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Integrated stratigraphy across the Aptian/Albian boundary at Col de Pré-Guittard (southeast France): A candidate Global Boundary Stratotype Section

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ABSTRACT

The outcrop of the Marnes Bleues at the Col de Pré-Guittard, 11 km north of the village of Rémuzat in the Département of Drôme in southeastern France is probably the most intensively studied succession spanning the Aptian/Albian boundary interval. Following the rejection of the proposed GSSP for the base of the Albian Stage (based on the first occurrence of the ammonite *Leymeriellla tardefurcata* in the section at Le Pillart, Tartonne, Alpes-de-Haute Provence), we re-visit the Pré-Guittard section. A new candidate GSSP defined by the first occurrence of the planktonic foraminifera *Microhedbergella renilaevis* Huber and Leckie, 2011 is here proposed. This first occurrence is placed in a 100 m section with 28 secondary markers, including calcareous nannofossils, planktonic foraminifera, palynomorphs, an inoceramid bivalve, ammonites, stable carbon isotopes, and local marker beds. The outcrop fulfils most of the physical criteria required of a Global Stratotype Section and Point.

1. Introduction

There is at present no agreed candidate Global Boundary Stratotype Section and Point for the base of the Albian Stage. In the report of the Working Party on the Albian Stage and Substage boundaries (Hart et al., 1996), two possible stratotype sections for the base of the Albian Stage were identified: that at Vöhrum (North Germany), and the Col de Pré-Guittard in Drôme, France (Fig. 1).

The section at Pré-Guittard (Figs. 2, 3) was examined in detail by Kennedy et al. (2000), who noted the presence of a minor discontinuity at the base of the organic-rich unit known as the Niveau Paquier, and suggested the more complete, but narrower interval exposed nearby at Le Pillart, Tartonne, Alpes-de-Haute Provence, as a candidate GSS, with the candidate GSSP defined on the first occurrence of the ammonite *Leymeriella tardefurcata* – the first feature noted by Hart et al. (1996, p. 51).

Publication of the report of the Working Party (Hart et al., 1996), and the study by Kennedy et al. (2000) led to a series of publications (discussed below) rejecting this proposed GSSP, largely on the basis of the absence of corresponding microfossil and chemostratigraphic events, the limited distribution of *Leymeriella tardefurcata*, and the problems of correlation of this datum outside southeast France (Premoli Silva, 2010). The subsequent conflicting proposals for the base of the Albian Stage are summarized in Fig. 3.

2. The view from Brussels

At the conclusion of the meeting of the Working Group on the Albian Stage, held during the Second International Symposium on Cretaceous Stage boundaries, in Brussels, September 8–16, 1995 (Hart et al., 1996), two possible Global Boundary Stratotype Sections and a number of potential Points (GSSP) were identified for the base of the Albian Stage. These were the first appearance of the ammonite *Proleymeriella* [*Leymeriella*] *schrammeni* (Jacob, 1907) in

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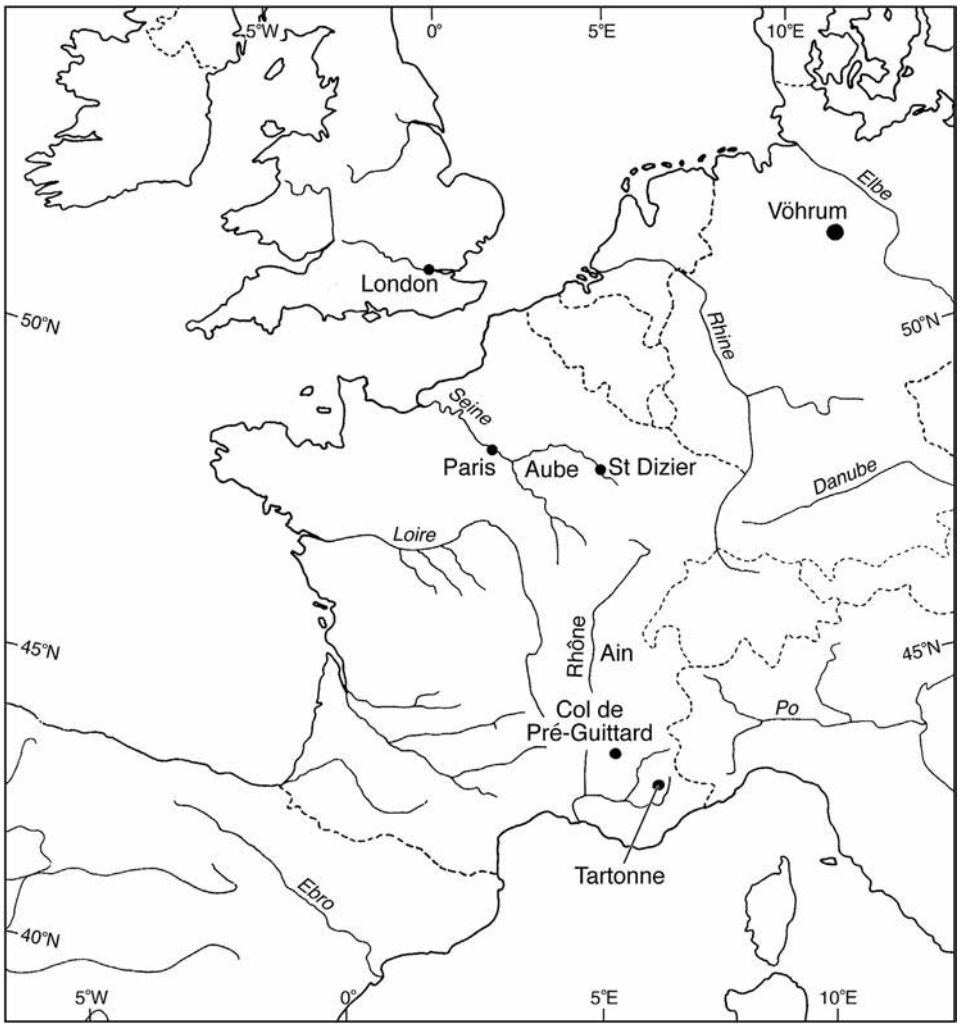

Fig. 1. Localities in France and Germany mentioned in the text.

artificial exposures at Vöhrum, west of Hannover in Niedersachsen, Germany (Owen, 1979, fig. 3; Hart et al. 1996, fig. 2), and the succession at the Col de Pré-Guittard, Arnayon, Drôme, France, with a range of possible markers, including the first occurrence of the ammonite *Leymeriella tardefurcata* (d'Orbigny, 1841), the first occurrence of the ammonite *Douvilleiceras* ex gr. *mammilatum* (Schlotheim, 1813), the first occurrence of the coccolithophore *Prediscosphaera columnata* (Stover, 1966), the last occurrence of the ammonite *Hypacanthoplites jacobi* (Collet, 1907), the top or bottom of the Paquier 'oceanic anoxic event', the topmost organic-rich bed of the faisceau Kilian, or "any other datum" (Hart et al., 1996, p. 51).

3. The views of Casey (1999)

Casey (1999) described the ammonite fauna of the Argiles à *Bucaiella* on the Normandy coast and, in the concluding section, drew attention to the difficulty of correlating the sequence of early members of the *Leymeriella* lineage outside " the narrow corridor of distribution of the genus, stretching from Iran to northern Greenland" (1999, p.626). Instead, he proposed the first occurrence of the genus *Hypacanthoplites* as "offering a more suitable marker for the base of the Albian", stating further that:

"There are a few drawbacks to taking *Hypacanthoplites* as the basal marker for the Albian. Differentiation of early *Hypacanthoplites* from late *Acanthohoplites* can be readily made only in microconchs or juveniles; the flat, delicately noded venter diagnostic of *Hypacanthoplites* being in these early forms a transient feature of the first few whorls. The genus has not been recorded from the Arctic and in some regions where faunas of primitive *Hypacanthoplites* are well represented in continuous ammonitiferous sequences, as in the Kopet-Dagh area of Turkmenistan, the published stratigraphy (e.g., Glazunova, 1953) is not sufficiently refined to pin-point the *nolani-jacobi* contact. However, the first occurrence of *Hypacanthoplites* is well documented in the stratigraphical column of Western Europe and can be determined in the expanded succession of the Vocontian Trough, France, one of the chief candidate-regions for Aptian/Albian boundary stratotype selection.

Not only does the appearance of *Hypacanthoplites* provide a practical baseline for the Albian Stage of wide applicability, but the return of the *jacobi* Zone to the Albian would go a long way towards eliminating a troublesome issue concerning the Aptian Stage. This is the question of whether the Aptian should be divided into two or three substages. Since Breistroffer (1947) added to the classic Lower ('Bedoulian') and Upper ('Gargasian') Aptian an uppermost

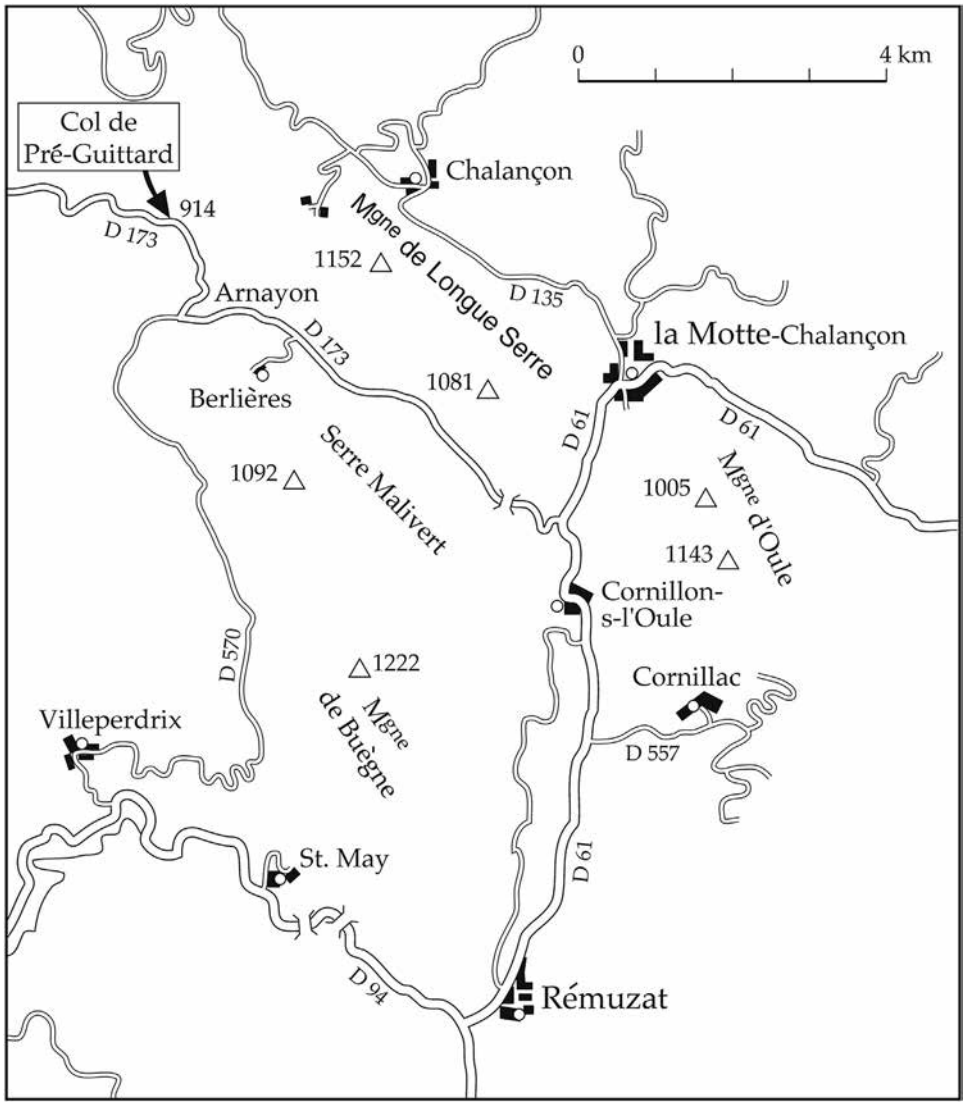

Fig. 2. Location map for the Col de Pré-Guittard, Arnayon (Drôme). Rémuzat lies about 50 km northeast of Orange.

'Clansayesian' Substage (=*nolani* and *jacobi* Zones of present usage), different practices have developed. In general, though not universal, workers in the Boreal realm tend to retain the classic twofold division, while those concerned with the Tethyan realm have favoured a threefold division by employing a 'Middle Aptian'

It is here proposed that the concept of a 'Clansayesian' or third substage of the Aptian be dropped, with the *jacobi* Zone being transferred to the Albian and the *nolani* Zone accepted as the topmost zone of the Upper Aptian. This would obviate the need for a 'Middle Aptian' and encourage international agreement on a simple bipartite division of the Aptian into Lower and Upper substages" (Casey, 1999, p.627).

There are several objections to adopting Casey's proposal, not least of which is his failure to provide details of a candidate GSSP, and the absence of any discussion of auxiliary markers. We would also note an earlier comment by Casey (1961, p.498), that "The *tardefurcata* Zone seems to mark a new beginning for the ammonites, in Europe at least (Casey, 1957), and this is the level best fitted to start the Albian".

4. The views of Kennedy et al. 2000

Kennedy et al. (2000) reviewed the history of the definition of the Aptian/Albian boundary, discussing in detail the ammonite schemes of Brinkmann (1937), Breistroffer (1947), Casey (1961, 1996, 1999), Kemper (1982), Owen (1996, 1999), and Ruffell and Owen (1995). The classic sequence in the Hannover area of Germany described by Brinkmann (1937) was reviewed in the light of subsequent work. The definition of the base of the Albian Stage at the first occurrence of the ammonite *Proleymeriella schrammeni* (Jacob, 1907) was rejected for, as these authors observed, this can only be recognized over a limited area near Hannover and no more widely recognized secondary markers have been documented.

Taking up the suggestion of the 1995 Brussels meeting, Kennedy et al. (2000) suggested an alternative Aptian–Albian boundary, defined by the first occurrence of the ammonite *Leymeriella* (*L.*) *tardefurcata* (d'Orbigny, 1841) in the expanded Marnes Bleues section at Tartonne, Alpes-de-Haute-Provence, France.

They documented in detail the palynomorph, calcareous nannofossil, planktonic foraminifera, ammonite, and inoceramid bivalve sequence, organic and inorganic carbon isotopes, trace-,

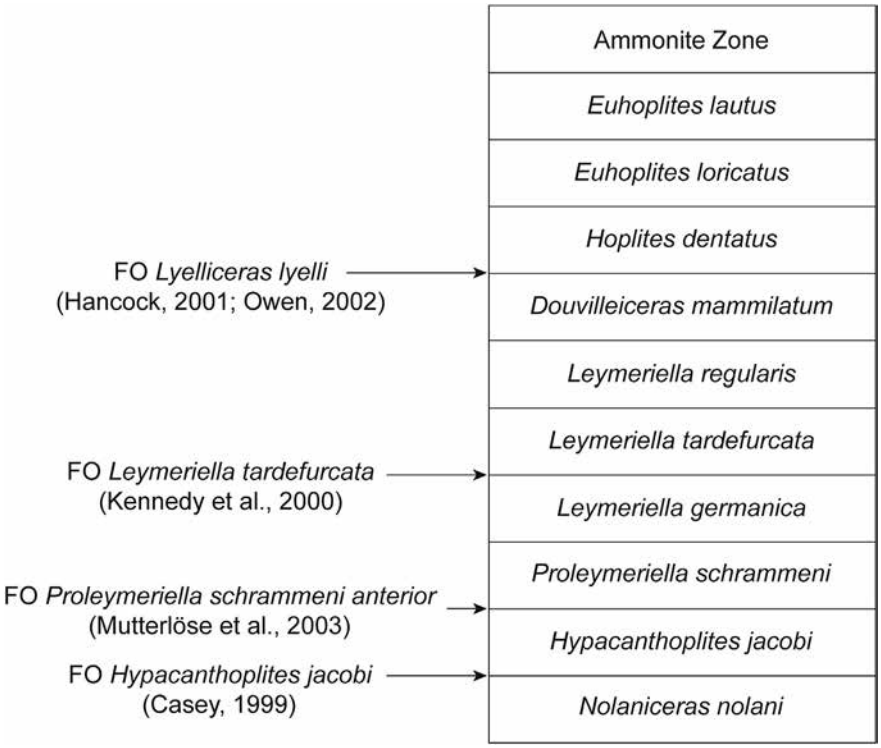

Fig. 3. Recently proposed markers for the base of the Albian Stage, plotted against a composite ammonite zonation after Hancock (1991) and Kennedy et al. (2000).

rare-earth, and major-element record, and strontium-isotope data for sections at the Col de Pré-Guittard, Arnayon (Drôme), and Tartonne (Alpes-de-Haute-Provence). The Pré-Guittard section, considered as a candidate Global Boundary Stratotype Section (GSS) for the base of the Albian Stage at the Second International Symposium on Cretaceous Stage boundaries held in Brussels in September 1995, provided a standard section for the boundary interval in SE France. In the context of a boundary defined at the first occurrence of the ammonite *Lemeriella* (*L.*) *tardefurcata*, it was shown to be unsuitable as a GSSP, because there is a minor hiatus at the critical level in the section. In contrast, the Tartonne section was shown to be a potential GSS, as the sequence is continuous across the critical interval. The Boundary Point for the base of the Albian Stage proposed by these authors was the first criterion proposed at Brussels: the first appearance of the ammonite *Leymeriella* (*L.*) *tardefurcata* at the base of the Niveau Paquier within the expanded Marnes Bleues sequence at Tartonne. The first appearance is only 60 cm above the last record of its presumed ancestor, *L.* (*L.*) *germanica* Casey, 1957. So defined, the boundary lies within the *Prediscosphaera columnata* Nannofossil (NF) Zone NC8/CC8, and the planktonic foraminifera *Hedbergella planispira* Partial Range Zone.

No major- or trace-element event was found to be associated with the proposed boundary, nor was an unequivocal oxygen or carbon isotopic signal detected. Strontium- isotope data from the Tartonne section are compatible with values elsewhere in the basin, and show that the base of the Albian, defined by the first appearance of *L.* (*L.*) *tardefurcata*, corresponds to an interpolated $^{87}Sr/^{86}Sr$ ratio of 0.707339 ± 0.000021 (data normalized to a value for the NBS 987 standard of 0.710250).

5. The views of Hancock (2001)

Hancock (2001) rejected the proposals of Kennedy et al. (2000), and proposed a radical alternative: to redefine the base of the Albian at the first occurrence of *Lyelliceras lyelli* , which currently defines the base of the Middle Albian in ammonite terms. *Lyelliceras lyelli* has a very widespread geographical distribution, as Hancock rightly states. Were his proposal to be adopted, there would have been a major change in nomenclature, with what is currently regarded as the lower Albian being transferred to the upper Aptian, and either a re-division of the Albian into newly defined lower, middle and upper Albian Substages, or the renaming of the currently defined middle Albian as a new lower Albian, with no middle Albian recognized. Such a change would have been a potential source of confusion, but this would not have been insurmountable. But there were more serious objections to the proposal, and these related to the matters of a candidate boundary section, and ancillary markers. These objections emerged from a consideration of Hancock's observations on possible boundary stratotypes (2001, pp. 679-680):

"Moreover, Hart (1973) has shown that "…appearing at – or about – the base of the *lyelli* (Sub)Zone [is] the distinctive foraminiferal species *Epistomina spinulifera.* Associated with this taxon in UK successions (Hart, 1973; Price, 1977; Hart et al., 1989) are *Conorboides lamplughi* and *Gavelinella tormapensis.* Magniez-Jannin (1983), working on the successions of the Aube has compared her micropalaeontological zonation with that of the ammonite faunas and located the base of the Middle Albian (see Amédro et al., 1995, fig. 6) in the middle of her Zone 2 (based on the appearance of *Valvulineria parva rotunda).* Using material from the same localities as Hart in S.E. England, Taylor (1982) has identified a number of calcareous nannofossils *(Prediscosphaera cretacea, Dictyococcites parvidentatus, Gaarderella granulifera* and *Braarudosphaera regularis)* that appear at, or about, the boundary." (Hart et al., 1996, p. 51).

"Whilst all these records will need to be checked again at other localities, there is promise here of foraminiferal and nannofossil back-up."

Hancock continues: "A potential boundary-stratotype is the section at Les-Côtes-Noires-de-Möeslaines near St Dizier, Haute-Marne, France. This section has been described by Destombes and Destombes (1965) and Owen (1971). There is a section and discussion in Hart et al. (1996, including figs. 4 and 5).

However, should Les Côtes-Noires prove to be unsuitable, there may be other possible sections in south-east France. Latil (1994a,b) does not mention any expanded sections and the famous *Lyelliceras*-rich occurrence at Escragnolles, northwest of Grasse in the Alpes-Maritimes, is in a condensed bed. However, the magnificent survey by Bréhéret (1997) in the Vocontian Trough has shown the large number of good sections previously unsuspected in this region.

The Djebel Ouenza region on the borders between Algeria and Tunisia has yielded ammonites of the correct general age (Dubourdieu, 1953). In this area also these are in condensed beds in a region where often the successions are much expanded. It is a reminder that the *lyelli* Zone probably reflects a time of a eustatic low sea-level, but it is only a third order cycle and is therefore less likely to give difficulties compared to those in the *tardefurcata* Zone".

Present accounts of the Côtes-Noires section are simply inadequate in terms of the necessary detail for it to be considered as a GSSP at this time. In particular, there is no detailed account of the ammonites, all-important for Hancock's proposal. The faunas in Destombes and Destombes (1965, p.260) are only listed at generic level in part, and no specific determinations are given at the critical levels: the actual first occurrence of *Lyelliceras lyelli* in the section has not been documented, nor is it known if its presumed ancestor, *Lyelliceras pseudolyelli* (Parona and Bonarelli, 1897) is present. The critical interval between what Owen (1971, p. 91) referred to the *eodentatus* Subzone, and the upper part of bed 7, which he referred to the *lyelli* Subzone, appears to be undated.

Hancock's suggestion that "there may be other possible sections in southeast France" may well be true, but none are known in which *Lyelliceras lyelli* occurs in an expanded section, no previous author known to us has ever described such a section, and we have seen no museum material to indicate the existence of such a section. Regarding the possibility of a candidate GSSP in the Djebel Ouenza region, the sequence examined by Latil (2011) demonstrated that the index species occurs in a condensed level with mixed faunas of middle and earliest late Albian age at Jebel El Hamra in Tunisia, as they do at Jebel Aïdel in Algeria.

6. The views of Owen (2002)

Owen (2002) rejected the north German successions as a possible site for a GSSP because of the absence of permanent exposures, and because the classic marker – the first appearance of *Leymeriella schrammeni* – could only be recognized over a very limited area. He rejected Casey's proposal because of the lack of an uncondensed permanent reference section. He rejected the proposal by Kennedy et al. (2000) of the first occurrence of *Leymeriella tardefurcata* in an expanded section in the Vocontian Basin because "the boundary point chosen is of local value only, set within a series of *Leymeriella* species chrons which are essentially confined to the European Province and immediately adjacent Tethyan and Boreal areas". Owen supported the proposal of Hancock (discussed above) with the first occurrence of *Lyelliceras lyelli* as the marker for the base of the Albian Stage, and made the following statement:

"In the southern and eastern boundaries of the Paris Basin, France, ephemeral sections spanning the current highest lower Albian and lowest middle Albian have been documented in detail (e.g., Owen, 1971, 1984, modified in Hart et al., 1996). Destombes and Destombes (1965) described the only 'permanent' section known in this region exposed in the natural river cliff at Les Côtes-Noires on the west bank of the River Marne, 1 km west of Möeslain (Haute Marne). There is evidence of the possibility of similar, but more permanent, sections across this boundary situated in the Vocontian Basin, as Hancock indicates. But this change in *Lyelliceras* from *pseudolyelli* morphs to typical *lyelli* morphs is seen in the Tethyan province from Peru in the west to the Indian subcontinent in the east, in greatly expanded sedimentary successions that are permanently physically accessible."

We have noted the inadequacy of the Côtes-Noires section above. As to the statement "There is evidence of the possibility of similar, but more permanent sections across this boundary situated in the Vocontian basin, as Hancock indicates", this evidence remains unpublished, and we know of no such sections (see also above). As to the possibility of greatly expanded sedimentary successions "in the Tethyan Province from Peru in the west to the Indian sub-continent in the east….. that are permanently physically accessible" (Owen, 2002, p.11), this remains a possibility only, in the absence the comprehensive documentation of such sections to the level required for consideration as a GSSP.

7. The views of Mutterlose et al. (2003)

Further contributions to the debate are given by Mutterlose et al. (2003). These authors provide a detailed account of the succession across the Aptian/Albian boundary in the classic German sense in the pit at Vöhrum. They discuss the work of Kennedy et al. (2000) in the Vocontian Basin, and their criticisms are repeated here:

"Aptian and Albian marls and black shales attain a thickness of up to 750 m in the Vocontian Basin of southeast France. The sediments of the 'Marnes Bleues Formation' of late Aptian and early Albian age attain a thickness of at least 200 m, and have been studied in detail by Kennedy et al. (2000). Their multidisciplinary study included palynomorphs, calcareous nannofossils, planktonic foraminifera, ammonites, stable isotopes ($\delta^{13}C$, $\delta^{18}O$, $^{87}Sr/^{86}Sr$) and trace elements. They proposed a biostratigraphic definition of the Aptian/Albian boundary in two sections: Col de Pré-Guittard and Tartonne, but only the Tartonne section yielded a continuous succession suitable for defining the boundary…

Lithological markers in these sections, such as the Jacob, Kilian and Paquier anoxic events, which were mentioned in Hart et al. (1996), are unsuitable as GSSPs, since they are a facies often of local to regional extent, varying in thickness and number of consistent beds within a few kilometres. The rare elements and the stable isotope distribution patterns in these sections do not show significant events that can be used stratigraphically. Unfortunately, thin horizons of possible tuff around the Fromaget and Jacob levels, which might correspond to the Vöhrum tuff, were not included in analyses in Kennedy et al. (2000). In particular, the $\delta^{13}C$ and $\delta^{18}O$ curves show a diagenetic overprint to be expected from whole rock samples in a mudstone facies and are thus not suitable for supra-regional correlation. A high resolution study of the stable isotopes from Aptian/Albian boundary interval may, however, supply in the near future a signal for defining the boundary.

Palaeontological markers are more informative and relevant, but are also problematic. Palynomorphs serve as a good local tool for the recognition of a hiatus at base of the Niveau Paquier in the Pré-Guittard section (Kennedy et al., 2000, p. 615, fig. 16). The LO of *Stiphrosphaeridium* (*P.*) *anthoporum,* which in higher latitudes

undoubtedly ranges into the Albian, approximates to the base of the *Leymeriella tardefurcata* Zone sensu Kennedy et al. (2000). The biostratigraphic signal to be derived from calcareous nannofossils is also biased. The important index species *Prediscosphaera columnata* (circular) has its FO in the Pré-Guittard section about 3 m above the top of the Paquier level, in the Tartonne section more than 11 m below the base of the Paquier level. This would imply diachroneity of the Paquier level between the two sections studied. Bown in Kennedy et al. (2000) implied that the circular form was difficult to determine. The earlier occurrence of *Prediscosphaera* forms known from the uppermost Aptian of north Germany are taxonomically less strictly defined (nearly round, subcircular) and thus difficult to use. The FO of the genus *Prediscosphaera (P. spinosa*) lies somewhere in the upper Lower Aptian (*Neohibolites ewaldi* belemnite Zone) and thus cannot be used to solve the Aptian/Albian boundary problem. Planktonic foraminifera are not helpful either, since the Aptian-early Albian interval is characterised by a distinctive crisis with only small *Hedbergella* being common. The top of the planktonic foraminiferal event 1 is marked by the temporary disappearance of the genus *Ticinella* and the LO [last occurrence] of *Ticinella bejaouensis*. This level, which may constitute a suitable boundary candidate for defining the Aptian/Albian boundary, has commonly been taken to lie close the boundary by many workers. According to Kennedy et al. (2000) it lies in the *H. jacobi* Zone, about 40 m below the Paquier level in the Pré-Guittard section. Owen (2002) has demonstrated the unsuitability of using the alleged FO of *Leymeriella (Leymeriella) tardefurcata* as marking the Aptian/Albian boundary in these French sections. *Leymeriella* is restricted to the European faunal province and immediately adjacent areas in the early part of the Lower Albian, and is, therefore, ineligible as a global marker…"

In conclusion, Mutterlose et al. state that:

"both the southeast French and northwest German successions are of limited use for defining the Aptian/Albian boundary on a global scale. Neither of the primary markers suggested (FO *Leymeriella* (*L.*) *tardefurcata* in southeast France, FO of *Leymeriella* (*Proleymeriella*) *schrammeni anterior* in northwest Germany) can be used on a global scale. In order to define the Aptian/Albian boundary not only in the classic areas of limited extent but also in the vast oceanic areas of the Atlantic, Indian and Pacific oceans, a distinct global physical boundary is required. This may be achieved eventually by absolute age dating of lavas and tuff horizons, by high resolution studies of stable isotopes, or, possibly, by planktonic organisms (dinoflagellate cysts, planktonic foraminifera, radiolarians). At present, the Aptian/Albian boundary based on the distribution of ammonites *Hypacanthoplites* and *Leymeriella*, cannot be determined on a global scale."

We would note the following in response to some of the points raised above. Kennedy et al. (2000) reported the presence of *Prediscosphaera columnata* (subcircular morphologies) in all samples from approximately 4 m above the Niveau Jacob at the Col de Pré-Guittard, and discussed the problems associated with identifying the first occurrence of truly circular specimens in a gradually evolving lineage. Rare, questionable circular specimens were also reported below the Paquier level, down to the Niveau Kilian level. This problem accounts for the stratigraphic discrepancies recorded between authors (see below), and for the documentation of apparent diachroneity between different sections (Herrle et al., 2004). Herrle and Mutterlose (2003, fig. 5) recorded the FO of *Prediscosphaera spinosa* (elliptical member of the lineage) within the Faisceau Fromaget at the Tarendol section, and *Prediscosphaera columnata* from a higher level, near the limestone DC2, which we estimate, from their figure, as 14 m above the Niveau Jacob, also in the Tarendol section. They did not discuss their taxonomic concepts for these species, and the stratigraphic discrepancies are most likely related to the application of slightly differing taxonomic limits. Mutterlose et al. (2003) document the transition from subcircular to circular *Prediscosphaera columnata* through the Aptian/Albian interval level at Vöhrum, with subcircular forms first recorded just above the first occurrence of what they term *Leymeriella* (*Proleymeriella*) *schrammeni*. This is substantially the same biostratigraphic level as in the Pré-Guittard section according to our observations.

Both Kennedy et al. (2000) and, in more detail, Herrle (2003), record significant nannoconid abundances through the Niveau Paquier, and this acme event may be of stratigraphic significance, at least regionally.

To summarize, *Prediscosphaera columnata* is a globally distributed planktonic species and should remain a candidate at least as a secondary marker event close to the Aptian/Albian boundary. However, strict morphological limits need to be applied in order to obtain stratigraphic consistency (see discussion in Kennedy et al., 2000 and Mutterlose et al. 2003).

As far as the stable-isotope signatures in calcareous mudstone facies are concerned, the $\delta^{13}C$ and $\delta^{18}O$ curves do indeed show some degree of diagenetic overprint (Weissert and Bréhéret, 1991). However, both the Kilian and Paquier levels show a reproducible negative carbon-isotope excursion that can be traced from the Tethyan region into the Atlantic, although there is the potential to confuse the two levels in incompletely recovered core material (Herrle, 2002; Herrle et al., 2004; Huber and Leckie, 2011; Trabucho Alexandre et al., 2011; Petrizzo et al., 2012).

8. The view of the Subcommission

The proposal of the first occurrence of *Leymeriella tardefurcata* at the base of the Niveau Paquier in the Tartonne section was considered by the Subcommission on Cretaceous Stratigraphy in 2010, and rejected on the basis of the absence of corresponding microfossil and chemostratigraphic events, the limited distribution of *Leymeriella tardefurcata*, and the problems of correlation of this datum outside Southeast France (Premoli Silva, 2010).

9. A candidate GSSP for the base of the Albian Stage

9.1. Historical background

The Étage Albien was introduced by Alcide d'Orbigny in 1843 (in d' Orbigny, 1842–3, p.404), as follows:

"Gault. L'étage ainsi nommée de ses argiles varie on ne peut d'avantage sous le rapport minéralogique. Il est en effet forme d'argiles, à ses parties moyennes, à Wissant (Pas-de-Calais), aux Côtes Noires (Haute-Marne), à Gaty, à Maurepaire, à Dienville (Aube), et à Folkestone (Angleterre); mais à Wissant même, à Ervy (Aube); à Saint-Florentin (Yonne), à la pêrte du Rhône (Ain) , à Macheromenil (Ardennes), à Varennes (Meuse) , il est aussi composé de grès verts, de grès blanchatres; à Escragnolle (Var), il est représenté par une véritable glauconie crayeuse; à la Montagne-des-Fis (Savoie), par des roches noirâitres compactes. On voit donc que les noms de *gault,* de *glauconie sableuse,* de *grès vert inférieur,* ne peuvent non plus être proprément appliqués dans tous les cas, ce qui me détermine à proposer, pour cet étage, le nom de terrain ALBIEN, 1'Aube (*Alba*) le traversant à Dienville et sur beaucoup d'autres points".

The succession in Aube was carefully documented by Rat et al. (1979), Amédro et al. (1995) and Colleté (2011). Although of considerable historic interest, the area is unsuitable for defining the base of the stage in contemporary terms. As Amédro et al. (1995, p. 34) note, "1'Albien type reste incomplétement connu. Cette situation est liée à 1'absence des coupes continues et à 1' importance de la couverture végétale qui rend les affleurements très rares et éphémères".

It is this lack of suitable permanent sections that makes Aube unsuitable as a location for a GSSP. Furthermore, the lowest fossiliferous Albian recognized is a condensed phosphatic nodule bed at the top of the Sables Verts de 1'Aube (Amédro et al., 1995), which has yielded *Hypacanthoplites milletioides* Casey, 1961, *H. milletianus* (d'Orbigny, 1841), *Leymeriella* (*L.*) *tardefurcata*, *L.* (*N.*) *regularis* (d'Orbigny, 1841), and *Douvilleiceras mammilatum* (Schlotheim, 1813). The underlying Sables Verts have not yielded diagnostic fossils, and rest unconformably on Aptian Argiles à Plicatules (Rat et al., 1979; Amédro et al., 1995).

9.2. The succession in the Vocontian Basin, SE France

That this area might provide the basis for a Global Standard Section for the base of the Albian Stage arose during discussions at the 1995 Symposium on Cretaceous Stage Boundaries held in Brussels. The debate is ably summarized by Hart et al. (1996, p. 49):

"Bréhéret et al. (1986) have described an integrated sedimentological, geochemical and palaeontological study of the Aptian/Albian succession in the Vocontian Trough. In particular, the succession on the Col de Pré-Guittard (Drôme) may be:

- the most complete succession across the boundary
- one of the best studied sections currently available
- well-exposed and unlikely to disappear over time
- readily accessible

It contains a range of faunal and floral groups together with the Paquier and Jacob "oceanic anoxic events". Using data from Bréhéret et al. (1986) it has been possible to construct a summary chart (figure 3 [of Hart et al.]), which shows a range of geological, sedimentological and palaeontological features that could be used to define the boundary. Options appear to be:

- FO of *Leymeriella tardefurcata*
- FO of *Douvilleiceras* ex. gp. *mammillatum*
- FO of *Prediscosphaera columnata*
- LO of *Hypacanthoplites jacobi*
- the Paquier "oceanic anoxic event" [top or bottom]
- the topmost organic-rich bed of the "faisceau Kilian"
- any other datum

While there are a number of gaps in our knowledge, the dinoflagellate cysts have recently been described by Vink (1995). These data show a number of possible datums between 50 m and 80 m (figure 3 of Hart et al.), with the most suitable horizon being located slightly above the boundary indicated in the figure. Bréhéret (pers. comm. to Han Leerveld [1996]) has indicated that the full data on the ammonite succession has yet to be published and that the boundary should be taken as lying between 42 m and 54 m. Bréhéret and Delamette have also suggested that there may even be a hiatus at, or about, the potential boundary.

Important extinctions of dinoflagellate cysts at, or about, the boundary include *Hystrichosphaerina schindewolfii* and *Cerbia tabulata* while *N. singularis*, *P. securigerum*, *Systematophora penicillata*, *Lithosphaeridium arundum* and *P. eisenackii* have their first appearance within the same interval. The planktonic foraminifera are very abundant in this succession but, unfortunately, cannot offer a suitable LAD or FAD at this level. Caron (as a co-author in Bréhéret et al., 1986) has shown that the planktonic foraminifera responded to the Paquier (and other) oceanic anoxic events by adjusting their position in the water column and often excluding those that lived in deeper-water environments. Ticinellids, and other stratigraphically important taxa, disappear at the critical level (figure 3 of Hart et al.), being replaced by a population of small, shallow-water, hedbergellids (Bréhéret et al., 1986, figs. 3, 11, 13, 14)".

9.3. The Col de Pré-Guittard revisited: a new candidate GSSP

Hart et al. (1996) recognized the importance of the section at the Col de Pré- Guittard. It was dismissed by Kennedy et al. (2000) as a candidate GSSP defined as the first occurrence of *Leymeriella* (*L.*) *tardefurcata* because there is a minor discontinuity at the base of the Niveau Pacquier at this locality. The section was reinvestigated by Petrizzo et al. (2012, 2013), who examined the planktonic foraminiferal record in greater detail than previous workers and generated a new stable-isotope curve. Key events were identified across the Niveau Kilian. Assemblages from below the Niveau Kilian are dominated by a few species of long-ranging *Hedbergella* and large-sized *Paraticinella*, which disappear close to the base of the Niveau Kilian. The planktonic foraminifera from across the Niveau Kilian and the succeeding levels studied are made up of minute but very distinctive smooth species: *Microhedbergella miniglobularis* Huber and Leckie, 2011, and *M. renilaevis* Huber and Leckie, 2011. This series of bioevents represents one of the most significant taxonomic turnovers in the history of the group and can be recognized worldwide. For example, the sequence of events across the Niveau Kilian replicates those established by Huber and Leckie (2011) and Huber and Leckie (2011) at DSDP and ODP sites in the southern South Atlantic (DSDP Site 511), Blake Plateau in the western North Atlantic (ODP Hole 1049C) and the southeast Indian Ocean (ODP Site 763). The key datum, the first occurrence of *Microhedbergella renilaevis* within the Niveau Kilian at the Col de Pré-Guittard, is proposed here as a candidate criterion for the base of the Albian Stage as it provides, for the first time, a datum within a section that fulfils many of the required criteria for a GSSP that can be correlated between onshore and offshore sections, from southeast France to the Atlantic and Indian Oceans (Huber and Leckie 2011).

We have integrated these new planktonic foraminiferal data, with new and previously published calcareous nannofossil, ammonite, bivalve, palynological, sedimentological and geochemical information to provide a comprehensive sequence of events, from oldest to youngest, summarized in Figs. 4 and 5, and is as follows:

(1) The topmost limestone of the Faisceau Fromaget PGO, the zero datum.
(2) The Niveau Jacob, at 2.5–4.0 m.
(3) The lowest occurrence of subcircular examples of the nannofossil *Prediscosphaera columnata* at 6 m.
(4) The lowest occurrence of circular examples of the nannofossil *Prediscosphaera columnata* and the lowest occurrence of the nannofossil *Helicolithus trabeculatus* at 29.5 m.
(5) The disappearance of the planktonic foraminiferan *Hedbergella infracretacea* at 33.5 m.
(6) The disappearance of the planktonic foraminiferan *Hedbergella aptiana* at 34.75 m.
(7) The disappearance of the planktonic foraminiferan *Paraticinella rohri* (=*Paraticinella eubejaouensis* in previous literature; see Ando et al., 2014) at 34.75 m.

(8) The lowest occurrence of the planktonic foraminiferan *Microhedbergella miniglobularis* at 35 m.
(9) The lowest occurrence of the nannofossil *Gartnerago stenostaurion* at 36 m.
(10) The disappearance of the planktonic foraminiferan *Pseudoguembelitria blakenosensis* at 36.8 m.
(11) The base of the laminated Niveau Kilian at 37 m.
(12) The minimum value of negative excursion of $\delta^{13}C$ at 37.4 m.
(13) **The proposed candidate boundary marker: the first occurrence of the planktonic foramininferan *Microhedbergella renilaevis* at 37.4 m.**
(14) The acme of the palynomorph *Hapsocysta peridictya* at 46 m.
(15) The lowest occurrence of the nannofossil *Broinsonia viriosa* at 60 m.
(16) The lowest occurrence of the nannofossil *Laguncula dorotheae*, at 63.3 m.
(17) The lowest consistent occurrence of circular morphotypes of the nannofossil *Prediscosphaera columnata*, at 66.6 m.
(18) The base of the Niveau Paquier at 68 m. This coincides with a minor discontinuity at the Col de Pré- Guittard.
(19) The lowest occurrence of the ammonite *Leymeriella (L) tardefurcata* at the base of the Niveau Paquier, 68 m. This corresponds to a distinctive geochemical signal in the organic matter present, a result of a significant contribution from Archaea (Kuypers et al., 2001, 2002).
(20) The lowest occurrence of the bivalve *Actinoceramus salomoni coptensis* at the base of the Niveau Paquier.
(21) The distinctive negative carbon-isotope excursion that begins just above the base of the Niveau Paquier in the Vocontian Basin, and is a local manifestation of Oceanic Anoxic Event 1b.
(22) The lowest occurrence of the ammonite genus *Douvilleiceras* within the Niveau Paquier.
(23) The lowest occurrence of the ammonite genus *Oxytropidoceras* within the Niveau Paquier.
(24) The highest occurrence of the ammonite *Hypacanthoplites anglicus* in the upper part of the Niveau Paquier.
(25) The termination of the carbon stable-isotope excursion associated with Oceanic Anoxic Event 1b, which is situated at the top of the Niveau Paquier in the Col de Pré-Guittard at approximately 70 m.
(26) The highest occurrence of the nannofossil *Broinsonia viriosa* at 70 m.
(27) The lowest occurrence of the nannofossil *Seribiscutum primitivum* at 95 m.
(28) The Niveau Leenhardt, with ammonites of the *Douvilleiceras mammillatum* group, 101.5 m above the top of the Faisceau Fromaget at Pré-Guittard.
(29) The occurrence of the ammonite *Hoplites (Isohoplites) steinmanni,* 109.5 m above the top of the Faisceau Fromaget at Pré-Guittard.

10. The Col de Pré-Guittard, Alpes-de-Haute-Provence, candidate Global boundary Stratotype Section and Point for the base of the Albian Stage

10.1. Location

The Col de Pré-Guittard section (Figs. 1, 2, 5) lies 11 km north-northwest of Rémuzat and 19 km northwest of Rosans in the Département of Drôme (Lambert coordinates 836,42;3248, 95; 1;25,000 topographic sheet Série Bleu 3138E, La Motte-Chalançon). It is reached by taking the D173 west from its junction with the D61, 2 km south of La Motte-Chalançon. The locality lies above and below the road at spot height 914, 500 m north of the Ferme Pré-Guittard. Previous key accounts of the section are presented by Bréhéret et al. (1986), Bréhéret (1997 and references therein), Kennedy et al. (2000) and Petrizzo et al. (2012; 2013).

10.2. Criteria fulfilled

It will be seen that the Col de Pré-Guittard section provides:

- A candidate Global boundary Stratotype Section and Point for the base of the Albian Stage that can be identified using the first occurrence of the planktonic foraminiferan *Microhedbergella renilaevis* within the Niveau Kilian, set within a matrix of secondary markers.
- The candidate boundary lies within the widely recognized crisis interval that affected planktonic foraminifera over wide areas of the globe within the lowermost NC8/CC8 nannofossil Zone.
- The candidate boundary coincides with the minimum value of a negative excursion of approximately 1‰ in carbonate ™^{13}C that can be traced into the Atlantic region (Herrle, 2002; Petrizzo et al., 2012, 2013; Trabucho Alexandre et al., 2011).
- The candidate boundary lies some distance beneath the onset of the negative stable carbon-isotope excursion associated with the globally recognisable Oceanic Anoxic Event 1b, as demonstrated previously through the work of Herrle (2002; see also Herrle 2003, Herrle et al., 2004, Herrle and Mutterlose, 2003, and Herrle et al., 2003a,b) elsewhere in the Vocontian Basin, and demonstrated in the Col de Pré-Guittard. It should be noted that some authors include the Niveau Kilian as a partial manifestation of a longer lasting OAE 1b to accompany the Niveau Paquier and Niveau Jacob (Leckie et al., 2002: Trabucho Alexandre et al., 2011).
- The succession that contains the candidate GSSP is rhythmically bedded in the Vocontian Basin, and so has the potential for development of an orbital timescale for the boundary events.

The proposed GSSP fulfils many, but not all, of the requirements set out by Remane et al. (1996):

- It provides an exposure over an adequate thickness that records an adequate time interval such that the boundary can be determined using auxiliary markers.
- There is continuous sedimentation across the boundary interval.
- The boundary interval is expanded, and marker events are well-separated.
- The boundary interval is not affected by syn-sedimentary or significant tectonic disturbance.
- Well-preserved (if crushed) macrofossils occur at several levels (most notably ammonites).
- There is a rich microfauna and nannoflora.
- The section is easily and freely accessible by road.
- The outcrops are permanent and renewed by periodic erosion.

It should however be noted that:

- Data from the Kilian Level in the Atlantic Ocean suggest that there are no diagnostic major- or trace-element events associated with the proposed boundary (Trabucho Alexandre et al., 2011).
- There are no dateable volcanic ashes that offer the possibility of radiometric dating in the section.

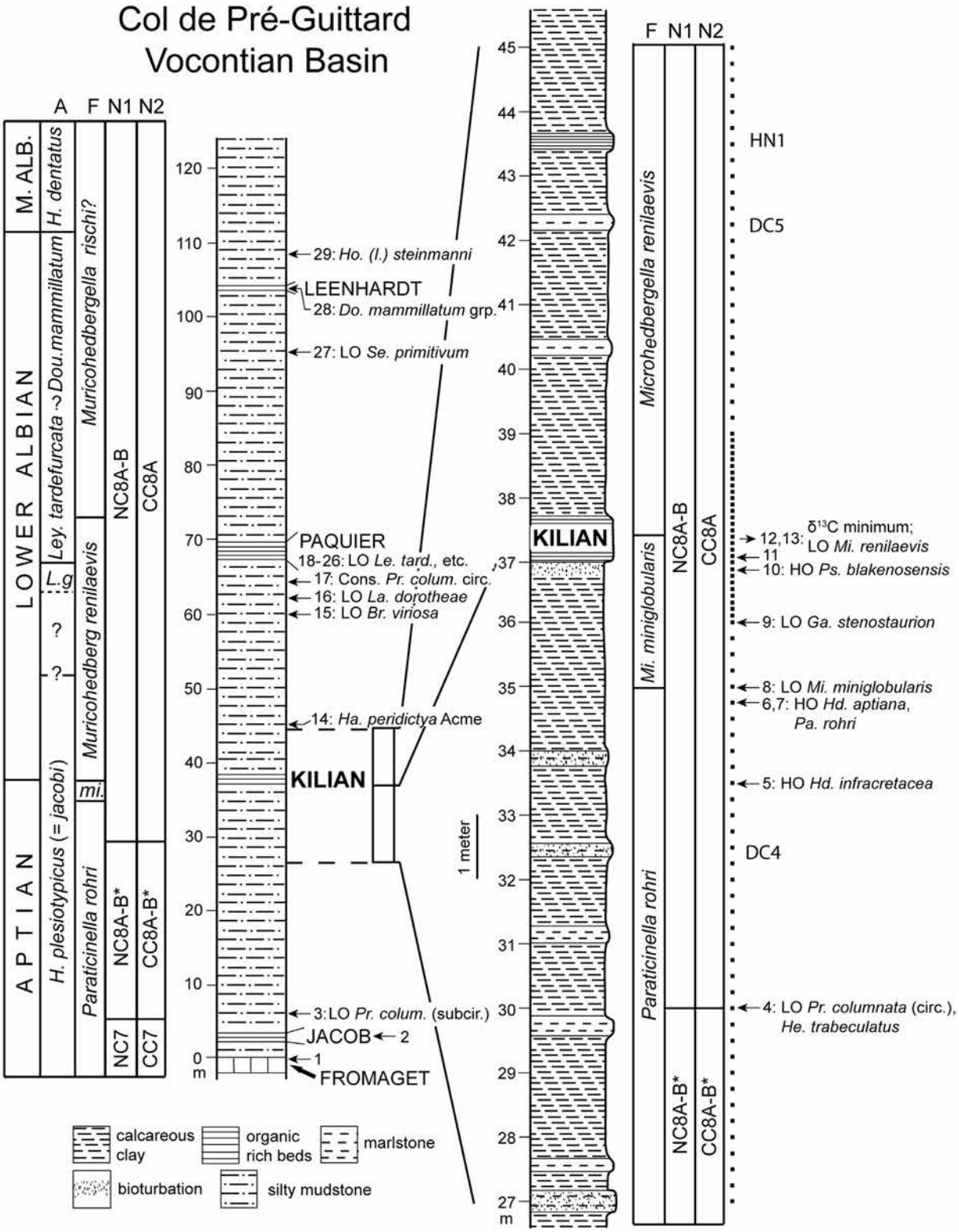

Fig. 4. The succession at the Col de Pré-Guittard, Arnayon (Drôme), showing local marker beds Fromaget, Jacob, Kilian, Paquier and Leenhardt. Numbers 1-29 refer to the sequence of events described in the text for the proposed candidate GSSP including the lowest occurrence of the planktonic foraminiferan *Microhedbergella renilaevis*, event 13, at the 37.4 m level (modified after Petrizzo et al., 2012). See text for complete spellings and explanation for unnamed events. Columns include A (ammonites - Kennedy et al, 2000), P (planktonic foraminifera - Petrizzo et al., 2013, with modification of *Pa. rohri* Zone, the equivalent of previously identified *Pa. eubejaouaensis* Zone), N1, calcareous nannofossils (NC = Roth et al., 1978 scheme) and N2 calcareous nannofossils (CC = Sissingh, 1977 scheme). LO = lowest occurrence, HO = highest occurrence. Abbreviated ammonite names are; *L.g., Leymeriella germanica*; *Ley*, *Leymeriella*; *Dou*., *Douvilleiceras*; *H*., *Hoplites*. The small squares to the right of the right column represent levels of samples taken for the study of Petrizzo et al. (2012).

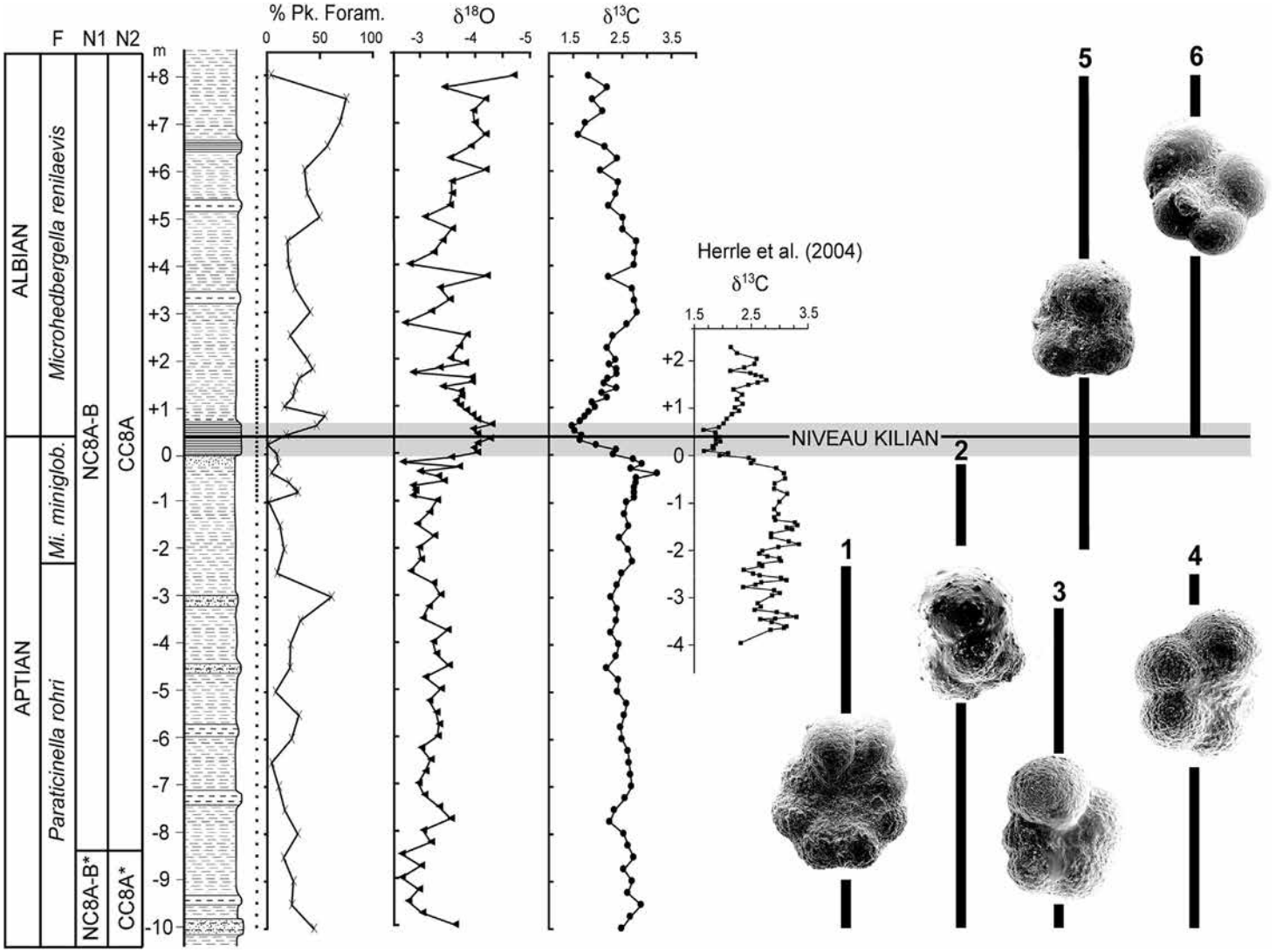

Fig. 5. Abundance (%) of planktonic foraminifera and oxygen- and carbon stable isotope stratigraphy from Petrizzo et al. (2012, 2013), and carbon-isotope data from Herrle (2002) through the Niveau Kilian at Pré-Guittard. Species illustrated (not to scale) with their ranges include: 1, *Paraticinella rohri*; 2, *Pseudoguembelitria blakenosensis*; 3, *Hedbergella infracretacea*; 4, *Hedbergella aptiana*; 5, *Microhedbergella miniglobularis*; 6, *Microhedbergella renilaevis*.

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