (Worsley, 1971) Applegate et al. in Covington & Wise, 1987
Rucinolithus pinnatus Bergen, 1994
Sollasites Black, 1967
Sollasites horbitis (Stradner et al. in Stradner & Adamik, 1966) Cepek & Hay, 1969
Speetonia colligata Black, 1971a
Staurolithites Caratini, 1963
Staurolithites angustus (Stover, 1966) Crux, 1991
Staurolithites imbricatus (Gartner, 1968) Burnett, 1997
Staurolithites crux (Deflandre & Fert, 1954) Caratini, 1963
Staurolithites matterlosit Crux, 1989
Staurolithes ellipticus (Gartner, 1968) Lambert, 1987
Tegumentum stradneri Thierstein in Roth & Thierstein, 1972
Tribachiatius Shamrai, 1963
Tubodiscus jurapelagicus (Worsley, 1971) Roth, 1973
Tubodiscus verenae Thierstein, 1973
Watsonia barnesiae (Black, 1959) Perch-Nielsen, 1968
Zeugrhabdotus birescenticulatus (Stover, 1966) Burnett in Gale et al., 1996
Zeugrhabdotus diplogramatus (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 Ibrahim, Applegate & Wise, 1987
Zeugrhabdotus scutula (Bergen, 1994) Rutledge & Bown, 1996
Zeugrhabdotus trivets Bergen, 1994
Zeugrhabdotus xenotus (Stover, 1966) Burnett in Gale et al., 1996
Foraminifera
Favusella hétérovica (Subbotina, 1953)

Ostracods
Protocythere triplicata (Roemer, 1841)

Ammonites
Acanthodiscus Uhlig, 1905
Acanthodiscus ottemeri (Neumayr & Uhlig, 1881)
Acanthodiscus radiatus (Bruguières, 1789)
Acanthodiscus rebouli Kilian, 1915
Acanthodiscus ruceki (Neumayr & Uhlig, 1881)
Acantholissonia Leanza, 1972
Bochianites Lory, 1898
Bochianites neocomiosis (d’Orbigny, 1842)
Breistrofferella Thieuloy, 1971
Breistrofferella castellanensis (d’Orbigny, 1840)
Breistrofferella varappensis (Baumberger, 1906)
Chacantuceras Aguirre-Urreta & Rawson, 1999
Crioceratites Léveillé, 1837
Crioceratites loryi (Sarkar, 1955)
Crioceratites molani (Kilian, 1910)
Criotrassina Thieuloy, 1977
Criotrassina furticulata Thieuloy, 1977
Distoloceras Hyatt in Zittel, 1900
Eleniceras Breskovski, 1967
Eleniceras paucinodum (Neumayr & Uhlig, 1881)
Endemoceras Thierrmann, 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 nequensis (Douvillé, 1910)
Jehnbianeloites Cooper, 1981
Jehnbianeloites quinquestriata (Besairie, 1936)
Karakaschiceras Thieuloy, 1971
Leopoldia Mayer-Emayr, 1887
Leopoldia desmoceroides (Karakasch, 1905)
Leopoldia leopoldina (d’Orbigny, 1840)
Lyticoceras Hyatt, 1900
Lyticoceras nodosostrictum (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 graciamum (d’Orbigny, 1841)
Ocostephanus Neumayr, 1875
Ocostephanus densicostatus (Wegner, 1909)
Ocostephanus nicklesi Wiedmann & Dienes, 1968
Ocostephanus Sayn Kilian, 1895
Oosterella Kilian, 1911
Oosterella cultrata (d’Orbigny, 1841)
Oosterella cultrata formos (Uhlig, 1882)
Oosterella ondulata Reboulet, 1996
Pavlovites Ivanov & Aristov, 1969
Pavlovites polyptychoides (Arisotov, 1967)
Plesiospidiscus Breistroffer, 1947
Plesiospidiscus 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)
Rodighieroites Company, 1987
Saynella Kilian, 1910
Saynella macronata (Baumberger, 1906)
Saynoloceras Munier-Chalmas, 1894
Saynoloceras 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 pachydracans (Thieuloy, 1977) included in Neocomites (Teschenites) by Klein (2005, p. 318)
Teschenites subflucticus Reboulet, 1996 included in Neocomites (Teschenites) by Klein (2005, p. 320)
Teschenites subpachydracans Reboulet, 1996 included in Neocomites (Teschenites) by Klein (2005, p. 320)

Brachiopods
Pygope Link, 1830