Abrupt planktic foraminiferal turnover across the Niveau Kilian at Col de Pré-Guittard (Vocontian Basin, southeast France): new criteria for defining the Aptian/Albian boundary

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With 4 figures, 4 plates and 2 tables

Abstract. A detailed and quantitative study of foraminiferal assemblages across the Niveau Kilian in the Col de Pré-Guittard section (Vocontian Basin, southeast France) ably documents the planktic foraminiferal turnover across the Aptian–Albian boundary interval. The latest Aptian assemblage is dominated by few long-ranging *Hedbergella* and large-sized *Paraticinella* that completely disappear near the base of the Niveau Kilian organic-rich level. Planktic foraminiferal assemblages from across the Niveau Kilian to the top of the studied section are composed of minute, but very distinctive smooth-surfaced species of *Microhedbergella miniglobularis* and *Mi. renilaevis*. The appearance of *Mi. renilaevis* in the middle part of the Niveau Kilian represents a major step in the evolution and diversification of the Albian planktic fauna. The lowest occurrence of this taxon is recorded immediately above the extinction level of the Aptian hedbergellids and corresponds with a dramatic decrease in the number of planktic and benthic foraminifera specimens, with a 1‰ negative $\delta^{13}C$ excursion in bulk carbonate, and evidence for regional rise in sea-surface temperature. Our careful study of the species composition permits refinement of the previous biozonation by using the appearance datum of *Mi. renilaevis* as a zonal boundary event. Changes include redefinition of the top of the *Microhedbergella miniglobularis* Zone and designation of a new *Microhedbergella renilaevis* Zone. The same sequence of events was reported from several deep-sea sites in the Atlantic and Indian Oceans. Therefore, documentation of the planktic foraminiferal turnover, combined with the carbon-isotope stratigraphy in the Col de Pré-Guittard section, provide new criteria for defining the Global Boundary Stratotype Section and Point for the base of the Albian Stage in a stratigraphically complete succession.

Key words. Aptian/Albian boundary, planktic foraminifera, biostratigraphy, species turnover, absolute abundance, chemostratigraphy

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1. Introduction

Apart from the terminal Cretaceous extinction, the planktic foraminiferal turnover across the Aptian/Albian boundary interval is the most dramatic event in the Cretaceous evolutionary history of planktic foraminifera, with a change from large-sized and heavily ornamented species in the latest Aptian to small-sized, globigeriniform specimens in the earliest Albian (e. g., Bréhéret et al. 1986, Leckie 1989, Tornaghi et al. 1989, Premoli Silva and Sliter 1999, Kennedy et al. 2000, Leckie et al. 2002). However, a detailed and reliable documentation of changes in species composition across the boundary has long been hindered by difficulties in the identification of small-sized species, mainly because of (1) poor preservation of the wall texture due to diagenetic alteration (2) unconformities in some sections (e. g., Amedro 1992, Erba et al. 1999, Huber and Leckie 2011) or (3) the effects of pronounced carbonate dissolution in the basal Albian (Tornaghi et al. 1989, Premoli Silva and Sliter 1999).

The recent study by Huber and Leckie (2011) of exceptionally well-preserved foraminifera from several DSDP and ODP deep-sea sections in the Atlantic and Indian Oceans represents a major advance in understanding this species turnover since it resolves the most important taxonomic and biostratigraphic discrepancies and improves documentation of the magnitude and rate of the species extinction and evolution across the Aptian–Albian boundary interval. Moreover, the documented changes in shell structure and ornamentation in well-preserved specimens (Huber and Leckie 2011) has provided the key to consistent identification of species in this time interval, hence enabling evaluation of stratigraphic completeness in sedimentary successions yielding small-sized planktic foraminifera difficult to identify at species level, particularly if affected by a moderate to severe diagenetic overprint.

The objective of this paper is to present a detailed and quantitative study of the planktic foraminiferal assemblages across the Niveau Kilian in the Col de Pré-Guittard section located in the Vocontian Basin (southeast France) (Fig. 1). This section was considered as a candidate Global Boundary Stratotype Section and Point (GSSP) for the base of the Albian Stage at the Second International Symposium on Cretaceous Stage Boundaries held in Brussels in September 1995 (Hart et al. 1996). The first appearance of the ammonite *Leymeriella tardefurcata* at the base of the Niveau Paquier black shale (Fig. 2) was proposed as the primary defining criterion. However, the Col de Pré-Guittard section was shown to be unsuitable as candidate GSSP by Kennedy et al. (2000), because of the presence of a hiatus at the base of the Niveau Paquier, and the section at Le Pillart, Tartonne (Alpes-de-Haute-Provence) was regarded as most suitable for placing the base of the Albian Stage. This proposal was not accepted by the International Subcommission on Cretaceous Stratigraphy because no corresponding microfossil or chemostratigraphic events were found associated with the *L. tardefurcata* datum, and the geo-
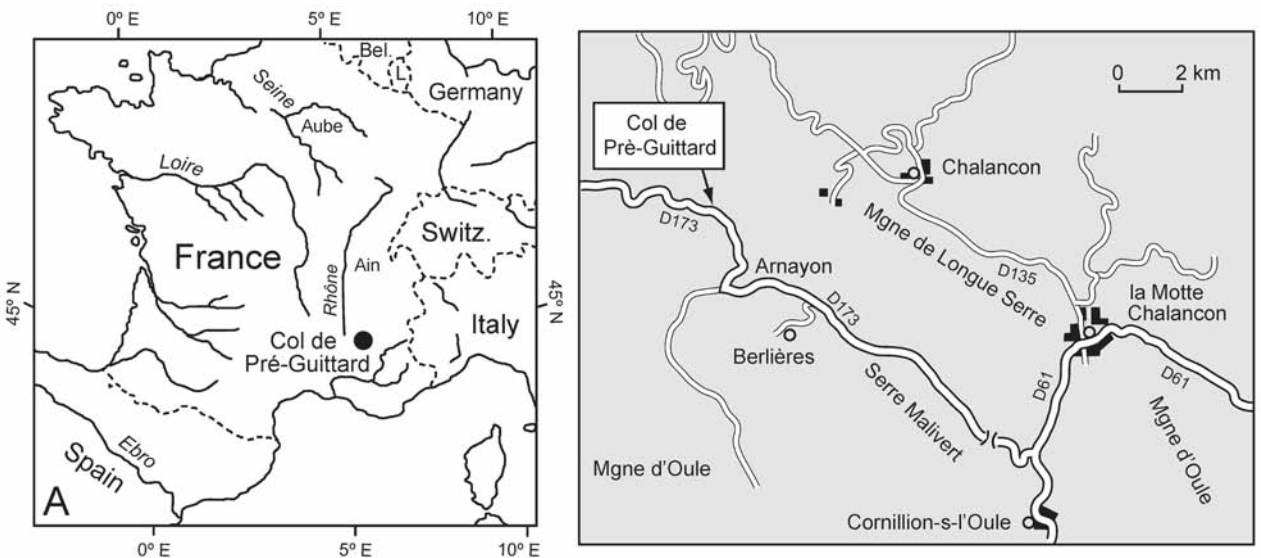

Fig. 1. Maps to show position of the Col de Pré-Guittard section (Vocontian Basin, southeast France; modified from Kennedy et al. 2000).

graphic distribution of *L. tardefurcata* was considered to be too limited and not well correlated with other sections outside southeast France (Premoli Silva 2010, see ISCS Annual Report 2010).

The problem of globally defining the Aptian/Albian boundary using ammonites that are strongly subject to provincialism has been discussed several times in the literature (e. g., Hart et al. 1996, Kennedy et al. 2000, Owen 2002). Moreover, the boundary has been either lowered by proposing as a primary criterion the first appearance of the genus *Hypacanthoplites* (Casey 1999, Moullade et al. 2011) or raised by using the appearance level of *Leymeriella tardefurcata* (Kennedy et al. 2000) or of *Lyelliceras lyelli* (Hancock 2001, Owen 2002). Some authors (Moullade 1966, 1974, Sigal 1977) have equated the Aptian/Albian boundary with the base of the *Leymeriella tardefurcata* Zone and, in the absence of significant planktic foraminifera appearances, have used as a boundary criterion the first occurrence of the easily identifiable benthic foraminiferan *Pleurostomella subnodosa*. Alternatively, the negative carbon-isotope excursion (1.5‰) recorded across the Niveau Paquier at L'Arboudeysse, about 10 km from Col de Pré-Guittard (Herrle 2002), has been proposed as a criterion to identify the Aptian/Albian boundary globally where uncertainties exist in the correlation of biostratigraphic marker species at regional and global scale and in different environments (Herrle et al. 2004). Therefore, an agreement on the most suitable primary defining criteria for the base of the Albian Stage is still lacking, probably because a section that fulfils most of the requirements for the definition of the GSSP (Remane et al. 1996) has not yet been proposed. Additional disagreements in placing the base of the Albian Stage may be summarized in a simple way as ranging from a "conservative approach" based solely on biostratigraphic criteria (e. g., Casey 1999, Owen 2002), returning to the original definition of the historical stratotypes as discussed and proposed by Moullade et al. (2011), to a "modern approach" that considers magnetic reversals and geochemical changes as more suitable for supra-regional to global correlation and the positioning of stage boundaries (e. g., Herrle et al. 2004, Gale et al. 2009).

In the Col de Pré-Guittard section, Caron (in Bréhéret et al. 1986 and Kennedy et al. 2000) reported major changes in the planktic foraminiferal assemblages beginning at 42 m below the Niveau Paquier and 11 m below the Niveau Kilian black shales. The observed changes included: 1) extinction of the late Aptian zonal biomarker *Paraticinella eubejaouaensis* (= *Ticinella*

bejaouaensis, see Premoli Silva et al. 2009); 2) a dramatic reduction in the size and diversity of hedbergellid planktic foraminifera; and 3) temporary disappearance of planktic foraminifera. At Col de Pré-Guittard, the stratigraphic interval immediately above the extinction level of *Pa. eubejaouaensis* was defined by "l'éclipse des *Ticinella*" (Caron in Bréhéret et al. 1986). This interval has historically been characterized by a depauperate, low-diversity assemblage and has been assigned to the *Hedbergella planispira* Zone (e. g., Sigal 1977, Tornaghi et al. 1989, Sliter 1989, Coccioni et al. 1990, Robaszynski and Caron 1995, Moullade et al. 2002) because of the strong morphological similarity between *Hedbergella planispira* (= *Muricohedbergella planispira*, see Huber and Leckie 2011) and the tiny early Albian hedbergellids (= *Microhedbergella*, see Huber and Leckie 2011). However, *Mu. planispira* possesses a test wall that is finely perforate and coarsely pustulose instead of the typical microperforate and generally smooth test wall of the small hedbergellids, and its lowermost range has been documented in the upper Albian (Moullade et al. 2002, Petrizzo and Huber 2006, Huber and Leckie 2011).

Huber and Leckie's (2011) SEM study of Caron's samples, which were collected at 5 m intervals at Col de Pré-Guittard, revealed the presence of the same new hedbergellid species described from the lowermost Albian at several deep-sea (DSDP/ODP) sites, with first appearances in the same relative stratigraphic order. These observations provided the impetus to recollect the Col de Pré-Guittard section at much higher resolution in order to evaluate the potential for using the planktic foraminiferal turnover, combined with carbon-isotope stratigraphy, to define the GSSP for the base of the Albian Stage.

2.   Locality and General Stratigraphy

The Col de Pré-Guittard lies in the northern part of the Vocontian Basin, southeast France, and is located 11 km north of the village of Rémuzat, Départment of Drôme (Lambert coordinates 863, 42; 3248, 95; Fig. 1). The exposures comprise extensive badland ravines and stream cuttings both above and below the D173 road, exposing over 170 m of the Marnes Bleues Formation of late Aptian to middle Albian age (Fig. 2). The lithostratigraphy of the Aptian to middle Albian succession and its correlation within the Vocontian Basin has been documented in great detail by Bréhéret
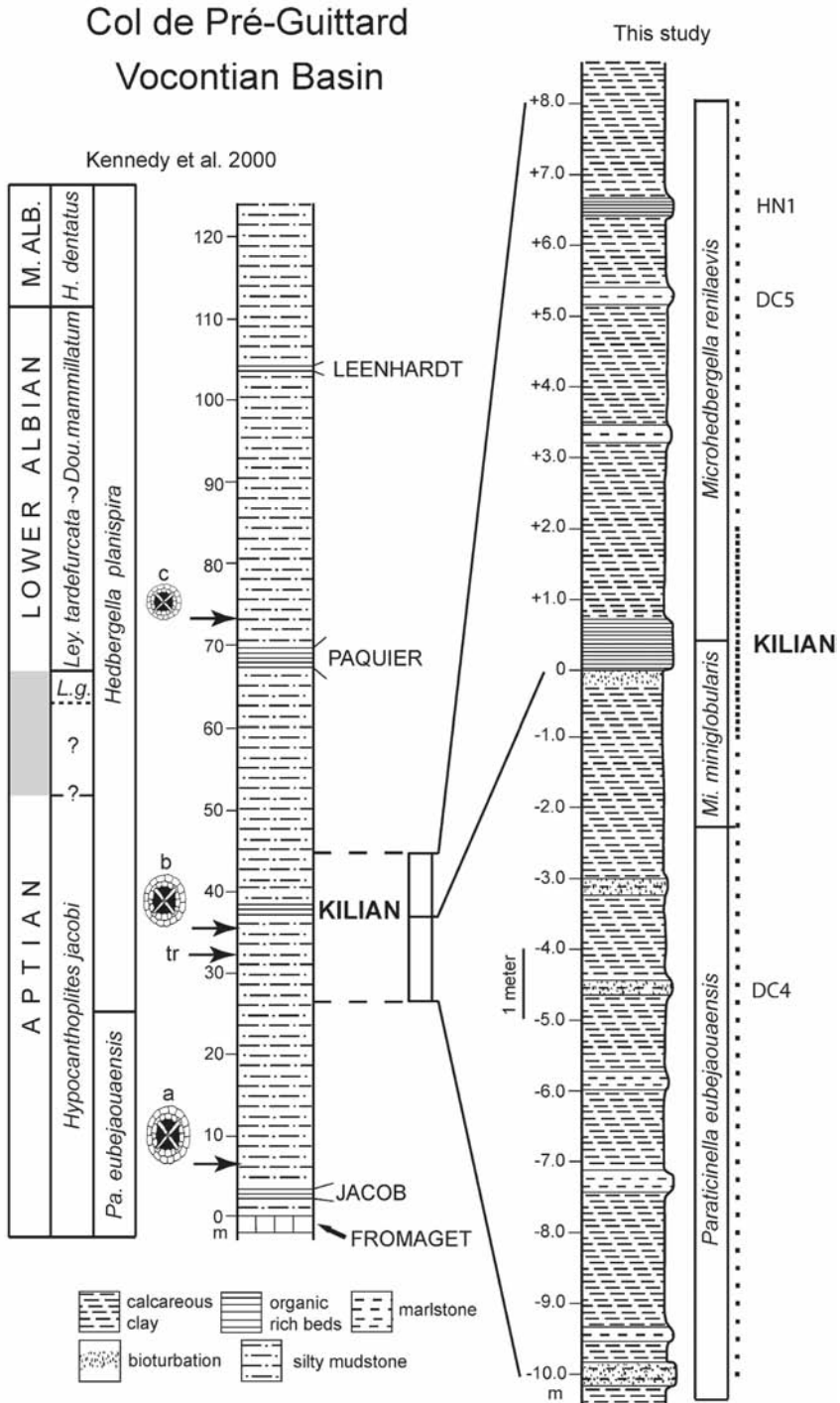
Fig. 2. Stratigraphy of part of the Marnes Bleues succession at Col de Pré-Guittard. The columns on the left are adapted from Kennedy et al. (2000) and show the ammonite, the planktic foraminifera zones and the main marker levels in the middle part of the succession. The zero datum is taken at the summit of the Fascieu Fromaget. Nannofossil datum levels follow Bown in Kennedy et al. (2000): a = *Praediscosphaera columnata* sub-circular, b = *P. columnata* near-circular, c = *P. columnata* circular; tr = *Helicolithus trabeculatus*. The column on the right shows the interval sampled and the planktic foraminifera biozonation according to the present study. The zero datum is at the base of the Niveau Kilian, and samples were taken at 10 or 20 cm intervals for 10 m beneath this, and 8 m above this level. The marker beds (DC4, DC5, Kilian, HN1) are taken from Bréhéret (1997). The background sediment is clay, but firmer marlstones (dashed lines) weather out from the surface. The upper part of these mudstones is commonly bioturbated. Organic-rich layers (e.g. Kilian and HN1) are marked by horizontal lines.

(1997) and the ammonite and planktic foraminifera distribution was described by Bréhéret et al. (1986). The biostratigraphy of Col de Pré-Guittard was further described by Kennedy et al. (2000), who documented nannofossils, planktic foraminifera, dinoflagellates and ammonites from the succession. The Col de Pré-Guittard section is one of the most complete, extensively exposed localities in the region, and is effectively a parastratotype for the middle part of the Marnes Bleues Formation (Bréhéret 1997).

The succession in the Marnes Bleues at Col de Pré-Guittard comprises calcareous clays and marls containing thin, locally developed black shales and calcareous cemented levels that are regionally continuous and serve as marker beds. At the base of the succession is the Faisceau Fromaget, a series of thin alternations of limestones and marls, the summit of which provides the zero datum in Fig. 2. The Niveau Jacob (2.5–4.0 m) is an organic-rich shale containing abundant aragonitic ammonites and plant fragments. The Niveau Kilian (38–39 m) is an inconspicuous, poorly fossiliferous, dark grey shale, whose base is conspicuously bioturbated. The most distinctive marker bed, the Niveau Paquier (68.5–70.0 m), comprises organic-rich paper shales with abundant ammonites including *Leymeriella tardefurcata* (Bréhéret et al. 1986, Kennedy et al. 2000). The Niveau Paquier and stratigraphically associated dark shales, including the Niveau Kilian, have been grouped together by some authors as recording the composite Oceanic Anoxic Event 1b (Bréhéret 1987, Arthur et al. 1990, Leckie et al. 2002). Both the Niveau Paquier and Niveau Kilian equivalent black-shale levels have been identified in north Atlantic deep-sea sections (e. g., Trabucho Alexandre et al. 2011, Huber et al. 2011).

2.1   Biostratigraphy

The ammonite biostratigraphy of Col de Pré-Guittard was described in detail by Kennedy et al. (2000). Because a very limited number of levels yielded ammonites, some zonal boundaries have to be inferred (Fig. 2). Faunas characteristic of the *Hypocanthoplites jacobi* Zone were collected in the Niveau Jacob and at the 50 m level between the Niveau Kilian and Niveau Paquier, but the upper limit of this zone was not located precisely at Col de Pré-Guittard. Taxa characteristic of the *L. tardefurcata* Zone were collected from the Niveau Paquier. However, at Tartonne, to the south (Fig. 1), the boundary between the *Leymeriella germanica* and *L. tardefurcata* Zones was identified immediately beneath the Niveau Paquier (Kennedy et al.

2000). The position of this boundary is therefore inferred at Col de Pré-Guittard. According to Kennedy et al. (2000), the ammonites from the Col de Pré-Guittard section do not provide complete documentation for defining the base of the Albian because either the appearance level of *L. tardefurcata*, or the disappearance level of *H. jacobi*, cannot be placed precisely (Fig. 2). However, the succession at the level of the Niveau Kilian described in this study falls within the upper part of the *H. jacobi* Zone of traditional usage.

The calcareous nannofossil biostratigraphy of the Col de Pré-Guittard section, documented by Bown (in Kennedy et al. 2000), did not reveal significant species turnover anywhere in the sequence. The most significant bioevent, which has been used by calcareous nannofossil workers as a proxy for the Aptian/Albian boundary, is the lowest occurrence of *Praediscosphaera columnata*, which is the nominal taxon for Zone NC8. Bown (in Kennedy et al. 2000) observed a morphologic transition in the evolution of this taxon from a sub-circular ancestral form in sample PG 2, sometimes identified as *Praediscosphaera spinosa*, to a near-circular (sample PG 8) and then a circular form in sample PG 17. In addition, the appearance of *Helicolithus trabeculatus*, recorded at 6.5 m below the Niveau Kilian (sample PG 7), corresponds to the observations made by Herrle and Mutterlose (2003) from the same section (Fig. 2).

2.2   Isotope stratigraphy

The carbon-isotope stratigraphy of the Aptian–Albian interval in the Vocontian Basin has been previously studied by Kennedy et al. (2000), Herrle (2002) and Gale et al. (1996, 2011). Herrle (2002) documented the high-resolution carbon-isotope stratigraphy of the Niveau Kilian at Col de Pré-Guittard and that of the Niveau Paquier at L'Arboudeysse, localities that are about 10 km apart. Both levels are associated with significant, short-lived negative excursions in $\delta^{13}C_{carb}$, of approximately 1‰ across the Niveau Kilian, and 1.5‰ across the Niveau Paquier. Accompanying negative excursions (~ 1.5‰) in $\delta^{18}O_{carb}$ also characterize both levels (Herrle et al. 2003).

3.   Sampling strategy and methods

From previous work, the foraminiferal events described herein were believed to fall approximately at the level of the Niveau Kilian (see for example Caron, in Bréhéret et al. 1986 and Kennedy et al. 2000). This

Table 1   Stable-isotope measurements.

Col de Pré-Guittard samples	Meters	$\delta^{13}C$	$\delta^{18}C$	Col de Pré-Guittard samples	Meters	$\delta^{13}C$	$\delta^{18}C$
C/O K +8	8.00	2.156	−4.221	C/O K 0.0	0.00	2.661	−3.561
C/O K +7.75	7.75	2.536	−2.966	C/O K −0.1	−0.10	3.068	−3.088
C/O K +7.5	7.50	2.235	−3.707	C/O K −0.2	−0.20	3.247	−2.211
C/O K +7.25	7.25	2.444	−3.491	C/O K −0.3	−0.30	3.021	−3.23
C/O K +7	7.00	2.093	−3.518	C/O K −0.4	−0.40	3.557	−2.521
C/O K +6.75	6.75	1.95	−3.713	C/O K −0.5	−0.50	3.131	−2.854
C/O K +6.5	6.50	2.49	−3.444	C/O K −0.6	−0.60	3.124	−2.956
C/O K +6.25	6.25	2.742	−3.069	C/O K −0.7	−0.70	3.091	−2.396
C/O K +6	6.00	2.399	−3.712	C/O K −0.8	−0.80	3.089	−2.44
C/O K +5.75	5.75	2.761	−3.102	C/O K −0.9	−0.90	3.089	−2.393
C/O K +5.5	5.50	2.711	−3.104	C/O K −1	−1.00	2.931	−2.835
C/O K +5.25	5.25	2.566	−3.066	C/O K −1.25	−1.25	2.887	−2.696
C/O K +5	5.00	2.856	−2.611	C/O K −1.5	−1.50	2.972	−2.473
C/O K +4.75	4.75	2.853	−3.105	C/O K −1.75	−1.75	2.785	−2.784
C/O K +4.5	4.50	3.134	−2.933	C/O K −2	−2.00	2.963	−2.508
C/O K +4.25	4.25	3.097	−2.77	C/O K −2.25	−2.25	3.048	−2.544
C/O K +4	4.00	3.084	−2.337	C/O K −2.5	−2.50	2.831	−2.352
C/O K +3.75	3.75	2.564	−3.733	C/O K −2.75	−2.75	2.735	−2.765
C/O K +3.5	3.50	3.046	−2.885	C/O K −3	−3.00	2.613	−2.897
C/O K +3.25	3.25	3.089	−3.064	C/O K −3.25	−3.25	2.736	−2.685
C/O K +3	3.00	3.144	−2.729	C/O K −3.5	−3.50	2.72	−2.578
C/O K +2.75	2.75	2.935	−2.252	C/O K −3.75	−3.75	2.608	−3.023
C/O K +2.5	2.50	2.651	−3.373	C/O K −4	−4.00	2.772	−2.763
C/O K +2.25	2.25	2.537	−3.234	C/O K −4.25	−4.25	2.716	−2.818
C/O K +2.0	2.00	2.708	−3.074	C/O K −4.5	−4.50	2.522	−3.046
C/O K +1.9	1.90	2.58	−3.339	C/O K −4.75	−4.75	2.764	−2.623
C/O K +1.8	1.80	2.728	−2.88	C/O K −5	−5.00	2.745	−2.902
C/O K +1.7	1.70	2.734	−2.395	C/O K −5.25	−5.25	2.93	−2.694
C/O K +1.6	1.60	2.55	−3.462	C/O K −5.5	−5.50	2.883	−2.821
C/O K +1.5	1.50	2.475	−3.465	C/O K −5.75	−5.75	2.808	−2.872
C/O K +1.4	1.40	2.727	−2.935	C/O K −6	−6.00	2.836	−2.847
C/O K +1.3	1.30	2.43	−3.259	C/O K −6.25	−6.25	2.958	−2.546
C/O K +1.2	1.20	2.536	−3.273	C/O K −6.5	−6.50	2.98	−2.719
C/O K +1.1	1.10	2.231	−3.173	C/O K −6.75	−6.75	3.01	−2.625
C/O K +1.0	1.00	2.293	−3.248	C/O K −7	−7.00	3.031	−2.497
C/O K +0.9	0.90	2.165	−3.363	C/O K −7.25	−7.25	2.897	−2.604
C/O K +0.8	0.80	2.082	−3.475	C/O K −7.5	−7.50	2.683	−2.872
C/O K +0.7	0.70	1.988	−3.563	C/O K −7.75	−7.75	2.588	−3.085
C/O K +0.6	0.60	1.822	−3.819	C/O K −8	−8.00	2.874	−2.585
C/O K +0.5	0.50	1.876	−3.483	C/O K −8.25	−8.25	2.959	−2.725
C/O K +0.4	0.40	2.019	−3.563	C/O K −8.5	−8.50	3.078	−2.192
C/O K +0.3	0.30	1.984	−3.79	C/O K −8.75	−8.75	2.873	−2.544
C/O K +0.2	0.20	2.312	−3.565	C/O K −9	−9.00	3.043	−2.193
C/O K +0.1	0.10	2.724	−3.496	C/O K −9.25	−9.25	2.955	−2.505
				C/O K −9.5	−9.50	3.227	−2.312
				C/O K −9.75	−9.75	3.008	−2.567
				C/O K −10	−10.00	2.831	−3.158

part of the succession at Col de Pré-Guittard was logged in detail and sampled in April 2010. To ensure precision in sampling level, samples were collected from below and above the base of the Niveau Kilian, which was taken as a zero datum (Fig. 2). A total of 91 samples was taken from an 18 m section (0 to −10 m, 0 to +8 m). Most were spaced at 25 cm intervals, but across the Niveau Kilian itself they were spaced at 10 cm. The succession comprises dark grey calcareous clays containing a number of thin, variably indurated marlstones, two of which were named 'DC4, DC5' by Bréhéret (1997). Several of the marlstone beds are strongly bioturbated and the burrows have a conspicuously dark infilling. The Niveau Kilian consists of some 0.8 m of darker, non-laminated slightly organic-rich clay with 1–2 % Total Organic Carbon (TOC: Bréhéret et al. 1986). The base is conspicuously burrowed down into the uppermost 15 cm of the underlying pale grey clay. A thin, darker level also with relatively enhanced TOC, 5–6 m above the Niveau Kilian, is called 'HN 1' (Bréhéret 1997).

Bulk-rock samples from the studied sections (Table 1) were analysed isotopically for $\delta^{13}C$ and $\delta^{18}O$ using a VG Isogas Prism II mass spectrometer with an on-line VG Isocarb with a common acid bath at Oxford University. Samples were cleaned with hydrogen peroxide (H_2O_2) and acetone [$(CH_3)_2CO$] and dried at 60 °C for at least 30 minutes. In the instrument they were reacted with purified phosphoric acid (H_3PO_4) at 90 °C. Normal corrections were applied and the results are reported, using the usual δ notation, in ‰ deviation from the PDB (Pee Dee Belemnite) standard. Calibration to the PDB standard via NBS-19 was made daily using the Oxford in-house (NOCZ) Carrara marble standard. Reproducibility of replicated standards was typically better than 0.1‰ for both $\delta^{13}C$ and $\delta^{18}O$.

A total of forty-eight samples was analyzed for foraminifera. Sample spacing varies from 50 cm to 20 cm in the 2 m interval containing the Niveau Kilian. Samples were mechanically disaggregated, soaked in hydrogen peroxide, washed under running water through 38–150 μm, 150–250 μm and > 250 μm sieves, then dried on a hot plate. The > 38 μm size fraction was analyzed for the presence of biostratigraphic marker species. The biostratigraphic framework used and the species concepts adopted in this study follow Huber and Leckie (2011) and references therein.

Planktic and benthic foraminifera were counted in nearly all samples. To perform the counts the > 63-μm size fraction was split, weighed and a fixed aliquot was spread over a gridded picking tray and all the specimens in the aliquot were counted. The abundance values are expressed as number of specimens per gram of coarse fraction > 63 μm. The stratigraphic distribution of planktic foraminifera and abundance counts of foraminifera are shown in Table 2. Species that are questionably present are denoted by a question mark. Planktic foraminifera are judged as having moderate (M) preservation when they are somewhat overgrown with secondary calcite and wall structures (e. g., pore size, perforation cones) are visible. Poor (P) preservation is denoted for specimens that are strongly recrystallized and whose wall microstructure cannot be observed.

4.   Biostratigraphy of Planktic Foraminifera

4.1   Description of the washed residues

The > 250 μm size fraction is mainly composed of clay chips, pyrite, fragments of macrofossils, ostracods, and echinoids. In the Col de Pré-Guittard section, planktic foraminifera are generally small-sized and are more common in the < 150 μm fractions. Large specimens of *Hedbergella* (~200 μm in diameter) are rare and restricted to the base of the stratigraphic section. Few specimens of *Paraticinella eubejaouaensis* (sensu Premoli Silva et al. 2009) and *Pa. transitoria*, with an average size of 300–600 μm, occur from the base of the section (sample FK −10) to sample FK −2.0 m. Radiolaria occur throughout in the < 150 μm size fraction (Table 2). Biserial agglutinated and trochospiral calcareous perforate benthic foraminifera are few to common in each size fraction examined. Preservation of planktic foraminifera is generally poor to moderate because most of the specimens show diagenetic alteration, hampering a detailed observation of their primary wall microstructure. Foraminifera occur in all the studied samples and show no evidence of carbonate dissolution such as fragmentation and etching of the test.

4.2   Identification of bioevents and remarks

Our detailed analyses permit the identification of four bioevents in the 3-m-thick stratigraphic interval containing the Niveau Kilian (Table 2; Fig. 2). Three bioevents are recorded below the base of the Niveau Kilian in the following stratigraphic order: 1) highest occur-

rence (HO) of *Paraticinella eubejaouaensis*, 2) lowest occurrence (LO) of *Microhedbergella miniglobularis* and 3) HO of *Pseudoguembelitria blakenosensis*. The LO of *Microhedbergella renilaevis* is found within the Niveau Kilian at 40 cm from its base.

The HO of *Paraticinella eubejaouaensis* is 2.25 m below the base of the Niveau Kilian. This event was identified up to 11.5 m below the base of the Niveau Kilian by Kennedy et al. (2000) (Fig. 2). Historically, the extinction level of *Pa. eubejaouaensis* was placed at the top of the *Hypocanthoplites jacobi* Ammonite Zone in the uppermost Aptian (Bréhéret et al. 1986, Robaszynski and Caron 1995, Kennedy et al. 2000) or at the base of the *Douvilleiceras mammillatum* Ammonite Zone in the lowermost Albian (Sigal 1977). However, the extinction of *Pa. eubejaouaensis* has been used to approximate the Aptian/Albian boundary, especially in the absence of macrofossils, because of its distinctive morphology and size, and its continuous stratigraphic distribution documented in a wide range of environmental settings (e. g., Sliter 1989, Cobianchi et al. 1997, Premoli Silva and Sliter 1999, Bellier et al. 2000, Coccioni et al. 2006).

The lowest occurrence of *Microhedbergella miniglobularis* is recorded 2.0 m below the base of the Niveau Kilian and 25 cm above the HO of *Pa. eubejaouaensis*. This species was described by Huber and Leckie (2011) from Aptian–Albian deep-sea sections in the South Atlantic (DSDP Site 511), western North Atlantic (ODP Site 1049), and in the southeast Indian Ocean (ODP Site 763) with its first occurrence near the top of the range of *Pa. eubejaouaensis*. This small but very distinctive species was regarded by these authors as equivalent to the morphotypes identified by Caron in Kennedy et al. (2000) as *Hedbergella* sp. 3 chambers/triangulata that occur just above the extinction of *Pa. eubejaouaensis*. We confirm the reliability of *Mi. miniglobularis* as a marker species for global correlation because it is consistently present in the stratigraphic interval following the disappearance of the large-sized *Pa. eubejaouaensis* co-occurring with the last long-ranging Aptian hedbergellids.

The extinction of *Pseudoguembelitria blakenosensis* falls 20 cm below the Niveau Kilian. This taxon was previously described by Huber and Leckie (2011) co-occurring with *Pa. eubejaouaensis* only at ODP Site 1049 (western North Atlantic). However, at DSDP Site 545 (eastern North Atlantic) Leckie (1984, 1987) observed an acme of high-spired specimens, identified as *Gubkinella graysonensis*, co-occurring with the last *Pa. eubejaouaensis*. These specimens are similar to *Ps. blakenosensis* (Leckie 2011, pers. comm.). In the Col de Pré-Guittard section, *Ps. blakenosensis* consistently co-occurs with *Pa. eubejaouaensis* and becomes rare before its disappearance at the base of the Niveau Kilian.

The appearance of *Microhedbergella renilaevis* is an easily identifiable bioevent that occurs above the extinction of the Aptian hedbergellids and within the Niveau Kilian at 40 cm from its base. This species, which co-occurs with common *Mi. miniglobularis*, was described by Huber and Leckie (2011) from Aptian–Albian deep-sea sections in the South Atlantic (DSDP Site 511), western North Atlantic (ODP Site 1049), and southeast Indian Ocean (ODP Site 763). Similar forms were identified as *Hedbergella* sp. 4 chambers/quadricamerata by Caron in Bréhéret et al. (1986) and in Kennedy et al. (2000) with their first occurrence in sample PG 9a about 4 m above the base of the Niveau Kilian.

4.3 Biozonation and comments on the assemblages

The biozonation presented below is adapted from Huber and Leckie (2011) with a few modifications based on the sequence of bioevents previously discussed. Zonal marker species and significant species are illustrated in Plates 1–4. Our documentation demonstrates the reliability of the lowest occurrence datum of *Mi. renilaevis* for global correlation. Changes to the previous biozonation include a new definition for the top of the *Microhedbergella miniglobularis* Interval Zone and designation of a new *Microhedbergella renilaevis* Partial Range Zone overlying the *Microhedbergella miniglobularis* Zone using the first appearance datum of *Mi. renilaevis* as a zonal boundary biomarker (Table 2; Fig. 2). The *Mi. miniglobularis* Zone identifies the brief interval documenting the Aptian–Albian planktic foraminiferal turnover. The zone is defined as the biostratigraphic interval containing the nominate taxon from the HO of *Pa. eubejaouaensis* to the LO of *Mi. renilaevis*. The new *Microhedbergella renilaevis* Zone corresponds to the biostratigraphic interval from the LO of *Mi. renilaevis* to the LO of *Microhedbergella rischi*.

The stratigraphic interval from the base of the section to sample FK −2.25 is assigned to the *Paraticinella eubejaouaensis* Total Range Zone (= *Ticinella bejaouaensis* Zone, Robaszynski and Caron 1995), based on the presence of the marker species (Table 2). Samples at the base contain few to common *Pa. eube-*
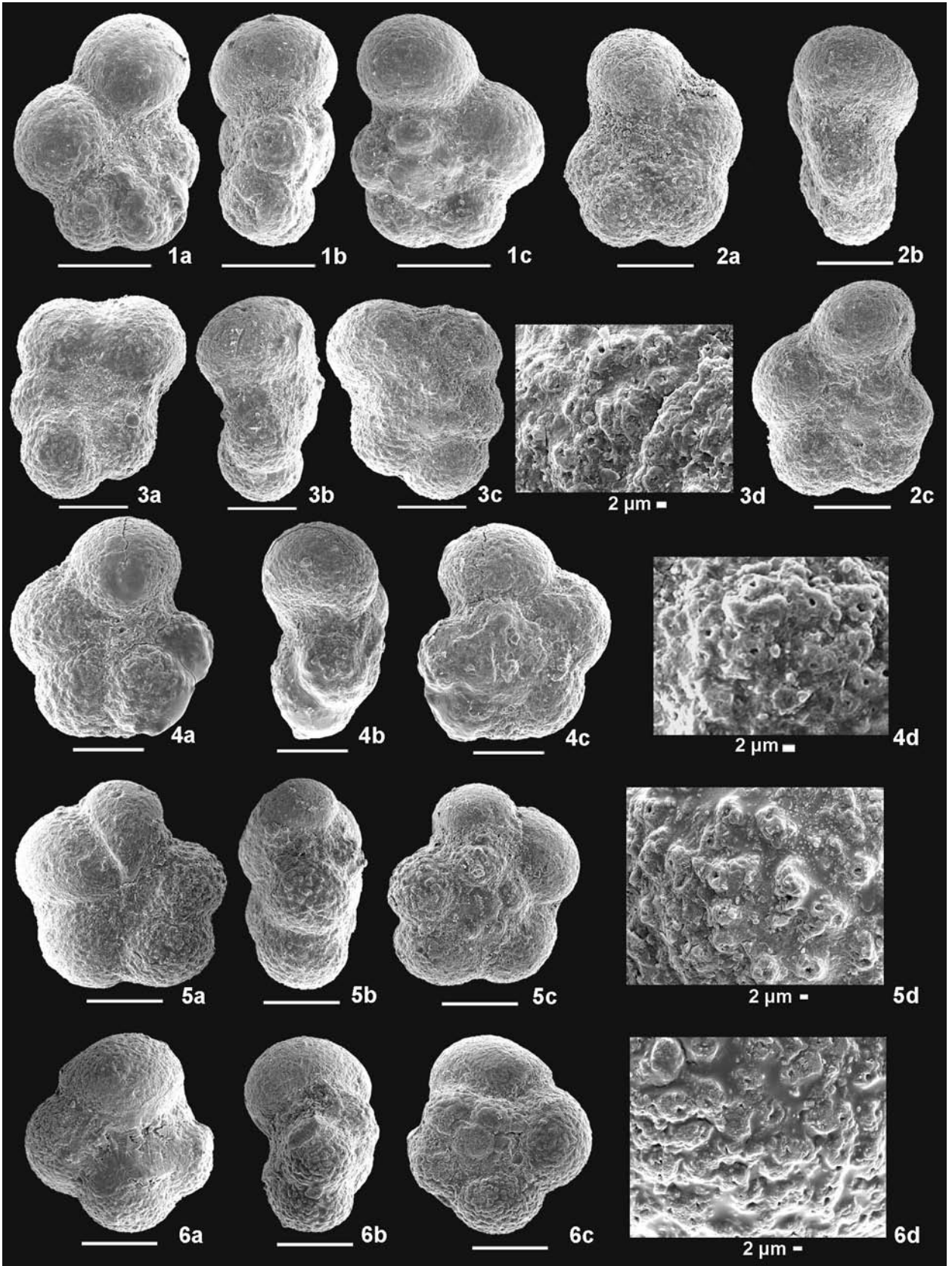
Plate 1. 1. *Hedbergella aptiana*, sample FK −9.5. 2. *Hedbergella aptiana*, sample FK −9.0. 3. *Hedbergella aptiana*, sample FK −9.0. 4. *Hedbergella infracretacea*, sample FK −5.5. 5. *Hedbergella infracretacea*, sample FK −9.5. 6. *Hedbergella infracretacea*, sample FK −10.0. Scale bars = 100 μm unless shown otherwise; a = umbilical view, b = lateral view, c = spiral view, d = magnified view of perforation cones.
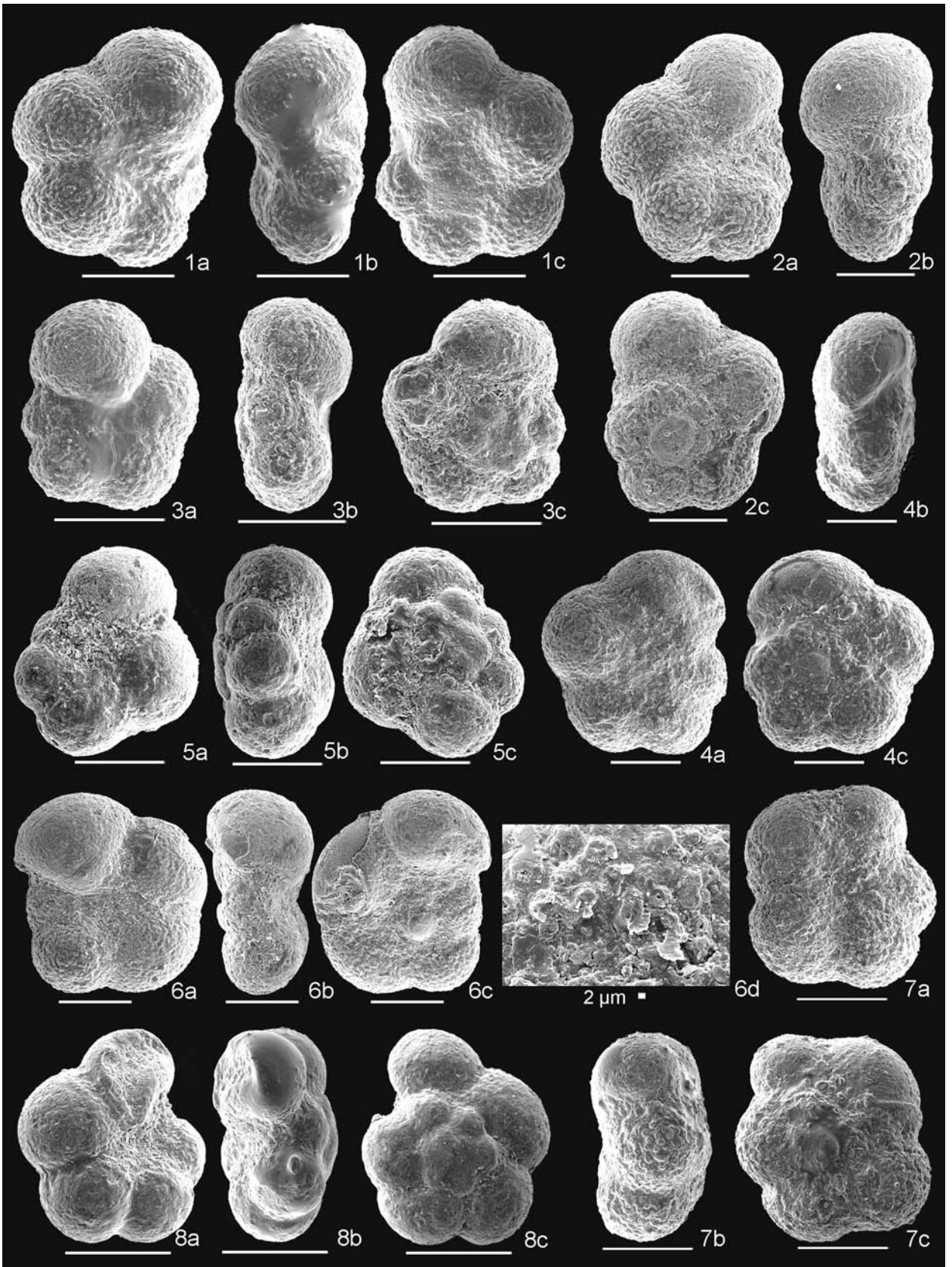
Plate 2. 1. *Hedbergella infracretacea*, sample FK −9.5. 2. *Hedbergella infracretacea*, sample FK −9.0. 3. *Hedbergella infracretacea*, sample FK −9.5. 4. *Hedbergella infracretacea*, sample FK −10.0. 5. *Hedbergella infracretacea*, sample FK −10.0, scale bar = 50 μm. 6. *Hedbergella gorbachikae*, sample FK −10.0. 7. *Hedbergella* cf. *infracretacea*, sample FK −9.5. 8. *Hedbergella excelsa*, sample FK −9.5. Scale bars = 100 μm unless shown otherwise; a = umbilical view, b = lateral view, c = spiral view, d = magnified view of perforation cones.
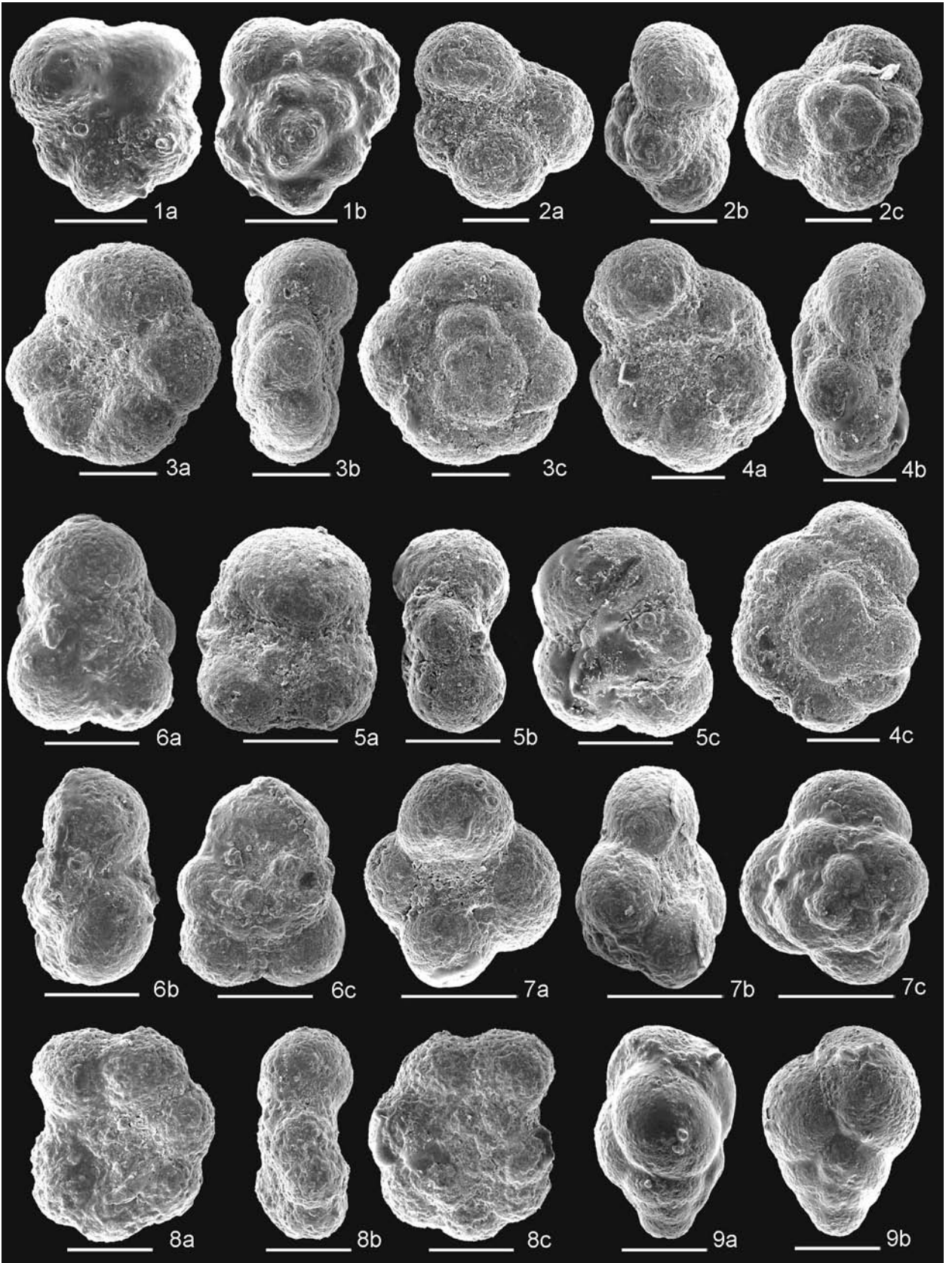
Plate 3. 1. *Hedbergella excelsa*, sample FK −0.8. 2. *Hedbergella praelippa*, sample FK −10.0. 3. *Microhedbergella* aff. *rischi*, sample FK +7.0. 4. *Microhedbergella* aff. *rischi*, sample FK −4.0. 5. *Microhedbergella miniglobularis*, sample FK +0.6. 6. *Microhedbergella miniglobularis*, sample FK +1.2. 7. *Hedbergella praelippa* high trochospire, sample FK −2.0. 8. *Microhedbergella* cf. *pseudoplanispira*, sample FK +0.6. 9. *Bulimina* sp., sample FK −0.4. Scale bars = 50 μm; a = umbilical view, b = lateral view, c = spiral view.
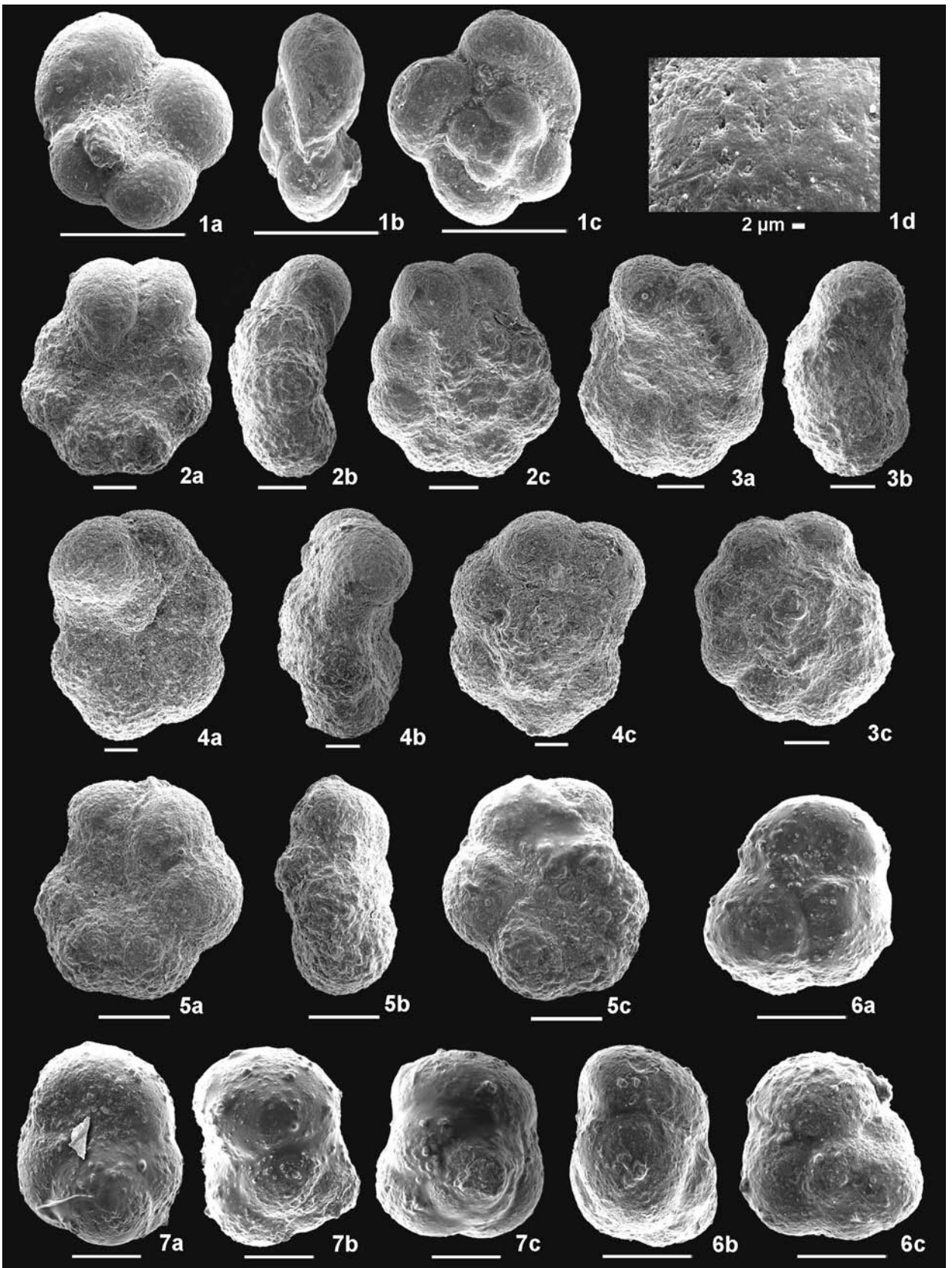
Plate 4. 1. *Microhedbergella renilaevis*, sample FK +7.0. 2. *Paraticinella eubejaouaensis*, sample FK −10.0. 3. *Paraticinella eubejaouaensis*, sample FK −9.0. 4. *Paraticinella transitoria*, sample FK −2.0. 5. *Paraticinella transitoria*, sample FK −10.0. 6. *Pseudoguembelitria blakenosensis*, sample FK −9.0, scale bar = 50 μm. 7. *Pseudoguembelitria blakenosensis*, sample FK −0.8, scale bar = 50 μm. Scale bars = 100 μm unless otherwise stated; a = umbilical view, b = lateral view, c = spiral view, d = magnified view showing smooth, microperforate wall surface.

jaouaensis and its closely related species *Pa. transitoria*. Both species occur in the > 250 μm size fraction, whereas the hedbergellids (*Hd. aptiana*, *Hd. infracretacea*, *Hd. praelippa*, *Hd. excelsa*) are more abundant in the smaller size fractions and progressively become rare and disappear at the top of the zone. *Pseudoguembelitria blakenosensis* consistently occurs in this biostratigraphic interval and is more common at the base of the section (Table 2). A progressive reduction in the number of species and deterioration of foraminiferal preservation is observed throughout the zone.

The occurrence of a single specimen of *Pa. transitoria* (Plate 4, Fig. 4) in the samples immediately above the last *Pa. eubejaouaensis* is not surprising since the former species has been reported to have a slightly higher range (Longoria 1974). The topmost part of the biozone is also characterized by the occurrence of peculiar, but poorly preserved specimens that are similar to *Microhedbergella rischi* (= *Hedbergella rischi* sensu Bellier and Moullade 2002) and are thus identified as *Mi.* aff. *Mi. rischi* (Plate 3, Figs. 3 and 4). This taxon displays a scattered stratigraphic range up-section (Table 2). However, the possible phylogenetic relationship between *Mi.* aff. *rischi* and *Mi. rischi* needs further investigation with information supported by stratophenetic observations.
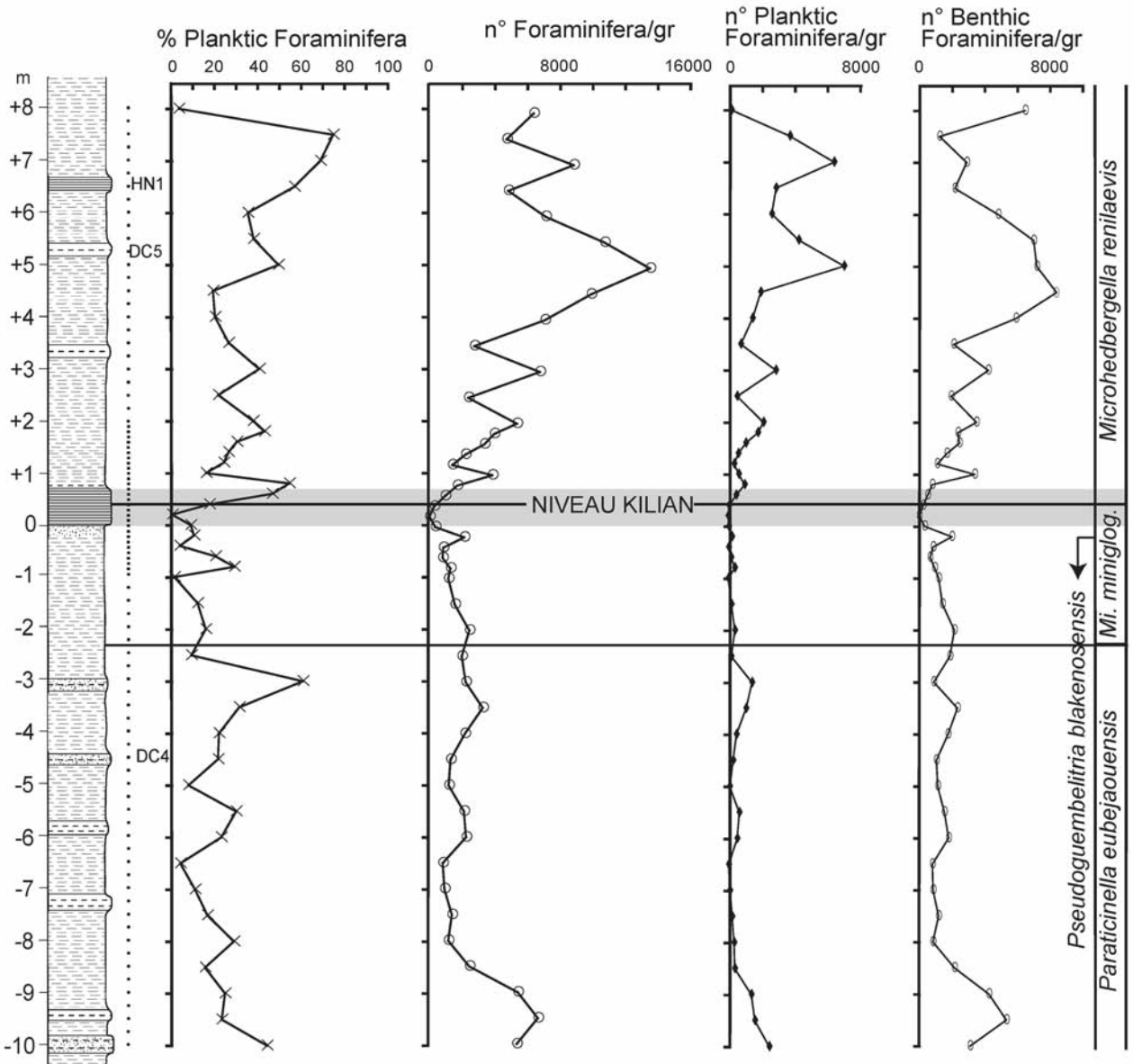

Fig. 3. Foraminiferal abundance data and percent planktic foraminifera. See text for further explanations.

Table 2   Distribution of planktic foraminifera and absolute abundance data for foraminifera. R = presence of Radiolaria.
Preservation ratings for planktic foraminifera: M = moderate; P = poor.

Col de Pré-Guittard samples	Meters	Radiolaria	Coarse fraction > 63 μm in gr	n° Planktic Foraminifera/gr	n° Benthic Foraminifera/gr	n° Planktic Foraminifera (1 split)	n° Benthic Foraminifera (1 split)	% Planktic Foraminifera
FK +8.0	8.00		0.1225	196	6271	8	256	3.0
FK +7.5	7.50	R	0.3196	3558	1239	379	132	74.2
FK +7.0	7.00		0.2013	6096	2832	409	190	68.3
FK +6.5	6.50		0.1794	2759	2140	165	128	56.3
FK +6.0	6.00		0.1913	2509	4689	160	299	34.9
FK +5.5	5.50		0.1552	4060	6767	210	350	37.5
FK +5.0	5.00	R	0.0561	6669	6954	187	195	49.0
FK +4.5	4.50		0.0639	1877	8117	40	173	18.8
FK +4.0	4.00	R	0.3297	1411	5733	93	378	19.7
FK +3.5	3.50		0.3909	729	2072	57	162	26.0
FK +3.0	3.00		0.3135	2743	4099	172	257	40.1
FK +2.5	2.50		0.1733	519	1921	30	111	21.3
FK +2.0	2.00		0.3673	2028	3403	149	250	37.3
FK +1.8	1.80		0.1836	1716	2321	105	142	42.5
FK +1.6	1.60	R	0.4069	1020	2408	83	196	29.7
FK +1.4	1.40		0.3930	585	1667	46	131	26.0
FK +1.2	1.20	R	0.4333	346	1108	30	96	23.8
FK +1.0	1.00	R	0.1669	611	3307	34	184	15.6
FK +0.8	0.80		0.4311	951	812	82	70	53.9
FK +0.6	0.60		0.4420	464	543	41	48	46.1
FK +0.4	0.40		0.5209	58	278	6	29	17.1
FK +0.2	0.20		0.5343	0	47	0	5	0.0
FK 0	0.00		0.4419	34	362	3	32	8.6
FK −0.2	−0.20	R	0.3284	219	1964	24	215	10.0
FK −0.4	−0.40		0.4818	31	861	3	83	3.5
FK −0.6	−0.60	R	0.4371	172	686	15	60	20.0
FK −0.8	−0.80	R	0.4468	381	951	34	85	28.6
FK −1.0	−1.00	R	0.3984	13	1192	1	95	1.0
FK −1.5	−1.50		0.4272	187	1416	16	121	11.7
FK −2.0	−2.00		0.4399	386	2114	34	186	15.5
FK −2.25	−2.25		data not available					
FK −2.5	−2.50		0.4150	181	1855	15	154	8.9
FK −3.0	−3.00		0.4803	1374	906	132	87	60.3
FK −3.5	−3.50		0.4137	1027	2297	85	190	30.9
FK −4.0	−4.00		0.4905	479	1743	47	171	21.6
FK −4.25	−4.25		data not available					
FK −4.5	−4.50	R	0.5995	284	1059	34	127	21.1
FK −5.0	−5.00		0.6502	92	1138	12	148	7.5
FK −5.5	−5.50		0.4152	638	1530	53	127	29.4
FK −6.0	−6.00		0.4334	519	1777	45	154	22.6
FK −6.5	−6.50		0.4652	32	828	3	77	3.8
FK −7.0	−7.00		0.4908	102	866	10	85	10.5
FK −7.5	−7.50	R	0.4122	230	1189	19	98	16.2
FK −8.0	−8.00	R	0.4241	342	861	29	73	28.4
FK −8.5	−8.50		0.6207	379	2127	47	264	15.1
FK −9.0	−9.00		0.4423	1334	4149	118	367	24.3
FK −9.5	−9.50		0.3127	1535	5180	96	324	22.9
FK −10	−10.00		0.3386	2362	3042	160	206	43.7

NIVEAU KILIAN

X = specimen figured in Plates 1–4; S = specimen identified at the stereoscope. Abbreviations for genera are as follows: *Hd.* = *Hedbergella*; *Mi.* = *Microhedbergella*; *Pa.* = *Paraticinella*; *Ps.* = *Pseudoguembelitria*.

Preservation	Guembelitria sp.	Hd. aptiana	Hd. excelsa	Hd. gorbachikae	Hd. infracretacea	Hd. cf. occulta	Hd. praelippa	Hd. ruka	Hd. trocoidea	Mi. miniglobularis	Mi. renilaevis	Mi. cf. pseudoplanispira	Mi. aff. rischi	Pa. eubejaouaensis	Pa. transitoria	Ps. blakenosensis	Age	Biozone
M										S	S		S				Early Albian	Microhedbergella renilaevis
M										S	S		S					
M										S	X		X					
M										S	S		S					
M										S	S		S					
M										S	S		S					
P										S	S		S					
P										S	S							
M										S	S							
P										S	S							
P										S	S							
P										S	S							
P	S?									S	S							
P	S									S	S		S					
P	S?									S	S		S					
M										X	S							
P										S	S		S					
P										S	S							
M										X	S	X	S					
P			S?							S	S							
P																	Late Aptian	Mi. miniglobularis
P										S			S					
P										S			S			S		
P					S					S		S	S					
P										S		S	S					
M			X							S						X		
P										S								
P			S		S								S					
P							X?			S	S				X	S		
P		S													S		Late Aptian	Paraticinella eubejaouaensis
P		S												S	S	S		
P		S												S	S	S		
P		S			S?									S	S			
M		S			S?								X			S		
P		S			S									S				
P		S			S									S	S			
P		S														S		
M					X									S		S		
P		S					S							S		S		
P		S																
P														S	S	S		
P		S					S	S						S	S			
M							S							S		S		
M							S	S	S					S		S		
M		X		S	X		S	S						X	S	X		
M		X	X	S	S		S	S						S	S	S		
M		S	S	X	X		X	S						X	X	S		

The stratigraphic interval from the extinction of *Pa. eubejaouaensis* to the lowest occurrence of *Microhedbergella renilaevis* at FK +0.4 is attributed to the *Microhedbergella miniglobularis* Zone and corresponds to the lowermost part of the *Hedbergella planispira* Zone of previous studies (e. g., Robaszynski and Caron 1995). The zone is characterized by the complete absence of planktic foraminifera in the > 250 μm size fraction. *Microhedbergella miniglobularis* is recorded consistently in the Col de Pré Guittard section above its lowest occurrence. Rare to few small *Mi.* aff. *rischi* and *Ps. blakenosensis* occur together with *Mi. miniglobularis* in the 2-m-thick interval below the Niveau Kilian. Planktic foraminiferal specimens are absent in sample FK +0.2 in which only a few trochospiral benthic species were observed. A distinctive, but poorly preserved group of specimens, here identified as *Mi.* cf. *Mi. pseudoplanispira* (Plate 3, Fig. 8) because of their resemblance to *Mi. pseudoplanispira* Huber and Leckie, 2011, are recorded in this biozone.

The top of the *Microhedbegella miniglobularis* Zone, previously defined by the LO of *Mi. rischi* (Huber and Leckie 2011), is here placed using the first appearance datum of *Microhedbergella renilaevis* at FK +0.4. The LO of *Mi. renilaevis* marks an important bioevent that correlates with the Niveau Kilian and represents a major step in the evolution and diversification of the Albian planktic fauna. The change of the
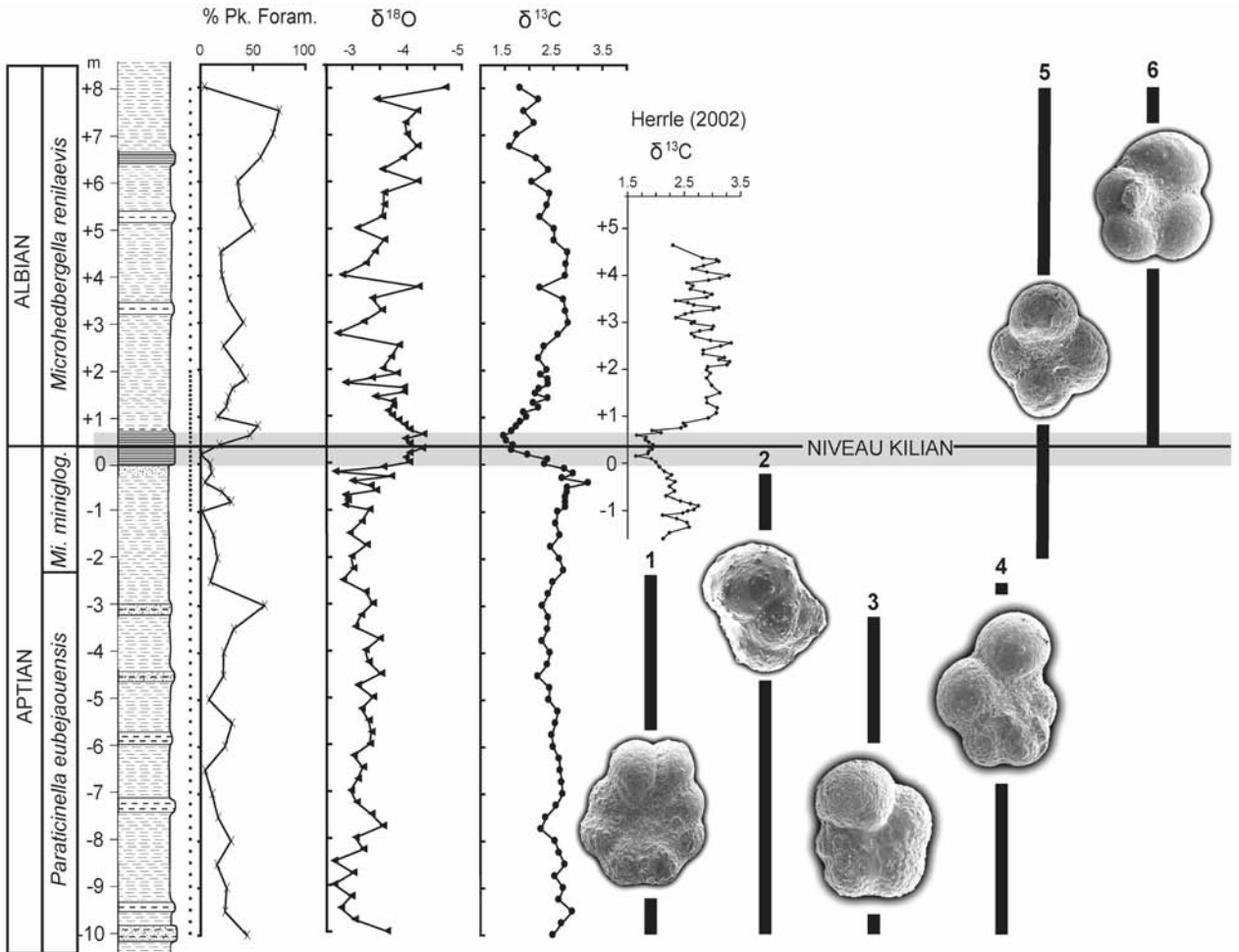

Fig. 4. Percent planktic foraminifera and stable-isotope stratigraphy of the Niveau Kilian at Pré-Guittard. The very slight mismatch between the carbon-isotope data of Herrle (2002) from that presented here is attributed to small diagenetically derived differences in lithology known to characterize this section (Weissert and Bréhéret, 1991): the negative excursion is, however, clear in both δ¹³C curves. Species illustrated with their ranges: 1. *Paraticinella eubejaouaensis*, sample FK −9.0. 2. *Pseudoguembelitria blakenosensis*, sample FK −0.8. 3. *Hedbergella infracretacea*, sample FK −9.5. 4. *Hedbergella aptiana*; sample FK −9.5. 5. *Microhedbergella miniglobularis*, sample FK +2.0. 6. *Microhedbergella renilaevis*, sample FK +7.0.

definition of the *Mi. miniglobularis* Zone is justified by the reliability of *Mi. renilaevis* as a biomarker; it is easily identified and it commonly occurs together with *Mi. miniglobularis* in the middle of the Niveau Kilian at a stratigraphic position immediately above the extinction level of the Aptian hedbergellids.

The overlying stratigraphic interval between the LO of *Mi. renilaevis* to the last sample analysed in this study at 8 m above the base of the Niveau Kilian is assigned to the new *Microhedbergella renilaevis* Zone. The upper boundary of the zone is not recorded in the studied stratigraphy as *Mi. rischi* is absent from the topmost sample analysed. The planktic foraminiferal assemblage is composed only of *Mi. renilaevis*, *Mi. miniglobularis* and *Mi.* aff. *rischi*. Rare guembelitriids occur 60 cm above the top of the Niveau Kilian. Preservation progressively improves through the upper part of the stratigraphic interval.

5.   Foraminiferal abundance data

Quantitative analyses reveal fluctuations in abundance and a progressive decrease of both planktic and benthic specimens starting 2 m above the base of the studied section at FK -8.0 (Fig. 3). Generally, benthic foraminifera are more abundant than planktic foraminifera and still occur, albeit in low numbers, where planktic foraminifera are rare or absent.

The major turnover in planktic species closely corresponds with the extinction of the Aptian biomarker *Pa. eubejaouaensis*, which is accompanied, within a 3-metre-thick interval, by the appearance of the small-sized (100 μm in average) species *Mi. miniglobularis* followed by the extinction of remaining Aptian taxa at the base of the Niveau Kilian. In this interval, minimum values in the number of planktic and benthic foraminifera and in the percent planktic foraminifera are reached; the percent of planktic foraminifera drops from 60 % to 0 % and this is accompanied by a dramatic decrease in the number of planktic and benthic forms, reaching 0 and 47 specimens per gram of coarse fraction, respectively (Table 2; Fig. 3). Remarkably, the semi-quantitative foraminiferal abundance data collected by Bréhéret (1997, fig. 184) at Col de Pré-Guittard show the same dramatic decrease in the number of foraminifera within the Niveau Kilian, but no evidence of an accompanying fall in the carbonate content.

The faunal perturbation expressed by the complete absence of planktic foraminifera closely correlates with the short-lived 1‰ negative $\delta^{13}C$ excursion

(Fig. 4). A rapid ~50 % increase in the percent planktic foraminifera is registered at the top of the Niveau Kilian (sample FK $+8.0$), 40 cm above the appearance of *Mi. renilaevis*. At this stratigraphic level there is a rapid increase in the number of planktic and benthic specimens from less than 100 specimens to thousands of specimens per gram and the change in faunal composition can be considered complete. This progressive increase in abundance of both planktic and benthic foraminifera continues up-section and is followed by fluctuations in the total number of specimens with a distinctive drop observed across the rich carbonate layer HN1 at FK $+6.5$.

6.   Remarks and identification of Kilian equivalent levels outside the Vocontian Basin

Correspondence between the planktic foraminiferal turnover, a dramatic reduction in the abundance of planktic specimens, the negative $\delta^{13}C$ and the $\delta^{18}O$ excursion, as observed at the Niveau Kilian in the Pré-Guittard section (Fig. 4) suggest a possible relationship between ocean physico-chemistry and plankton dynamics. However, it is puzzling that no significant corresponding change in composition of the calcareous nannofossil assemblages has been observed in studies of the Pré-Guittard sequence (Bown, in Kennedy et al., 2000, Herrle and Mutterlose, 2003). Nevertheless, Herrle et al. (2003) documented high-frequency productivity changes across the Niveau Kilian with a dominance of high-productivity nannofossil indicators and a low abundance of benthic eutrophic indicators (*Gavellinella* spp.), and interpreted the formation of the organic-rich layer as resulting from poor oxygenation and enhanced preservation of organic matter.

Within the western Tethys, negative $\delta^{13}C$ (both in bulk carbonate, organic matter and marine and terrestrial biomarkers) and $\delta^{18}O$ excursions have been reported from organic-rich horizons, equivalent to the Niveau Kilian, in the eastern North Atlantic Mazagan Plateau at Site 545 (previously regarded as a Paquier equivalent by Herrle et al. 2004, Wagner et al. 2008, see Huber and Leckie 2011, for stratigraphic revision and Trabucho Alexandre et al. 2011, for discussion), and in the western North Atlantic Newfoundland Basin at Site 1276 (Trabucho Alexandre et al. 2011). Increase in organic-matter content, decrease in oxygen-isotope values, as well as nannofossil paleotemperature in-

dices and TEX$_{86}$ data from the Kilian equivalent horizons are in agreement with the data recorded at Pré-Guittard (Herrle et al. 2003) and also indicate a modest rise in seawater surface temperatures (~3.5 °C) across the subtropical North Atlantic region (Wagner et al. 2008, Trabucho Alexandre et al. 2011).

A significant decrease in abundance of planktic foraminifera has been documented across the Monte Nerone Level (Coccioni et al. 1990, 2006) in the Umbria-Marche Basin at Poggio le Guaine section. The planktic assemblage resembles that observed at Pré-Guittard, being composed of very rare and tiny hedbergellids and therefore assigned to the *Hedbergella planispira* Zone (sensu Sigal 1977, Robaszynski and Caron 1995) by Coccioni et al. (1990, 2006). The similarity in composition of the planktic foraminifera indicates that the Monte Nerone Level is probably correlative with the Niveau Kilian, as was suggested by Erbacher (1994). However, the equivalence cannot be proved until high-resolution biostratigraphic, isotopic, marine and terrestrial biomarkers or other data are available for correlation.

The abrupt and dramatic extinction of Aptian planktic foraminifera described at DSDP Site 511 in the southern South Atlantic (Huber and Leckie, 2011) is directly associated with a 1.8‰ positive δ^{13}C shift followed by a 4.4‰ negative shift (Huber et al. 2010). This finding outside the Tethys demonstrates that the faunal turnover across the Aptian-Albian interval is globally widespread and appears to be synchronous.

Understanding the causes of the major planktic foraminiferal extinction event will require the study of additional biostratigraphically complete sections yielding well-preserved calcareous plankton assemblages.

Conclusions

Our detailed documentation of foraminiferal species content and abundance across a continuous Aptian–Albian sedimentary sequence exposed at the Col de Pré-Guittard section permits a reliable description of the magnitude and rate of planktic foraminiferal turnover despite diagenetic alteration of the foraminiferal assemblages. The biozonation applied in the present study is based on changes in species composition and foraminiferal abundance as follows (from base to top):

1) *Paraticinella eubejaouaensis* Total Range Zone: progressive decrease in number and abundance of the Aptian long-ranging small-sized *Hedbergella*

with perforation cones and of the large-sized *Paraticinella* species.

2) *Microhedbergella miniglobularis* Interval Zone: appearance of the first smooth-walled *Microhedbergella* species. Extinction of all the Aptian species and a dramatic decrease in abundance of planktic and benthic specimens occur in the lowermost part of the Niveau Kilian.

3) *Microhedbergella renilaevis* Interval Zone: appearance of *Mi. renilaevis* in the middle part of the Niveau Kilian representing a major step in the evolution and diversification of the Albian planktic fauna. Minimum values in the number of foraminiferal specimens and the lowest occurrence of *Mi. renilaevis* correspond with a 1‰ negative δ^{13}C excursion across the Niveau Kilian.

In spite of the poor foraminiferal preservation, the sequence of events observed at the Pré-Guittard section is in agreement with that reported by Huber and Leckie (2011) from deep-sea Atlantic and Indian Ocean records. Thus, the extinction of the *Paraticinella* species, the planktic foraminiferal turnover, the appearance of *Mi. renilaevis* and the negative carbon-isotope shift in the Pré-Guittard section are globally identifiable events that could be used as primary and secondary criteria to define the GSSP for the base of the Albian Stage.

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