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The Cenomanian stage

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Abstract

Following discussions at the Second International Symposium on Cretaceous Stage Boundaries, held in Brussels, 8-16 September 1995, the Cenomanian Working Group, identified as marker for the base of the Cenomanian the first occurrence of the planktonic foraminiferan *Rotalipora globotruncanoides*. As GSSP (Global Boundary Stratotype Section and Point) for the base of the Cenomanian Stage, it proposed in the Mont Risou section (Rosans, Hautes-Alpes, France) the point of the first occurrence of the planktonic foraminiferan *Rotalipora globotruncanoides*, 36 m from the top of the Marnes Bleues Fm. For the Mont Risou section biostratigraphic data on calcareous nannofossils, planktonic foraminifera, ammonites, bivalves and carbon and oxygen isotopes have been studied.

The base of the Middle Cenomanian substage is the first appearance of the ammonite *Cunningtoniceras inerme* with the entry of *Inoceramus schoendorfi* and *Rotalipora reicheli* as secondary markers, with the Southerham Grey Quarry section at Lewes in Sussex (England) as stratotype for the Lower-Middle Cenomanian boundary.

For the base of the Upper Cenomanian no agreement was reached.

Key-words: Cenomanian, Upper Cretaceous, biostratigraphy, ammonites, inoceramids, foraminiferids, nannofossils, isotope stratigraphy, GSSP.

Résumé

A la suite des discussions au cours du "Second International Symposium on Cretaceous Stage Boundaries" tenu à Bruxelles (8-16 Septembre 1995), le Groupe de Travail du Cénomanien a choisi comme marqueur pour la base du Cénomanien l'apparition du foraminifère planctonique *Rotalipora globotruncanoides*. Comme "GSSP" (Global Boundary Stratotype Section and Point) pour la base du Cénomanien, le Groupe de Travail propose dans la coupe du Mont Risou (Rosans, Hautes-Alpes, France) la première apparition de ce foraminifère à 36 m sous le sommet de la Formation des Marnes Bleues. Pour la section de Mont Risou existent des données biostratigraphiques concernant les nannofossiles calcaires, les foraminifères planctoniques, les ammonites et les bivalves; les isotopes du carbone et de l'oxygène ont été étudiés.

La base du Cénomanien moyen a été placée à l'apparition de l'ammonite *Cunningtoniceras inerme* et, comme marqueurs secondaires, on a désigné *Inoceramus schoendorfi* et *Rotalipora reicheli*; comme stratotype pour la limite Cénomanien inférieur-moyen, on propose la carrière Southerham Grey, à Lewes (Sussex, Angleterre).

Pour la base du Cénomanien supérieur aucune décision n'a encore été prise.

Mots-clefs: Cénomanien, Crétacé supérieur, biostratigraphie, ammonites, inocéramidés, foraminifères, nannofossiles, stratigraphie isotopique, "GSSP".

Отчёт по Сеноманскому ярусу.

Резюме.
В результате обсуждений, прошедших в течение «Второго Международного Симпозиума по вопросам Границ Мелового Яруса» в Брюсселе (8-16 сентября 1995 года), Рабочая Группа Сеноманского яруса выбрала в качестве индекс-вида для основания Сеноманского яруса появление планктонического фораминифера *Rotalipora globotruncanoides*. В качестве «GSSP» (Global Boundary Stratotype Section and Point) для основания Сеноманского яруса Рабочая Группа предлагает первое появление данного фораминифера на глубине 36 метров от вершины отложения Marnes Bleues, в разрезе Mont Risou (Rosans, Hautes Alpes, Франция). Для разреза Mont Risou существуют биостратиграфические данные, касающиеся меловых нанофоссилий, планктонических фораминифер, аммонитов и двустворчатых моллюсков; изотопы углерода и кислорода также были изучены.
Основание подъяруса среднего Сеномана определяется при появлении аммонита *Cunningtoniceras inerme*; в качестве вторичных индекс-видов выбраны *Inoceramus schoendorfi* и *Rotalipora reicheli*. В качестве стратотипа для границы нижнего и среднего Сеномана учёные предлагают Карьер Southerham Grey, в Lewes (Sussex, Англия).
Что касается основания верхнего Сеномана, то на данный момент не было принято никакого решения.

Ключевые слова: Сеноманский ярус, верхний мел, биостратиграфия, аммониты, иноцерамы, фораминиферы, нанофоссилии, изотопическая стратиграфия, «GSSP».

HISTORICAL SUMMARY

The Cenomanian stage was proposed by D'ORBIGNY (1847) for the strata seen at Le Mans (lat.: Cenomanum-Paléontologie Française, Terrains Cretacés, **4:** 270) in the Paris Basin.

HANCOCK (1960) recognised three ammonite zones in the Cenomanian sequences of the Sarthe region, including the stratotype of D'ORBIGNY:

Upper Cenomanian - *Calycoceras naviculare* Zone

Middle Cenomanian - *Acanthoceras rhotomagense* Zone

Lower Cenomanian - *Mantelliceras mantelli* Zone

JUIGNET (1974, 1980), KENNEDY (1984) gave a more detailed subdivision with at least two standard zones in each substage.

Albian-Cenomanian boundary

Boundary criteria for the Albian-Cenomanian boundary which were under discussion in the first International Symposium on Cretaceous Stage Boundaries (BIRKELUND *et al.* 1984, HANCOCK, 1984) in Copenhagen.

Ammonite-based zonation

- Base of the *Hypoturrilites schneegansi* Zone established by DUBOURDIEU (1956) on the basis of Cenomanian sections in Tunisia and Algeria.
- Base of the *Graysonites adkinsi* Zone, first defined in Texas (MANCINI, 1979), but widely distributed in Tethyan and Pacific regions.
- Base of the *Neostlingoceras carcitanense* Zone in the Cenomanian of Europe.

[In many areas of the Northern Lower Temperate Realm (Boreal) there is a more or less important sedimentological hiatus between the Albian and Cenomanian].

- Base of the *Mariella (Wintonia) brazoensis* Zone underlying the *Graysonites adkinsi* Zone in Texas (YOUNG, 1957). This zone was not recognised outside of Texas till now and was not recommended.

Microfossil-based zonation

- LO of the planktonic foraminiferan *Planomalina buxtorfi* happens slightly earlier than the FO of the ammonite

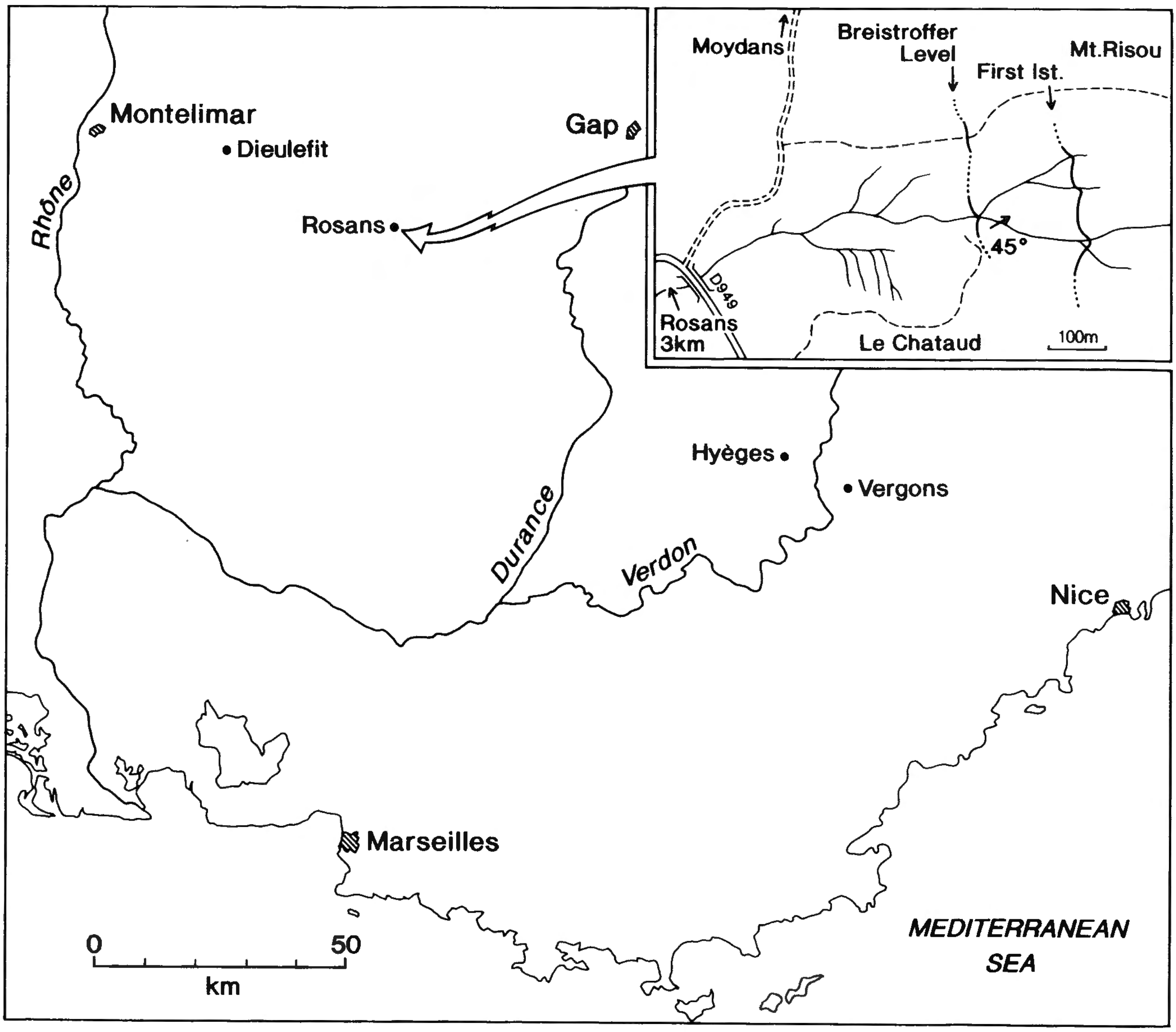


Fig. 1 — Locality map showing the position of the Mont Risou outcrops (from GALE *et al.*, 1996).

Hypoturrilites schneegansi. The occurrence of *Pl. buxtorfi* just below the Cenomanian is coincident with a flood occurrence of *Globigerinelloides bentonensis* (Morrow) used as Albian-Cenomanian boundary over the North Sea Basin (HART *et al.*, 1981).

- In Tethyan shelf carbonate successions the foraminiferal genus *Orbitolina* is useful: FOs of *O. (Orbitolina) concava concava* and *O. (O.) conica* are used at this level.
- The FO of the coccolith *Eiffelithus turriseiffellii* below the base of *Hypoturrilites schneegansi* can be traced in Tethyan and Boreal Realms.

Suggested stratotype

GALE *et al.* (1995, 1996) presented a proposal for a potential Albian-Cenomanian boundary stratotype at Mont Risou near Rosans (Hautes-Alpes, France) with boundary criteria. The base of the Cenomanian stage corresponds to the base of the widely recognised *Mantelliceras mantelli* Zone at Mont Risou. If *Mantelliceras mantelli* is absent, *Neostlingoceras* is a proxy ammonite.

Using a *planktonic foraminiferal succession* in the Mont Risou section GALE *et al.* explain:

''There are two possible planktonic foraminiferan proxy markers for the Albian-Cenomanian boundary, defined by the ammonite fauna at -30 m:
The first occurrence of *Rotalipora globotruncanoides* at -36 m, and its common occurrence at -27 m. The latter is a more reliable datum. It should be noted, that these planktonic foraminifera datums are only 6 m below and 3 m above the ammonite datum in what is a highly expanded section, while the first occurrence of *Rotalipora globotruncanoides* in the Kalaat Senan region of Central Tunisia (ROBASZYNSKI *et al.* 1993, 1994) is also just below the base of the Cenomanian as defined by ammonites''.

Bivalve succession

Not mentioned in Copenhagen, but useful for zonation at Mont Risou is the bivalve succession. *Aucellina* is common in the Upper Albian and extends into the basal Cenomanian strata in England, France, Germany, Poland and Russia (*Aucellina/ultimus* event). Two inoceramid species are overlapping in one bed at Mont Risou. In the basal layers *Inoceramus anglicus* (WOODS, 1912, pl. 45, figs. 8-10, text-fig. 29), extending from the Upper Albian to the Lower Cenomanian, were observed. In the hanging wall (upper part of the *Neostlingoceras carcitanense* Zone) *Inoceramus crippsii crippsii* Mantell is common. The Lower Cenomanian begins with *Inoceramus crippsii crippsii* Mantell in the case of a sedimentological hiatus. This is typical for many sections in Germany, Poland and Russia.

Substage boundaries

LOWER / MIDDLE CENOMANIAN BOUNDARY

Ammonite succession

KENNEDY (1995) defines this boundary with the first appearance of the genera *Acanthoceras* and *Cunningtoniceras* above beds with *Mantelliceras*. The lowest ammonite fauna of Middle Cenomanian age is characterised by *Cunningtoniceras* (Sarthe: KENNEDY & JUIGNET, 1993; Boulonnais: ROBASZYNSKI *et al.*, 1994; S. England: PAUL *et al.*, 1994; Tunisia: ROBASZYNSKI *et al.* 1993, 1994; Turkmenia: ATABEKIAN, 1985; Texas: KENNEDY & COBBAN, 1990).

According to KENNEDY (1995) the lowest Middle Cenomanian faunas are characterised by different species of the genus *Cunningtoniceras* (*C. inerme, C. cunningtoni*) rather than *Acanthoceras rhotomagense* in the Northern Lower Temperate Realm and Tethyan Realm.

Bivalve succession

The proposed boundary agrees with the first rare appearance of *Inoceramus schoendorfi* Heinz together with *I. crippsii hoppenstedtensis* Tröger, rare *I. crippsii crippsii* Mantell, *I. virgatus virgatus* Schlüter and *I. virgatus scalprum* J. Böhm.

MIDDLE/UPPER CENOMANIAN BOUNDARY

Ammonite succession

Referring to the ammonites there is a disagreement in the position of the *Acanthoceras jukesbrownei*-Zone. This zone is placed in the Middle Cenomanian by many authors but in the Upper Cenomanian by others. KENNEDY (1995) explains:

''There is thus a need for a decision on the principle of where to place the *Ac. jukesbrownei*-Zone, in the Middle versus Upper Cenomanian. My own view is that the base of the *jukesbrownei,* marked by the first appearance of the index species, is not a good datum for the base of the Upper Cenomanian substage. *Ac. jukesbrownei* has a very limited geographic distribution with records from southern England, the Boulonnais south to Sarthe, Provence, Ariège in France, Germany, Poland and Turkmenia only. A better datum, likely to be more widely recognised, is the top of the *jukesbrownei* Zone, marked by the replacement of *Acanthoceras* by *Calycoceras (Calycoceras)* and *Cal. (Proeucalycoceras)*, a boundary in keeping with HANCOCK's original faunal concepts, reiterated subsequently (HANCOCK 1960, 1991; HANCOCK *et al.*, 1993). The name of the zone above the *jukesbrownei*-Zone is, however, a matter of contention.

Cal. (Calycoceras) naviculare (Mantell) originally used as index species, is absent from the lower part of the zone, and extends into the succeeding *Metoiococeras geslinianum*-Zone and correlatives. Indeed it is the commonest in this zone in the United States Western Interior, and the holotype comes from this level in Sussex, England.

Eucalycoceras pentagonum (Jukes-Browne) was proposed as a substitute index by JUIGNET & KENNEDY (1976), but it too first appears well above the extinction point of *Acanthoceras jukesbrownei* and extends into the succeeding *geslinianum/gracile*-Zone in Sarthe and Alpes-Maritimes in France, South Dakota and Colorado in the USA.

A third substitute index species, *Calycoceras (Proeucalycoceras) guerangeri* (Spath) was proposed by WRIGHT *et al.* (1984). The first occurrence of this species is significantly lower than that of both *Calycoceras (Calycoceras) naviculare* (Mantell) and *Eucalycoceras pentagonum* (Jukes-Browne) while its geographic distribution from southern England to Sarthe, Alpes-Maritimes and Alpes-de-Haute-Provence in France, Portugal(?), Tunisia and New Mexico (USA) spans Boreal and Tethyan Realms''.

Bivalve succession

The top of the *jukesbrownei* Zone nearly agrees with the first appearance of *Inoceramus pictus pictus* Sowerby, widely distributed in the Boreal and Pacific realms. The *jukesbrownei* Zone is characterized by *I. atlanticus* Heinz.

PROPOSALS PRESENTED AT THE BRUSSELS SYMPOSIUM (11-14 September 1995)

After intensive and extensive discussions concerning biostratigraphic, lithostratigraphic, taxonomic problems and problems of preservation the working group presented the following proposals:

• **The basal boundary criterion for the Cenomanian stage should be the first appearance of the planktonic foraminiferan *Rotalipora globotruncanoides* SIGAL, 1948.**

Votes were unanimously in favour (17 yes, no abstentions).

• **Possible basal boundary stratotypes for the Cenomanian Stage:**
Mont Risou near Rosans in southeastern France (proposed by A. S. Gale, W. J. Kennedy, J. A. Burnett, M. Caron & J. D. Marshall)

Section in the Kalaat Senan region, N. of Kef el Azreg, Tunisia (proposed by F. Robaszynski, F. Amédro, C. Dupuis, J. Hardenbol)

[Section described by ROBASZYNSKI *et al.* (1993, 1994) from near Kef el Azreg, Tunisia, as a candidate for the official Albian-Cenomanian boundary stratotype. This section was discussed at length at the Brussels meeting, and a preliminary decision taken to designate it as a subsidiary reference section. As at Mont Risou, *Rotalipora globotruncanoides* first occurs a short distance below the first record of the ammonite *Mantelliceras*, and there is an interval of 18.5 m between the last *Cantabrigites* and the first *Mantelliceras*, but *Mortoniceras (Durnovarites)* extends to within 1 m of the first *Mantelliceras*. (ROBASZYNSKI *et al.*, 1994, fig. 12) rather than the 98 m interval present at Mont Risou].

After intensive discussions a vote was taken for the **acceptance of the Mont Risou section as a stratotype (GSSP) for the Cenomanian basal boundary**.

Votes: 17 yes, 6 no, 4 abstentions.

In the light of this vote in favour of the Mont Risou section, it was decided that **the proposed section in Tunisia was proposed as reference section in the Tethyan Realm.**

The evidence from nannofloral occurrences, phosphatisation of ammonites and other fossils and channelling of the basal contact suggested, that there was condensation or even a non sequence in the basal Lower Cenomanian part of the Tunisian section.

• **The basal boundary criterion for the Middle Cenomanian substage should be situated at the first appearance of the ammonite *Cunningtoniceras inerme* with the entry of *Inoceramus schoendorfi* and *Rotalipora reicheli* as secondary markers.**

Votes: 17 yes, 3 abstentions.

Three potential basal boundary stratotypes for the Middle Cenomanian substage were discussed:
• Southerham Grey Quarry, Lewes, Sussex, England.

• The coastal section between Folkestone and Dover, Kent, England.

• The coastal section at Cap Blanc Nez, Boulonnais, Northern France.

According to the postal vote (extended deadline till 15.01.96) the **Cenomanian W.G. proposed the Southerham Grey Quarry section at Lewes in Sussex (England) as stratotype for the Lower-Middle Cenomanian boundary**.

Votes: in favour of the Southerham Grey Quarry: 12; in favour of the Folkestone-Dover coastal section: 1, in favour of the Cap Blanc Nez, Boulonnais coastal section: none; abstentions: 2

• **Basal Upper Cenomanian boundary**

In the case of the lower boundary criterion for the Upper Cenomanian substage no agreement was reached. The following possible boundary criteria were discussed:

a. The entry of *Acanthoceras jukesbrownei*

b. The upper limit of *Acanthoceras jukesbrownei*

c. The entry of *Calycoceras (Proeucalycoceras) gueran-geri*

d. The entry of *Calycoceras naviculare*

e. The entry of *Eucalycoceras pentagonum*

f. The entry of the *Inoceramus pictus* - group

It was considered that criteria **d** and **e** were currently unsatisfactory in view of insufficient data on these taxa. The discussion then concentrated on the criteria **a, b, c,** and **f.**

It was recommended, that a working party chaired by F. Robaszynski should investigate these criteria in more detail in sections in southern France, which may well prove the best potential substage boundary stratotype. F. Robaszynski accepted this proposal.

DESCRIPTION OF THE CANDIDATE GLOBAL REFERENCE SECTION FOR THE BASAL CENOMANIAN AT MONT RISOU, SE FRANCE

The Albian-Cenomanian boundary succession at Mont Risou, 5 km E of Rosans, Hautes-Alpes, France (Figure 1, p. 58) is described in detail in GALE *et al.* (1996). In this succession, the Albian-Cenomanian boundary falls in an expanded, continuous sequence, deposited in the rapidly subsiding Vocontian Basin.

Macrofaunas are of mixed Boreal and Tethyan affinities, and the sequence yields ammonites, inoceramid bivalves, nannofossils and planktonic foraminifera, and preserves an original stable isotope record. The outcrops cover many thousands of square metres, the sequence is rapidly eroding with good access.

The base of the Cenomanian was defined in Brussels by the first occurrence of the planktonic foraminiferan *Rotalipora globotruncanoides* SIGAL, 1948 with the Mont Risou section as the global reference section, where the datum level lies 36 m below the top of the Marnes Bleues Formation as defined by a zero datum limestone at the base of the succeeding limestone.

The Vocontian Basin underwent rapid subsidence from the Middle Jurassic (Callovian) to the Late Cretaceous, and thick successions of deep-water pelagic limestones and hemipelagic marls accumulated. In this region, the Aptian, Albian and earliest Cenomanian stages are represented by up to 750 m of **the Marnes Bleues Formation**, comprising rhythmically bedded dark marls, with distinctive horizons of laminated organic-rich black shales, rare marly limestones, clastic turbidites and slumps. Condensed horizons are infrequent, and represented by glauconitic beds.

In the upper part of **the Marnes Bleues** (Figure 2), a distinct and widely traceable horizon (Br: **Breistroffer Level** of BRÉHÉRET, 1988a) is about 10 m in thickness and includes beds of laminated, dark grey marls. From these BRÉHÉRET (1988b) recorded a "Vraconian" (Late Albian) fauna. Above, the uppermost 100 m of the Marnes Bleues comprise grey marls containing infrequent barytes-cemented concretions, small pyritised fossils and concretions, and prominent-weathering thin (10-30 cm) units containing more carbonate. Pyritised ammonites are locally common and are well-known for the presence of a rich Tethyan ammonite assemblage (JACOB 1907; THOMEL 1987, 1992) regarded as both Upper Albian and Lower Cenomanian by previous authors.

1-2 m beneath the top of the formation is a thin (< 0.3 m), dark marl containing small concretions of iron pyrites, abundant small pectinids (*Syncyclonema*) and ammonites, especially *Idiohamites, Algerites* and *Scipo-noceras.*

The base of the overlying **un-named formation** of marly limestones and marls of Cenomanian age is marked everywhere in the basin by a bundle of 4-5 thin (0.1-0.2 m) limestones which locally form a low scarp near the top of the badlands cut in the Marnes Bleues. The base of the lowest limestone provides a distinctive zero datum against which faunas in the underlying marls can be located. A succession of weaker limestone bundles are overlain by some 20 m of marls which display few bedding features. Above, thick bundles containing up to 15 thin marly limestones alternate with dark marls. The bivalve *Inoceramus crippsii crippsii* Mantell, is abundant from +52 to +62 m.

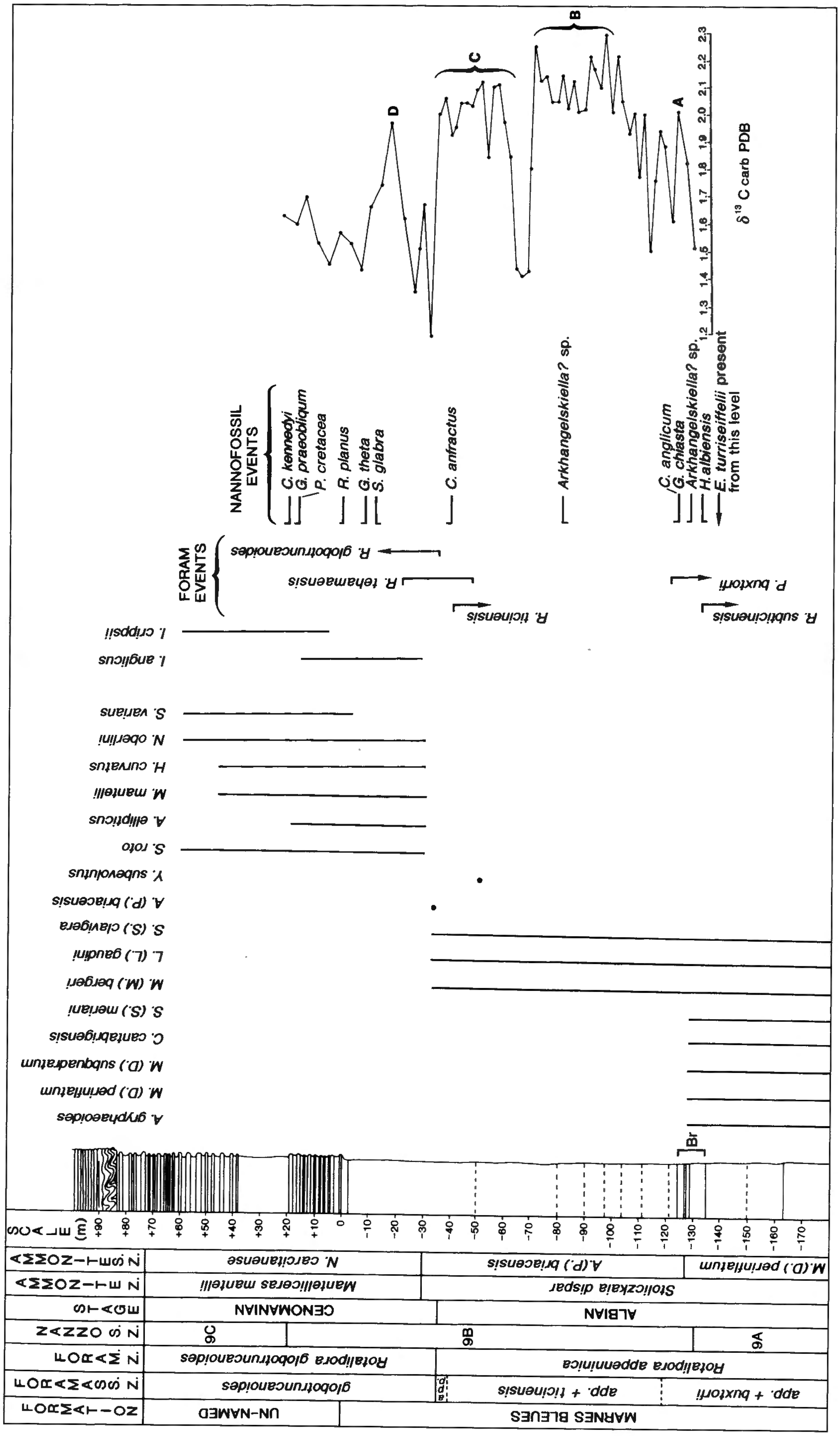
The best Albian/Cenomanian transition is visible on the west side of Mont Risou, north of Le Chataud, where a continuously accessible succession of nearly 250 m, from the Breistroffer Level in the Marnes Bleues to a horizon 85 m above the base of the overlying Cenomanian marly limestones and marls (Figure 2).

The planktonic foraminiferal succession

CARON *in* GALE *et al.* (1996) examined planktonic foraminifera from the Marnes Bleues Formation spanning levels -136 to -15 m (Figure 3).

The following bioevents were recognised:

(1). Abundant *Planomalina buxtorfi* to -120 m and its absence above -116 m.
(2). *Costellagerina libyca* from -112 m to -136 m (base of the sampled interval).
(3). Diverse *Rotalipora* association, with *R. ticinensis*


FORMATION
FORAMASS. Z.
FORAM. Z.
NANNOS. Z.
STAGE
AMMONITE Z.
AMMONITES. Z.
SCALE (m)
UN-NAMED
MARNES BLEUES
globotruncanoides
app. + ticinensis
app. + buxtorfi
Rotalipora globotruncanoides
Rotalipora appenninica
9C
9B
9A
CENOMANIAN
ALBIAN
Mantelliceras mantelli
Stoliczkaia dispar
N. carcitanense
A.(P.) briacensis
M.(D.) perinflatum
Br
A. gryphaeoides
M. (D.) perinflatum
M. (D.) subquadratum
C. cantabrigensis
S. (S.) meriani
M. (M.) bergeri
L. (L.) gaudini
S. (S.) clavigera
A. (P.) briacensis
Y. subevolutus
S. roto
A. ellipticus
M. mantelli
H. curvatus
N. oberlini
S. varians
I. anglicus
I. crippsii
FORAM EVENTS
R. tehamaensis
R. globotruncanoides
R. ticinensis
R. subticinensis
P. buxtorfi
NANNOFOSSIL EVENTS
C. kennedyi
G. praeobliqum
P. cretacea
R. planus
G. theta
S. glabra
C. anfractus
Arkhangelskiella? sp.
C. anglicum
G. chiasta
Arkhangelskiella? sp.
H.albiensis
E. turriseiffelii present from this level
A
B
C
D
δ13 C carb PDB

and *R. appenninica* from -40 m to the base of the sampled interval.
(4). Simultaneous appearance of *R. gandolfii* and *R. tehamaensis* at the -40 m level.
(5). First appearance of *R. globotruncanoides* at -36 m, which defines the base of the Cenomanian stage, following the preliminary conclusions of the Brussels meeting.
(6). Common *R. globotruncanoides* at -27 m.

The planktonic foraminiferal zonation of ROBASZYNSKI & CARON (*in* press) can be applied to the sequence, with the *Rotalipora appenninica* Zone extending from the base of the sampled interval to the first appearance of *R. globotruncanoides* at -36 m. The base of the succeeding *R. globotruncanoides* Zone is marked by the appearance of the index species. The *R. appenninica* Zone can be divided into three assemblage subzones in the Mont Risou section, the *R. appenninica* and *Planomalina buxtorfi* Subzone extends from the base of the sampled interval to -116 m, the *R. appenninica* and *R. ticinensis* Subzone from -116 to -40 m and the third Subzone corresponds to the interval from -40 to -36 m, where *R. appenninica* is present and *R. ticinensis* absent.

The ammonite succession

KENNEDY *in* GALE *et al.* (1996) presented the following scheme of assemblage Zones and Subzones:

SUBSTAGE	ZONE	SUBZONE
LOWER CENOMANIAN		(*Mantelliceras saxbii*
	Mantelliceras mantelli	(*Sharpeiceras schlueteri*
		(*Neostlingoceras carcitanense*
		(*Arrhaphoceras (Praeschloenbachia)*
		(*briacensis*
UPPER ALBIAN		(
(part)		(
		(*Mortoniceras (Durnovarites)*
	Stoliczkaia dispar	(*perinflatum*
		(
		(*Mortoniceras (Mortoniceras)*
		(*rostratum*

The lowest faunas from that part of the Mont Risou sequence (Figures 2) extend through more than 50 m of section. The range of *Mortoniceras (Durnovarites) perinflatum* defines the upper limit of its subzone at -126 m. Above, an interval of 96 m (-126 to -30 m) in which *Mortoniceras (Durnovarites)* and *Cantabrigites* are absent but *Stoliczkaia (S.) clavigera* present and represents SCHOLZ's (1973) *briacensis* Subzone (a specimen of the index species was found at -32 m).

The base of the overlying *Mantelliceras mantelli* Zone is marked by the appearance of the index species 2 m higher at -30 m. *Neostlingoceras oberlini* (DUBOURDIEU, 1953), a typical species of the *N. carcitanense* Subzone occurs at the same level and defines the base of the *carcitanense* Subzone, exactly coincident with the base of the *mantelli* Zone.

In ammonite terms the base of the Cenomanian at Mont Risou is the first occurrence of *Mantelliceras mantelli*, or *Neostlingoceras oberlini* at the -30 m level, that is to say 30 m below the first limestone bed in the sequence, the base of which defines the top of the Marnes Bleues, and 6 m above the boundary datum, the first occurrence of *Rotalipora globotruncanoides* at -36 m, in the uppermost part of the *briacensis* Subzone.

The bivalve succession

Although of low diversity, the inoceramid and *Aucellina* faunas from Mont Risou are important because they demonstrate the range of species in an expanded Albian-Cenomanian boundary sequence where they can be placed in relation to ammonite Subzones.

Aucellina are common but poorly preserved in the *perinflatum* Subzone at Mont Risou. The genus is absent above the Breistroffer Level (-135 to -126 m). [In England and Germany *Aucellina* species extends into the Early Cenomanian and can be a good markers for the base of the stage (MORTER & WOOD, 1983)].

A distinctive, undescribed *Inoceramus* is common throughout the Albian part of the succession at Mont Risou (see GALE *in* GALE *et al.*, 1996, figs. 21 f, j; 31, g? h).

Two *Inoceramus* species occur in the Cenomanian at Mont Risou, overlapping in a single bed only. *Inoceramus anglicus* Woods occurs infrequently in the *carcitanense* Subzone from -30 to +4 m. [Elsewhere the main occurrence of this species is in the Late Albian, although it also occurs in the *carcitanense* Subzone in Southern England, Germany and elsewhere in Europe].
Inoceramus crippsii crippsii Mantell is common in the upper part of the *carcitanense* Subzone at Mont Risou. *I. crippsii crippsii* is uncommon in the lower part of its range at Mont Risou (+4 m) but becomes abundant and attains large sizes in the 5 bundles of thin limestones between +52 and +62 m.

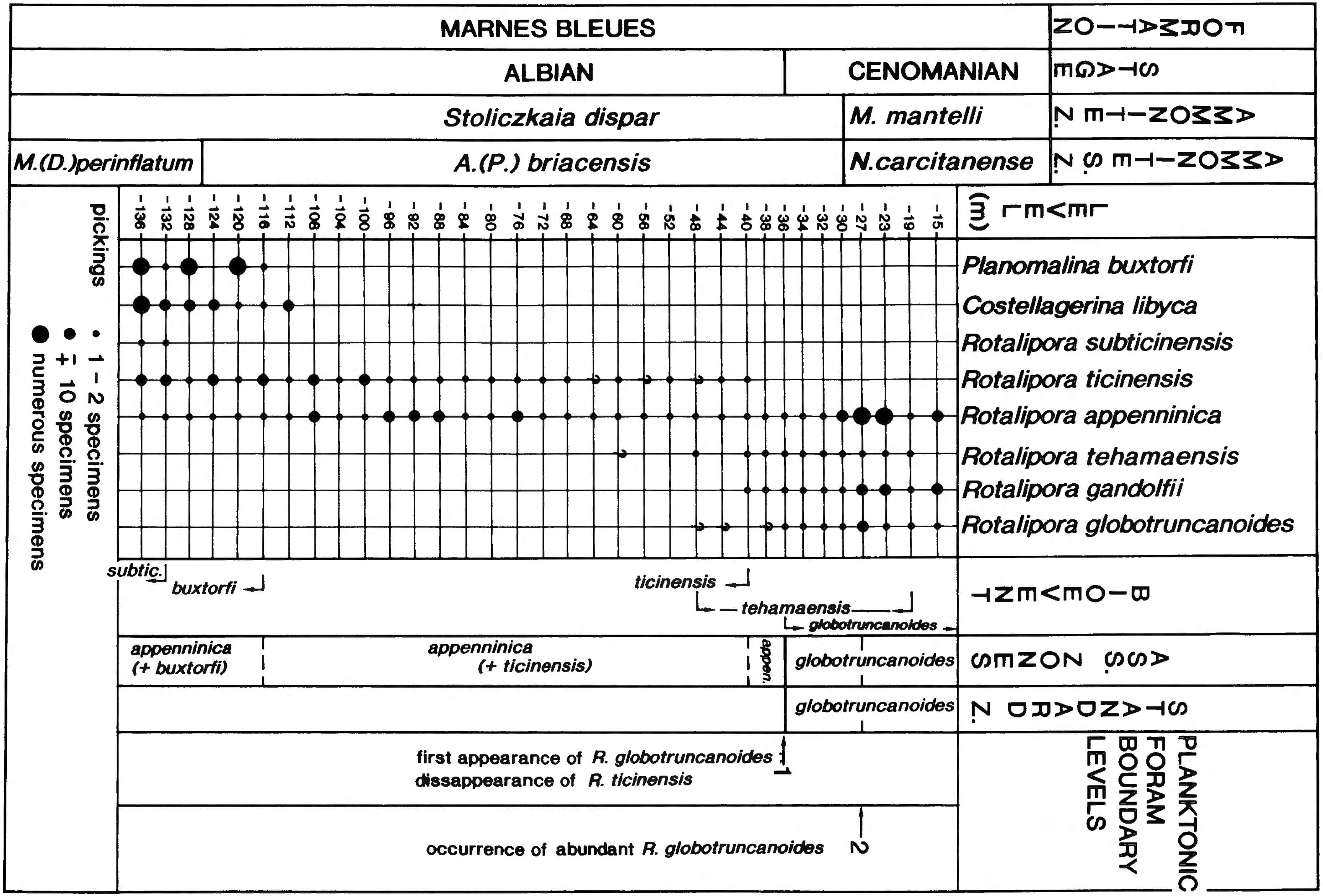
The nannofossil succession

BURNETT *in* GALE *et al.* (1996) recognised 153 nannofossil taxa from the samples at Mont Risou.

In nannofossil terms, the Albian-Cenomanian boundary falls within SISSINGH's (1977) NF Biozone CC9, as defined from the FO of *Eiffellithus turriseiffelii* to the FO of *Microrhabdulus decoratus*. This zone was originally

←

Fig. 2 — Integrated litho- and biostratigraphy across the Albian-Cenomanian boundary at Mont Risou. Selected macrofossil ranges, planktonic foraminiferan and nannofossil events, and the $\delta^{13}C$ curve are shown. A - D are specific peaks in the $\delta^{13}C$ curve mentioned in the text. Br = Breistroffer level (from GALE *et al.*, 1996).


MARNES BLEUES
FORMATION
ALBIAN
CENOMANIAN
STAGE
Stoliczkaia dispar
M. mantelli
AMMONITE Z.
M.(D.)perinflatum
A.(P.) briacensis
N.carcitanense
AMMONITE S. Z.
-136 -132 -128 -124 -120 -116 -112 -108 -104 -100 -96 -92 -88 -84 -80 -76 -72 -68 -64 -60 -56 -52 -48 -44 -40 -38 -36 -34 -32 -30 -27 -23 -19 -15
(m) LEVEL
Planomalina buxtorfi
Costellagerina libyca
Rotalipora subticinensis
Rotalipora ticinensis
Rotalipora appenninica
Rotalipora tehamaensis
Rotalipora gandolfii
Rotalipora globotruncanoides
pickings
• 1 – 2 specimens
● ∓ 10 specimens
● numerous specimens
subtic.
buxtorfi
ticinensis
tehamaensis
globotruncanoides
BIOEVENT
appenninica (+ buxtorfi)
appenninica (+ ticinensis)
appen.
globotruncanoides
A.S. ZONES
globotruncanoides
STANDARD Z.
first appearance of R. globotruncanoides 1
dissappearance of R. ticinensis
occurrence of abundant R. globotruncanoides 2
PLANKTONIC FORAM BOUNDARY LEVELS

described from the Col de Palluel (Hautes-Alpes, SE France), based on the work of THIERSTEIN (1973), and has subsequently been subdivided by PERCH-NIELSEN (1979, summarised in 1985), using the LO of *Hayesites albiensis* and the FO of *Corollithion kennedyi*/LOs of *Watznaueria britannica* and *Braarudosphaera africana*. Thus, the boundary more precisely falls within NF Biosubzone CC9B, since the LO of *Hayesites albiensis* and the FO of *Corollithion kennedyi* were both recognised in the Mont Risou section (although only one specimen of each was found) (Figure 2).

The low nannofossil biostratigraphical resolution is not insurmountable. The Late Albian and Early Cenomanian encompassed a period of rapid and diverse evolution within the nannofossil family Arkhangelskiellaceae, specifically within the genera *Broinsonia, Crucicribrum* and *Gartnerago*.

The FO of *Corollithion kennedyi* was used by PERCH-NIELSEN, at the same level as the LOs of *Braarudosphaera africana* and *Watznaueria britannica*, as the first post-boundary marker. This easily-recognisable taxon was first described in 1981 and, therefore, has only rarely been cited in the literature, which mainly predates this.

Preservation of the nannoflora assemblages at the Mont Risou section is moderate throughout the sequence.

Examination of the complete and expanded Albian-Cenomanian sequence at Mont Risou has allowed a tentative sequence of events (including many from the Arkhangelskiellaceae) to be determined in relation to the established ones. These events are summarised in Figure 2.

Although the use of FOs which occur close to the base of the sequence studied may be suspect, since preservation or low abundances may have precluded their identification in the lower two samples, one was identified immediately above the LO of *Hayesites albiensis* (-132 m): the FO of *Arkhangelskiella*? sp. (-128 m). This is followed by the FOs of *Crucicribrum anglicum* and *Gartnerago chiasta* at -124 m. (N.B. PERCH-NIELSEN (1985) has the LO of the former taxon coinciding with the LO of *Hayesites albiensis*). All of these taxa are arkhangelskiellids. None are common (i.e. they occur in abundances of <1 specimen per field of view) but their stratigraphical ranges are reasonably consistent.

No apparently reliable events occur over the following 40 m. *Calculites anfractus* has its FO at -40 m, 4 m below the Albian-Cenomanian boundary, followed by the LO of *Staurolithites glabra* 24 m above the boundary at -12 m. Higher up the section, *Gartnerago theta* and *Radiolithus planus* have their FOs at -8 m and 0 m respectively. Four metres below the FO of *Corollithion kennedyi* (+20 m), are the apparently coincident FOs of *Gartnerago praeobliquum* and *Prediscosphaera cretacea sensu stricto*, at +16 m. The LOs of *Braarudo*sphaera *africana, Crucicribrum anglicum* and *Watznaueria britannica* occur stratigraphically higher.

If the FO of *Calculites anfractus* and the LO of *Staurolithites glabra* prove to be correlatable elsewhere, then these two taxa could define a nannofossil subzone around the boundary.

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Fig. 3 — Planktonic foraminiferan occurrences across the Albian-Cenomanian boundary in the Mont Risou section (from GALE *et al.*, 1996).

Carbon and oxygen isotope stratigraphy

Discussed in detail by GALE & KIDD *in* GALE *et al.* (1996).

– **Oxygen isotope record**

The $\delta^{18}O$ curve for the Risou section (Figure 4) shows small scale variance in the order of 0.3 for much of the lower, Albian, part of the succession, values mostly falling between -3.8 and -4.1. In the Cenomanian part of the section above (-30 m up to + 20 m) values rise to a maximum value of -3.5. The possibility that these values are altered by the addition of isotopically light cement during burial diagenesis has to be considered, because the Marnes Bleues in the Vocontian Basin have been buried up to several kilometres.

– **Carbon isotopes**

$\delta^{13}C$ in carbonate sediments is relatively stable and more likely to survive the effects of burial diagenesis than are oxygen isotopes.

Additional evidence for a primary $\delta^{13}C$ signal in the Mont Risou section comes from the lack of correlation between lithologies and carbon isotope values.

The carbon curve (Figure 4) registers a broad overall peak (maximum values of 2.3 at -104 m) through much of the Mont Risou section, broken into four discrete peaks (lettered A, B, C, D in Figures 2 and 4) by sharp, short-lived falls of $\delta^{13}C$ of up to 0.8. These peaks and troughs do not correspond to lithological changes, are defined by numerous points, and thus probably represent secular change. Peak B registers the highest values which progressively fall through C and D. However, to demonstrate convincingly the primary nature of the Mont Risou $\delta^{13}C$ signature, it is necessary to find similar coeval curves in other localities (cf. SCHOLLE & ARTHUR, 1980).

Carbon curves based on bulk carbonate analyses across Albian-Cenomanian boundary sections have been published previously by JENKYNS *et al.* (1994, fig 10) for Gubbio, Marche, Italy, and by MITCHELL & PAUL (1994, fig. 1) for the section at Speeton in Yorkshire, England, both based on whole-rock analyses.

The sequence of biostratigraphic and lithological marker events in the Mont Risou sequence

Figure 2 summarizes the distribution of selected key lithological, isotopic, faunal and floral events across the Albian-Cenomanian boundary in the Marnes Bleues succession at Mont Risou: from oldest to youngest:

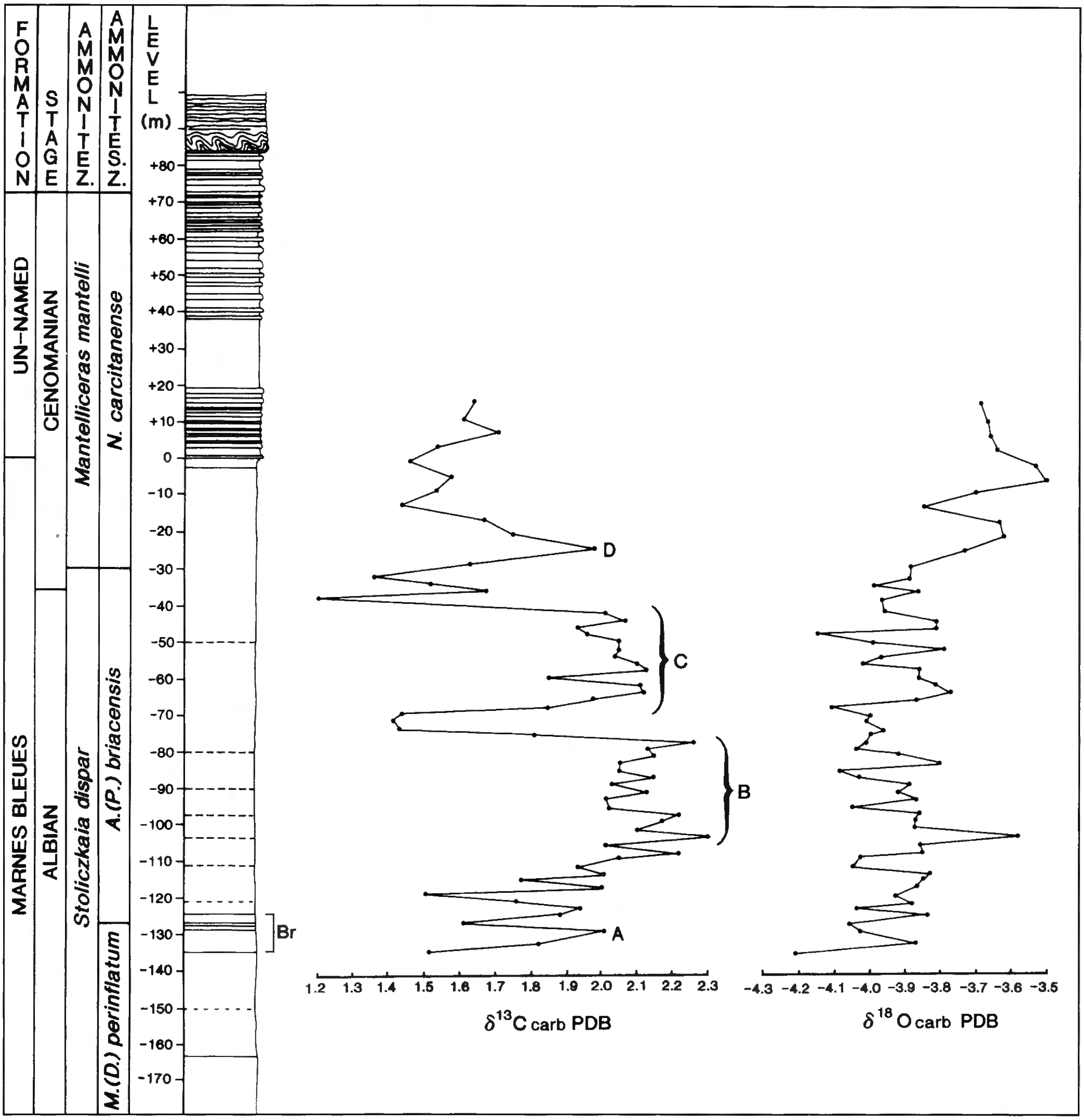

Fig. 4 — The $\delta^{13}C$ and $\delta^{18}O$ curves across the Albian-Cenomanian boundary in the Mont Risou section. A - D are specific peaks mentioned in the text. Br = Breistroffer level (from GALE *et al.*, 1996).

(1). Base of the Breistroffer Level at -135 m.
(2). LO of the planktonic foraminiferan *Rotalipora subticinensis* at -132 m.
(3). LO of the nannofossil *Hayesites albiensis*, also at -132 m.
(4). LO of the ammonites *Durnovarites* and *Cantabrigites*, also at -132 m.
(5). FO of the nannofossil *Arkhangelskiella*? sp. at -128 m.
(6). Top of the Breistroffer Level at -124 m.
(7). FO of the nannofossils *Gartnerago chiasta* and *Crucicribrum anglicum* at -124 m.
(8). LO of the planktonic foraminiferan *Planomalina buxtorfi* at -116 m.
(9). LO of the planktonic foraminiferan *Costellagerina libyca* at -112 m.
(10). LO of the nannofossil *Arkhangelskiella*? sp. at -80 m.
(11). FO of the planktonic foraminiferan *Rotalipora tehamaensis* at -48 m.
(12). LO of the planktonic foraminiferan *Rotalipora ticinensis* at -40 m.
(13). FO of the planktonic foraminiferan *Rotalipora gandolfii*, also at -40 m.

(14). FO of the nannofossil *Calculites anfractus*, also at -40 m.
(15). FO of the planktonic foraminiferan *Rotalipora globotruncanoides* at -36 m, which defines the base of the Cenomanian stage.
(16). LO of the predominantly Albian ammonites *Lechites gaudini, Stoliczkaia clavigera, Mariella miliaris* and *Hemiptychoceras subgaultinum* at -32 m.
(17). FO of the classic Cenomanian ammonite markers *Neostlingoceras oberlini, Mantelliceras mantelli, Hyphoplites curvatus* and *Sciponoceras roto* at -30 m.
(18). Common occurrence of the planktonic foraminiferan *Rotalipora globotruncanoides* at -27 m.
(19). LO of the nannofossil *Staurolithites glabra* at -12 m.
(20). FO of the nannofossil *Gartnerago theta* at -8 m.
(21). The zero datum, the first limestone in the sequence.
(22). FO of the nannofossil *Radiolithus planus* at the zero datum.
(23). FO of the nannofossils *Gartnerago praeobliquum* and *Prediscosphaera cretacea sensu stricto* at +16 m.
(24). FO of the nannofossil *Corollithion kennedyi* at +20 m.

The major faunal change in the ammonite fauna occurs between -30 and -32 m, with the disappearance of typical Albian taxa at -32 m and the appearance of typical Cenomanian taxa at -30 m, a short distance above the base of the Cenomanian as defined by the first appearance of *Rotalipora globotruncanoides* at -36 m.

At Mont Risou, a typical *N. carcitanense* Subzone fauna is found from -30 to +20 m, with elements ranging higher. Between +52 and +62 m five bundles of thin limestones yield abundant large *I. crippsii crippsii* and numerous inflated *Mantelliceras.*

The Albian-Cenomanian boundary in the eastern Anglo-Paris Basin can be shown by faunal correlation with Mont Risou to be marked by hiatus and condensation of a greater magnitude than hitherto suspected. This comprises two discrete parts: a gap represented by the terminal Albian surface, equivalent to 100-150 m of marls at Mont Risou, with part of the *perinflatum* Subzone and all of the *briacensis* Subzone missing, and the highly condensed Glauconitic Marl, which is represented by some 60-100 m of *carcitanense* Subzone marls and limestone at Mont Risou.

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