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The Global Boundary Stratotype Section and Point (GSSP) for the base of the Cenomanian Stage, Mont Risou, Hautes-Alpes, France

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Following the unanimous recommendation of the International Commission on Stratigraphy, the Global boundary Stratotype Section and Point (GSSP) for the base of the Cenomanian Stage is defined at a level 36 metres below the top of the Marnes Bleues Formation, a level that corresponds to the the first appearance of the planktonic foraminiferan Rotalipora globotruncanoides *Sigal, 1948, on the south side of Mont Risou, east of Rosans, Haute-Alpes, France, where it can be placed in the context of a series of secondary marker levels based on nannofossils, planktonic foraminifera, ammonites, and an ornate $\delta^{13}C$ curve.*

Introduction

The present document defining a Global boundary Stratotype Section and Point (GSSP) for the base of the Cenomanian Stage of the Upper Cretaceous arises from the recommendations of the Cenomanian Working Group of the Subcommission on Cretaceous Stratigraphy at its meetings during the Second International Symposium on Cretaceous Stage Boundaries held in Brussels from September 8–15, 1995.

The proposal was subsequently submitted to the Subcommission of Cretaceous Stratigraphy, which voted 18 yes, abstain 2. A revised proposal was submitted to the International Commission on Stratigraphy, which voted unanimously in favour of the proposal. The International Union of Geological Sciences was requested to ratify this decision; the proposal was finally ratified on 10 December 2001.

Historical background

When Alcide d'Orbigny began to divide up the Cretaceous system into stages, he at first recognized only two in what is now known as the Upper Cretaceous: the Turonian and Senonian (*Paléontologie française, Terrains Crétacés, II Gastropodes,* pp. 403–406). With respect to the Turonian, his words are: "je propose de désigner à l'avenir l'étage qui m'occupe sous le nom de terrain Turonien, de la Ville de Tours (*Turones*) ou de la Touraine (*Turonia*), situées sur ces terrains" (d'Orbigny, 1842-1843, p. 405), defining the Turonian as equivalent to the Craie Chloritée, Craie tuffeau, Glauconie crayeuse,

Grès Vert Supérieur etc., and taking the name from Touraine (Roman Turonia). Five years later, he realized that two distinct ammonite and rudist faunas were present, and he restricted the term Turonian to beds corresponding to his third zone of rudists, yielding "*Ammonites lewesiensis, peramplus, Vielbancii, Woolgari, Fleuri-ausianus, Deverianus* etc.", "le plus beau type côtier étant très prononcé dans toute la Touraine, et nous donnerons à la partie inférieure le nom d'étage Cénomanien, le Mans (*Cenomanum*), en montrant à la fois le type sous-marin" (d'Orbigny, 1848–1851, p. 270).

In the second volume of *Prodrome* d'Orbigny (1850) listed 809 species as characteristic of the Cenomanian, 46 of them ammonites, of which 10 were specifically cited from Sarthe, in which Le Mans lies. Localities mentioned are Saint-Calais, Le Flèche, Cérans, Ecommoy, Grand Lucé, Coudrecieux, Vibraye, Lamnay and La Ferté-Bernard.

Faunas from the Cenomanian of Sarthe were described by Guéranger (1867) in his *Album paléontologique du département de la Sarthe*, one of the earliest publications with photographs of fossils, and the stratigraphy was investigated in particular by Guillier (1886). The ammonites were then neglected for almost 100 years, until Hancock (1960) listed all the stratigraphically localized Cenomanian ammonites he was able to trace in the Le Mans and Paris Collections, as well as new material collected by him, a total of 161 specimens. This work forms the basis of all subsequent studies.

It is to the researches of Pierre Juignet and his collaborators that our present knowledge of the Cenomanian Stage in the environs of Le Mans stems; see in particular Juignet (1974, 1977, 1978), Juignet, Kennedy & Wright (1973), Kennedy & Juignet (1973, 1977, 1984, 1983, 1994a, 1994b), Juignet, Kennedy & Lebert (1978), Juignet et al. (1984) and Robaszynski et al. (1998).

From these works it has become recognized that the paucity of exposure in the environs of Le Mans makes it unlikely that a boundary section could ever be designated in the historical type area of the stage.

The Global boundary Stratotype Section and Point for the base of the Cenomanian Stage

Location

The GSSP is located on the western flanks of Mont Risou (1183 m), in NE-SW trending gullies in badlands, 3.15 km east of the centre of the town of Rosans, Hautes-Alpes, France (Figures 1–3),

around a point 5° 30' 43" E, 44° 23' 33" N (Lambert II Zone coordinates 852.725; 1937.625), on the 1:25,000 French Série Bleue 1:25,000 Sheet 3239 Ouest, Rosans (Gale et al. 1996).

The boundary lies 36 m below the top of a thick sequence of constantly eroding marls, the Marnes Bleues of French workers, but can be located in the field in relation to the first limestone that defines the base of the overlying, unnamed unit of limestone-marl alternations (Figures 3, 4) (this limestone marker bed was taken as the base of the Cenomanian by Moullade (1966), and Porthault (1974, 1978) in their classic studies of the Cretaceous of the Vocontian Basin).

Access

The GSSP can be reached by taking the D994 road east from Rosans, and turning south on the D949 (signpost: St. André-de-Rosans). Beyond the buildings at Notre Dame, the road describes a hairpin bend, and crosses the Lidane stream. Just east of the 668 m spot height a track leads left (NNE) up the lower slopes of Mont Risou: the gullies that encompass the GSSP are easily accessible on foot.
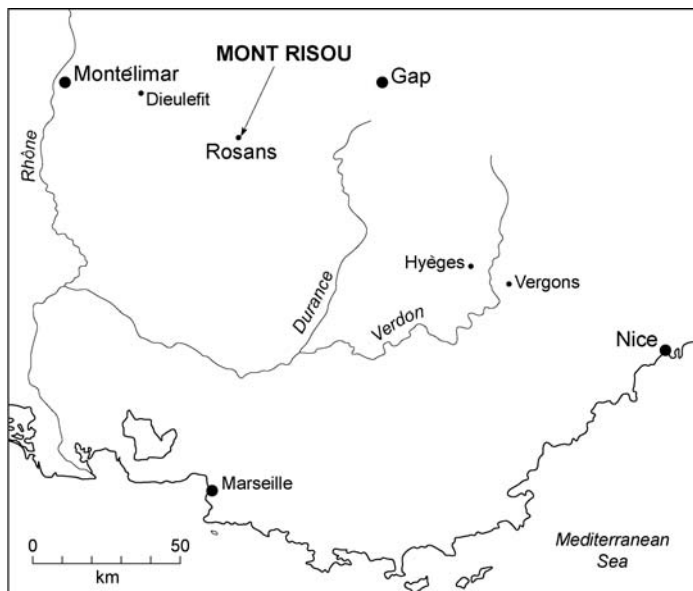

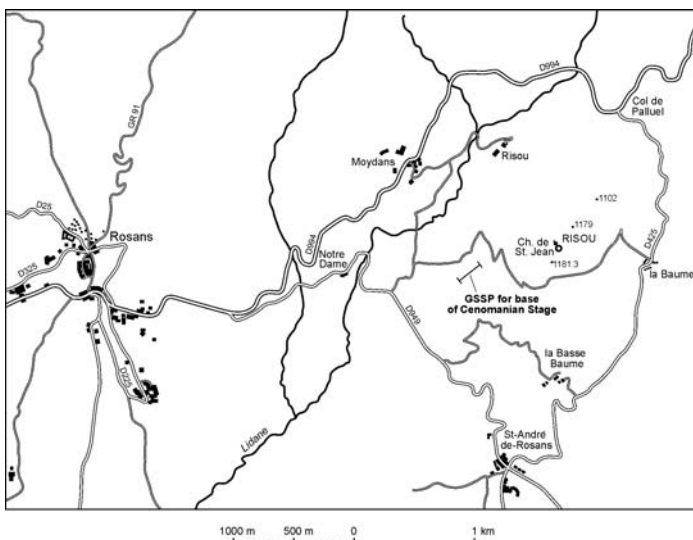*Figure 1 Locality map for Mont Risou, Hautes-Alpes, France.*

Figure 2 Locality map for the Global boundary Stratotype Section and Point for the base of the Cenomanian Stage, on the western slopes of Mont Risou, east of Rosans, Hautes-Alpes, France.
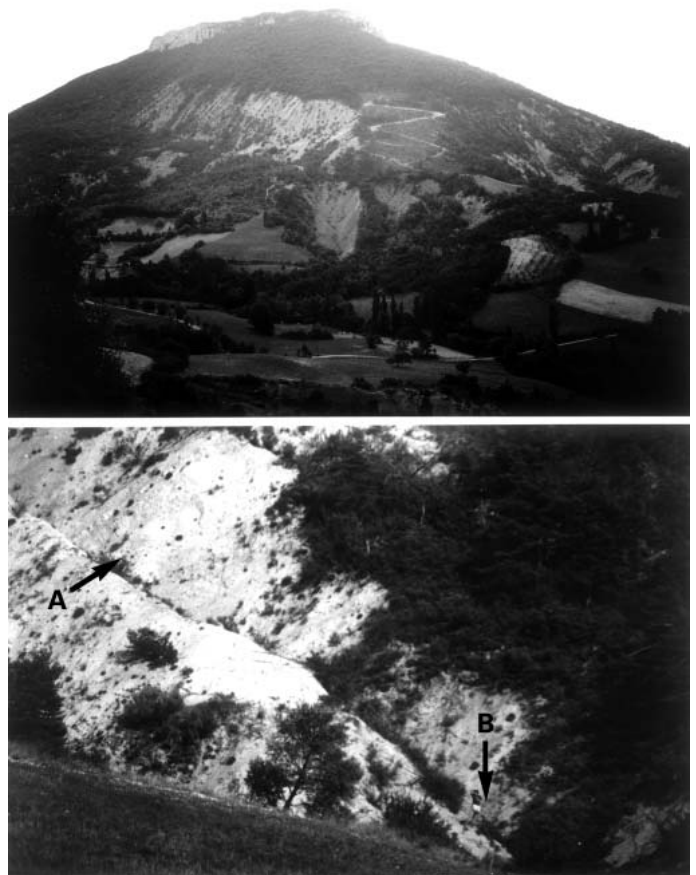

Figure 3 Outcrop photographs of the Global boundary Stratotype Section and Point for the base of the Cenomanian Stage, on the western slopes of Mont Risou, east of Rosans, Hautes-Alpes, France. A – Distant view of Mont Risou from the south. The summit ridge is formed by Turonian limestones. The Marnes Bleues and succeeding un-named unit crop out in badlands east and west of the zig-zag track. B – Typical outcrop of the Global Boundary Stratotype Section and Point for the base of the Cenomanian stage. A: marker limestone bed, the base of which defines the upper limit of the Marnes Bleues; B: the GSSP, 36 m below the top of the Marnes Bleues Formation.

Description of the GSSP

The Global boundary Stratotype Section and Point for the base of the Cenomanian Stage is the level 36 m below the top of the Marnes Bleues that corresponds to the first occurrence (FO) of the planktonic foraminifer *Rotalipora globotruncanoides* Sigal, 1948, in the Marnes Bleues Formation. This can be most readily located in the field by measuring down from the base of the lowest limestone of the overlying unnamed limestone-marl unit of Cenomanian age (Figure 3). A detailed log of the sequence is shown in Figure 4.

The GSSP succession in the top 136 m of the Marnes Bleues Formation is of marls with varying carbonate and organic carbon content. Levels with higher carbonate content weather out as slightly more resistant levels, as indicated on the logs. Levels of higher organic carbon content are frequently laminated, and are again slightly more resistant to weathering. Bréhéret (1988a, 1988b, 1997) has recognised a series of such levels in the Marnes Bleues of the Vocontian Basin, and assigned names to the more important. The highest of these marker beds, the Niveau Breistroffer (Breistroffer Level) occurs 135 to 124 m below the top of the GSSP, and is the only prominent marker in the section below the zero datum at the base of the unnamed formation that overlies the Marnes Bleues.

The Niveau Breistroffer is well exposed immediately beneath a stream junction. It comprises decimeter- to meter-scale alternations
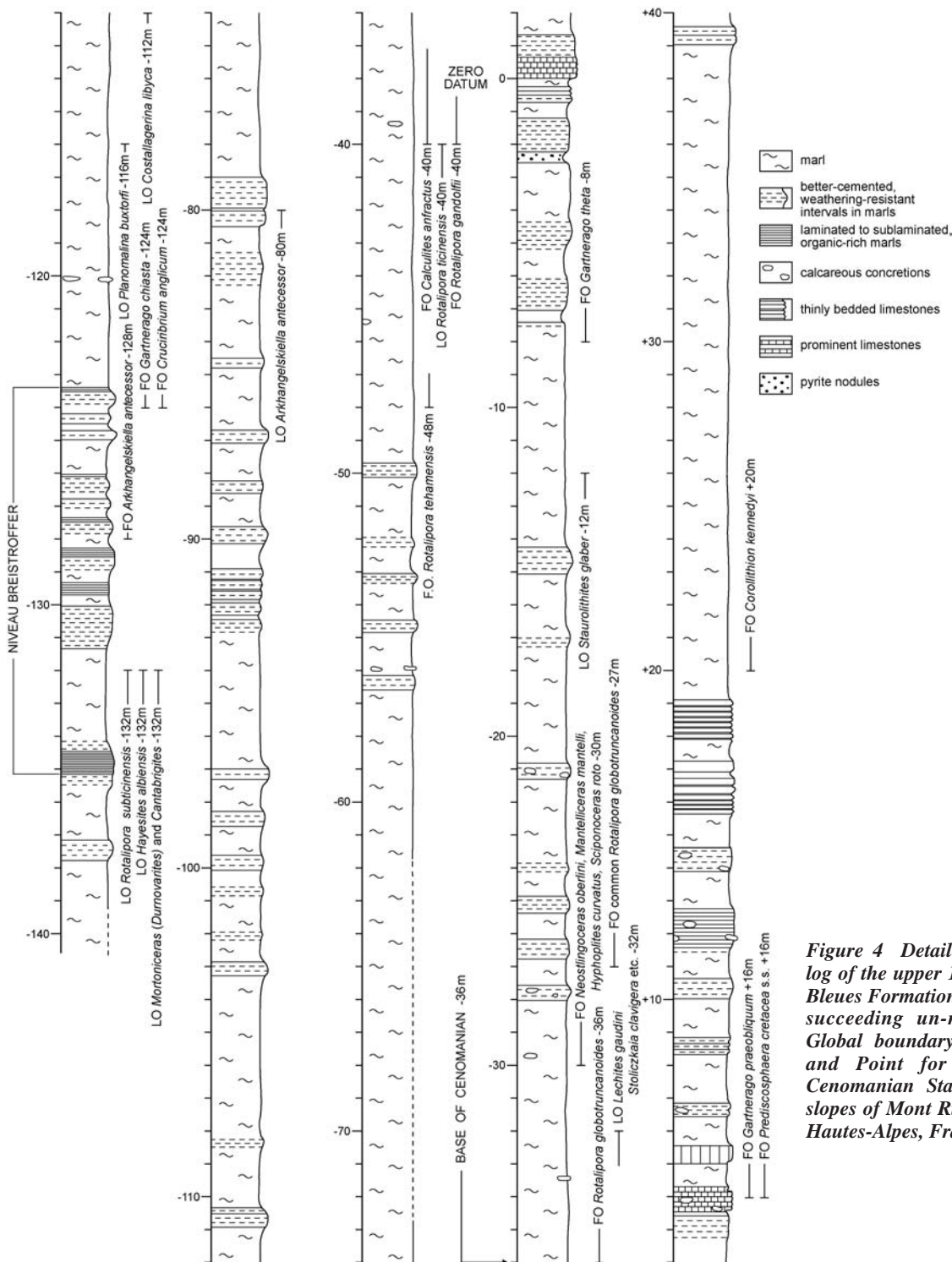
Figure 4 Detailed lithostratigraphic log of the upper 150 m of the Marnes Bleues Formation, and the base of the succeeding un-named unit at the Global boundary Stratotype Section and Point for the base of the Cenomanian Stage, on the western slopes of Mont Risou, east of Rosans, Hautes-Alpes, France.

of more or less calcareous, dark grey bioturbated marl, and five beds of dark, laminated marl that are relatively organic-rich. The second laminated layer is 0.5 m in thickness, and contains a diverse ammonite fauna and infrequent bivalves. A similar, but slightly less abundant ammonite fauna is found in the third and fourth laminated layers.

Above the Niveau Breistroffer are 12 m of grey, bioturbated, poorly fossiliferous marls (−123 to −135 m) containing an impersistent bed of barytes — cemented concretions. The overlying 31 m of marls (−92 to −123 m) are rhythmically bedded on a meter scale, and limited macrofaunas were collected. At −80 m is a bed containing abundant ammonites, notably heteromorphs.

The boundary level: primary and auxiliary biostratigraphic markers

Three groups provide the principal biostratigraphic markers for the boundary interval: ammonites, planktonic foraminifera, and nannofossils, with inoceramid bivalves (which are poorly represented in the Marnes Bleues) as a further group. Figure 5 shows the occurrence data for ammonites in the sequence, Figure 6 the data for planktonic foraminifera, and Figure 7 the nannofossil data.

The distribution of key faunal and floral events across the Albian-Cenomanian boundary in the Marnes Bleues succession at the Mont Risou GSSP are plotted in Figure 10, and are, from oldest to youngest:
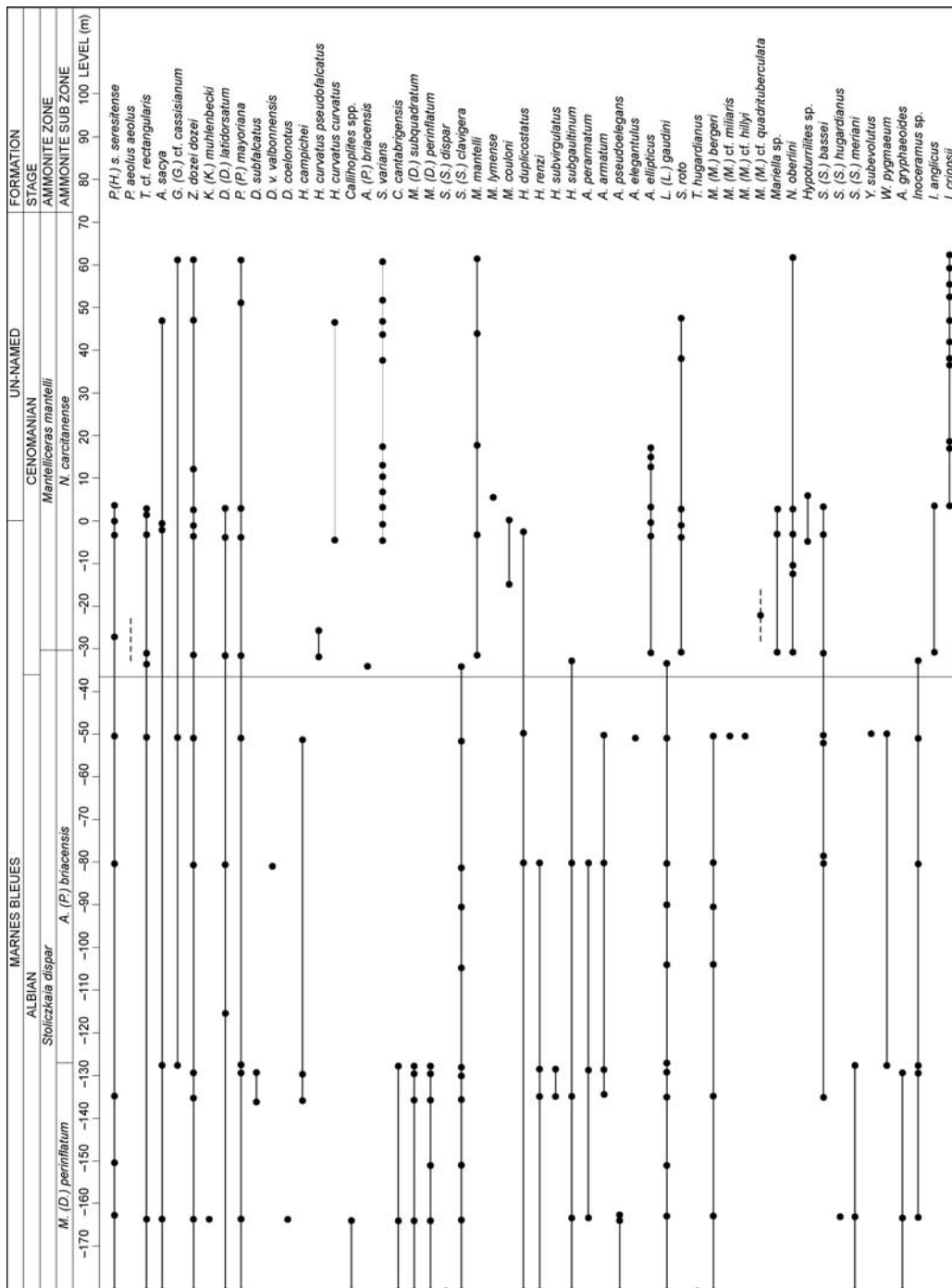
Figure 5 *Distribution of ammonites and inoceramid bivalves in the top 80 m of the Marnes Bleues Formation and the base of the succeeding unnamed unit at the Global boundary Stratotype Section for the base of the Cenomanian Stage on the western flanks of Mont Risou, east of Rosans, Hautes-Alpes, France.*

Base of the Niveau Breistroffer: − 135 m.

● The last occurrence of the planktonic foraminiferan *Rotalipora subticinensis* at −132 m.

● The last occurrence of the nannofossil *Hayesites albiensis*, also at -132 m.

● The last occurrence of species of the ammonite genera *Mortoniceras (Durnovarites)* and *Cantabrigites*, also at −132 m.

● The first occurrence of the nannofossil *Arkhangelskiella antecessor* at −128 m.

Top of the Breistroffer Level: −124 m.

● The first occurrences of the nannofossils *Gartnerago chiasta* and *Crucicribrium anglicum* at −124 m, (local events).

● The last occurrence of the planktonic foraminiferan *Planomalina buxtorfi* at −116 m.

● The last occurrence of the planktonic foraminiferan *Costellagerina libyca* at −112 m.

● The last occurrence of the nannofossil *Arkhangelskiella antecessor* at −80 m.

● The first occurrence of the planktonic foraminiferan *Rotalipora tehamaensis* at −48 m.

● The last occurrence of the planktonic foraminiferan *Rotalipora ticinensis* at −40 m.
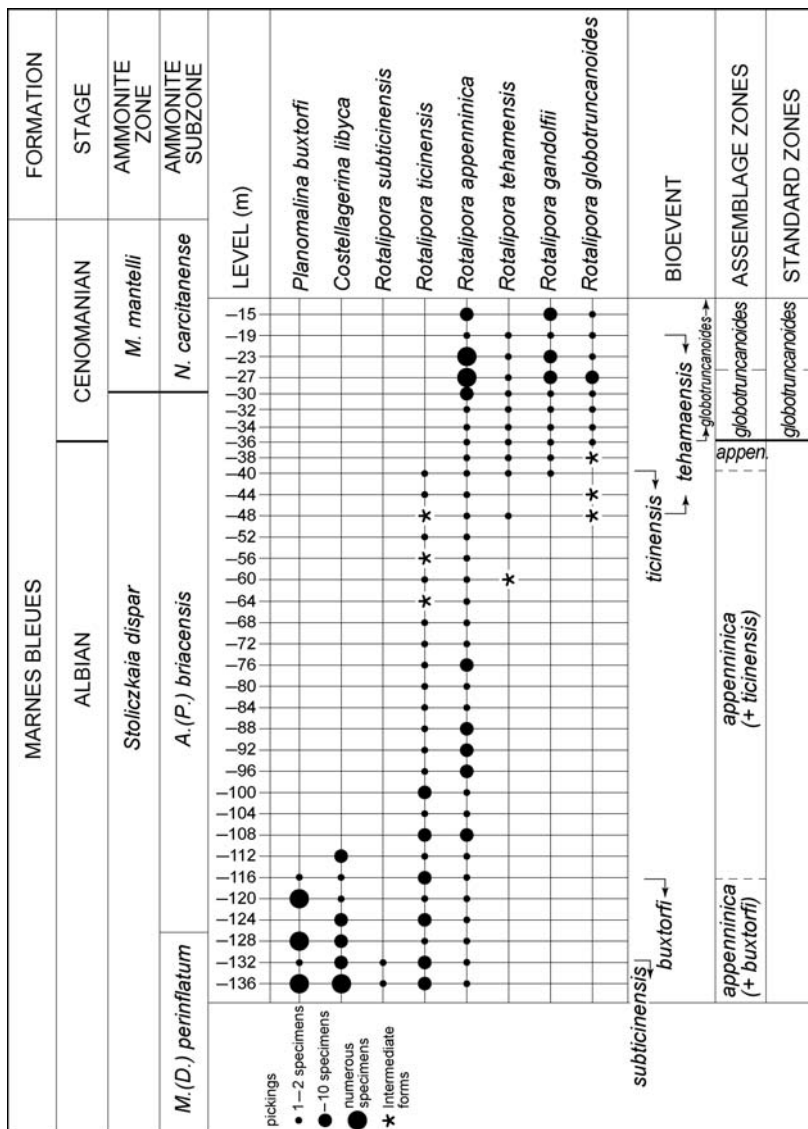
Figure 6 *Distribution of planktonic foraminifera in the top 136 m of the Marnes Bleues Formation at the Global boundary Stratotype Section for the base of the Cenomanian Stage on the western flanks of Mont Risou, east of Rosans, Hautes-Alpes, France. See text for discussion.*

● The first occurrence of the planktonic foraminiferan *Rotalipora gandolfii*, also at −40 m.

● The first occurrence of the nannofossil *Calculites anfractus*, also at −40 m.

● **The base of the Cenomanian stage is defined as the level 36 m below the top of the Marnes Bleues, which corresponds to first occurrence of the planktonic foraminiferan *Rotalipora globotruncanoides*.**

● The last occurrence of the typically Albian ammonites *Lechites gaudini, Stoliczkaia clavigera, Mariella* cf. *miliaris* and *Hemiptychoceras subgaultinum* at −32 m.

● The first occurrence of typically Cenomanian ammonites *Neostlingoceras oberlini, Mantelliceras mantelli, Hyphoplites curvatus* and *Sciponoceras roto* at −30 m.

● The common occurrence of the planktonic foraminiferan *Rotalipora globotruncanoides* at −27 m.

● The last occurrence of the nannofossil *Staurolithites glaber* at −12 m.

● The first occurrence of the nannofossil *Gartnerago theta* at −8 m.

Zero datum, the first limestone in the sequence

● The first occurrence of the nannofossils *Gartnerago praeobliquum* (local event) and *Prediscosphaera cretacea* sensu stricto (local event) at +16 m.

● The first occurrence of the nannofossil *Corollithion kennedyi* at +20 m.

The assemblages of planktonic foraminifera in the inteval studied (−136 to −15m below the top of the Marnes Bleues) show no major faunal change. The more complex specimens, typically about 500 microns in diameter, with single keel and supplementary apertures on the umbilical side, are represented by the *Rotalipora* group. They show progressive diversification up the section, and it is this that provides the basis for biostratigraphic subdivision and correlation.

The last occurrence (LO) of *Rotalipora subtichinensis* is at −132 m (Figure 6). Above, the assemblages is characterised by the co-occurrence of *Rotalipora ticinensis* and *R. appeninica*, up to the level of first occurrence (FO) of *R. tehamensis* and *R. gandolfii* at −40 m. This corresponds to the last occurrence of *R. ticinensis* in the Risou section. The first occurrence (FO) of *Rotalipora globotruncanoides* at −36 m marks the base of the Cenomanian stage. These four species of *Rotalipora* (*globotruncanoides, appenninica, tehamensis, gandolfii*) coexist from −36 m to −19 m, and form a subzonal association that is a useful indicator for the base of the stage.

The gradual evolution of the polyphyletic *Rotalipora* group (cf. Gonzalez Donoso in Robaszyski et al., 1994, p. 428) can be followed through the interval studied. Two lineages that arose during the late Albian are present at the base of the section. The first, represented by *Rotalipora subticinensis*, arose from *Ticinella praeticinensis* by acquisition of a peripheral keel, giving rise to *Rotalipora subticinensis*, which gave rise in turn to *R. ticinensis*. This last named gave rise, in turn, to *R. tehamensis* (−48 m), and *R. globotruncanoides* (−36 m). The second lineage arose from *Ticinella raynaudi,* and is represented by *Rotalipora appenninica* and R. *gandolfii* (−40 m).

These two lineages are readily traced in the present succession on the basis of a series of intermediate forms, marked by an asterisk in Figure 6, which occur in the transitional intervals in which the new species arose.

In a broader context, the *Ticinella praeticinensis–Rotalipora subticinensis–R. ticinensis–R. globotruncanoides–R. greenhornensis* lineage is of great value in Upper Albian to Upper Cenomanian biostratigraphy, showing gradual progressive changes, a feature that strengthens the case for the selection of the first occurrence of *Rotalipora globotruncanoides* as the key biostratigraphic marker for the base of the Cenomanian stage.

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. Nine ammonite taxa pass across the boundary; they are long-ranging desmoceratids, puzosiids, phylloceratids and gaudryceratids of typically Tethyan aspect. There is no lithological break or change in the intervening 2 meters between the last Albian and the first Cenomanian ammonites. The Albian-Cenomanian boundary, as seen at Risou, is marked by a sudden turnover of about 65% of ammonite taxa. Several of the changes presumably reflect evolutionary transitions which occurred rapidly elsewhere (*Stoliczkaia clavigera→Mantelliceras mantelli; Lechites gaudini→*Sciponoceras roto*), with subsequent migration into the area. See Appendix II for further details on ammonites, nannofossils, and planktonic foraminifera in the sequence.

Distribution of calcareous nannofossils in the top 136 m of the Marnes Bleues Formation, Mont Risou. Sample columns (left to right): RI-136m, RI-132m, RI-128m, RI-124m, RI-120m, RI-116m, RI-111m, RI-108m, RI-104m, RI-100m, RI-96m, RI-92m, RI-88m, RI-84m, RI-80m, RI-76m, RI-72m, RI-68m, RI-64m, RI-60m, RI-56m, RI-52m, RI-48m, RI-44m, RI-40m, RI-36m, RI-32m, RI-28m, RI-24m, RI-20m, RI-16m, RI-12m, RI-8m, RI-4m, RI 0m, RI+4m, RI+8m, RI+12m, RI+16m, RI+20m.

Header rows: 1 ABUNDANCE, 2 PRESERVATION.

#	TAXON
3	Ahmuellerella octoradiata
4	Amphizygus brooksii
5	Axopodorhabdus albianus
6	Biscutum cf. B. ellipticum
7	Biscutum ellipticum
8	Braarudosphaera africana
9	Broinsonia enormis
10	Broinsonia signata
11	Bukrylithus ambiguus
12	Calcicalathina alta
14	Calculites percenis
13	Calculites sp.2
15	Chiastozygus bifarius
16	Chiastozygus litterarius
17	Chiastozygus platyrhethus
18	Corollithion signum
19	Corollithion? madagaskarensis
20	Cretarhabdus conicus
21	Cretarhabdus striatus
22	Cribrosphaerella ehrenbergii
23	Cyclagelosphaera margerelii
24	Discorhabdus ignotus
25	Eiffellithus cf. E. gorkae
26	Eiffellithus cf. E. parallelus
63	Eiffellithus cf. E. striatus
27	Eiffellithus turriseiffelii
59	Eiffellithus? hancockii
28	Eprolithus apertior
29	Eprolithus floralis
30	Flabellites oblongus
31	Gaarderella granulifera
32	Gartnerago nanum
33	Grantarhabdus coronadventis
40	Helenia chiastia
55	Helicolithus compactus
34	Helicolithus trabeculatus
35	Isocrystallithus compactus
36	Lapideacassis mariae
37	Lithraphidites carniolensis
38	Lithraphidites pseudoquadratus
39	Manivitella pemmatoidea
41	Nannoconus sp. (x-section)
42	Nannoconus truitti rectangularis
43	Owenia hillii
44	Prediscosphaera columnata
45	Repagulum parvidentatum
46	Retecapsa angustiforata
47	Retecapsa crenulata
48	Rhagodiscus achlyostaurion
49	Rhagodiscus angustus
50	Rhagodiscus asper
51	Rotelapillus crenulatus
52	Seribiscutum gaultensis
53	Sollasites horticus
54	Staurolithites angustus
58	Staurolithites cf. S. mutterlosei
56	Staurolithites crux
57	Staurolithites gausorhethium
60	Staurolithites? sp.
61	Tegulalithus tesselatus
62	Tegumentum stradneri
64	Tetrapodorhabdus decorus
65	Thoracosphaera saxea
66	Tranolithus gabalus
67	Tranolithus orionatus
68	Watznaueria barnesiae
69	Watznaueria biporta
70	Watznaueria britannica
71	Watznaueria fossacincta
72	Watznaueria manivitiae
73	Zeugrhabdotus bicrescenticus
74	Zeugrhabdotus cf. Z. embergeri
75	Zeugrhabdotus diplogrammus
76	Zeugrhabdotus embergeri
77	Zeugrhabdotus erectus
78	Zeugrhabdotus noeliae
79	Zeugrhabdotus scutula
80	Zeugrhabdotus xenotus
81	Cyclagelosphaera rotaclypeata
82	Hayesites albiensis
83	Holococcolith sp.1
84	Lucianorhabdus salomonii

NANNOFOSSILS, MONT RISOU

Figure 7 Distribution of calcareous nannofossils in the top 136 m of the Marnes Bleues Formation at the Global boundary Stratotype Section for the base of the Cenomanian Stage on the western flanks of Mont Risou, east of Rosans, Hautes-Alpes, France.

(Continued)

NANNOFOSSILS, MONT RISOU (CONT'D)

RI-136m	RI-132m	RI-128m	RI-124m	RI-120m	RI-116m	RI-112m	RI-108m	RI-104m	RI-100m	RI-96m	RI-92m	RI-88m	RI-84m	RI-80m	RI-76m	RI-72m	RI-68m	RI-64m	RI-60m	RI-56m	RI-52m	RI-48m	RI-44m	RI-40m	RI-36m	RI-32m	RI-28m	RI-24m	RI-20m	RI-16m	RI-12m	RI-8m	RI-4m	RI 0m	RI+4m	RI+8m	RI+12m	RI+16m	RI+20m		SAMPLE / TAXON
F		F	F		R	F	F	R	R	R		R			R			R	R		R					F	R	F	F	F	F			R	F	F	F		F		85 Nannoconus regularis
R			R			R		R				F	F				R	R			R	R	R	R			R	F	F	R	R						R	R		86 Staurolithites glaber
R			R																																	R	R			87 Staurolithites sp.
		F	R	R		R	R			R			R																											88 Arkhangelskiella antecessor
	R	R	R				R			R	R			R																						R	R			89 Crucibiscutum hayi
	R	R			R				R	R			R			F		R	R	R			R			R	R	F				R	R	R	R	F	F		R	90 Haqius circumradiatus
	R	F					R																																R	91 Nannoconus minutus
	F		F		F			R	R	R			R	R			F		R	R	R			R		R	R	R	R			R	F	R						92 Percivalia fenestrata
	R		F	R	R	F							F	R	R	R	F	F		F	R	F	R	F	F	R		R		R	R	F	F					F		93 Rhagodiscus splendens
		R	R	R		R		R	R	R	F	F	F	F	F	F	F	R	R	R	F	R	F	F	F	F	F	F	F	F	F		F	R	R	F		F		94 Broinsonia matalosa
		R	R			R	R	R		R	F	F	F	R	F	F	F	R	R	R	R	R	R	R	F	R	R	R	R			F	R	R	R			R	R	95 Crucicribrum anglicum
		F	R			F		R		R	R	R	R	F	R	R	R		R	R	R	F	R	F	F	R	R	F	R	R	R	R		F		F	R	F		96 Gartnerago chiasta
		R	R	R		R	R		R	R	R	R		R					R			R	F		R	R	R	R	R		F			R	F	R	F		97 Orastrum perspicuum
		R			R			R			R			R	F	R	R	R	R	F	R	F	R	R		F	R		R	R		F	R	F	F		R	98 Scapholithus fossilis
		R	R	F	R	R	R	R			F	F	F	R	R	R		R		R	R		R			R	F	R			F	F	F		F		99 Staurolithites laffittei
	R																						R	R													R	100 Chiastozygus trabalis
	R		R								R															R												101 Crepidolithus? sp.
	R		R	R		R		R		R	R	R	R		F	R	F	R	R	R			F	R		F	F		R		F	R		102 Cylindralithus nudus
	R			R	F		R	F	F	F	R	F	R	F	F	F	F	F	F	F	F	F	F	R							R	103 Eiffellithus monechiae
	R	R			R														R	R				R	R	R	R	R	R		F	F	R	R	R	F	104 Nannoconus elongatus
	R					R			R			R					R					R			R	R		R	105 Nannoconus truitti truitti
	R		F	F																					R				R	106 Prediscosphaera spinosa
	R				R		R		R		R	R	F	R		R	R	R	R	F	R	R		R		110 Rhagodiscus gallagherii
	R		R					R		R				R		R		107 Rhagodiscus infinitus
	F	R	R	R													R		R	108 Seribiscutum primitivum
	R					F		F		R		R			R			109 Tranolithus minimus
		R			R			R									111 Holococcolith sp.2
		R			R		R								112 Nannoconus vocontiensis?
		R		R			R	R	F		R		R		F	R	113 Watznaueria ovata
			R		R									114 Cyclagelosphaera shenleyensis
			R						R	F	R	F		F	F	F	F	F	115 Chiastozygus sp.
			R		R		R		R	R	R	F	R	116 Nannoconus multicadus
			F		R		F	F	F	F	F	F	R	F	F	F	F	R	F	R	117 Loxolithus armilla
			R		F		F			R	118 Nannoconus sp.
			R					R	R	F	R	119 Radiolithus hollandicus
			R		R	R		R	R	120 Staurolithites? aenigma
			R		R		R	R	121 Biscutum thurowii
			R		R	R	R	122 Acuturris scotus
			R	R		R	R	123 Lapideacassis glans
			R	124 Semihololithus? sp.
			R	R		R	R	R	125 Stoverius achylosus
			R		R	126 Ceratolithina hamata
			R	R	R	R	R	R	R	127 Hemipodorhabdus gorkae
			R		R		R		R	R	128 Calcicalathina? cf. C. oblongata
			R		R		R	129 Microrhabdulus belgicus
			R	F	F		F		R		R	F		F	F	130 Prediscosphaera ponticula
			R	R			R	R	131 Ceratolithina spp.
			R			F	F	132 Ceratolithina cruxii
			R		R		R	R	F	R	F	R	134 Nannoconus truitti frequens
			R	135 Percivalia hauxtonensis
			R	133 Zeugrhabdotus burwellensis
			R	R		R	R	136 Calculites anfractus
			F	R		R	137 Rhagodiscus asper (no spine)
			R		R	R	R		R	138 Microrhabdulus cf. M. decoratus
			R	139 Boletuvelum? sp.
			R	140 Braloweria boletiformis
			R	141 Cyclagelosphaera deflandrei
			R		R		R	R	R	142 Nannoconus dislocatus
			R	143 Calculites sp.1
			R	144 Cylindralithus serratus
			F		F	R	R	R	R	145 Gartnerago theta
			R	146 Nannoconus dauvillieri
			R	R	R	R	147 Radiolithus planus
			F	148 Braarudosphaera bigelowii
			R	149 Gartnerago praeobliquum
			F	R	150 Prediscosphaera cretacea
			R	151 Scampanella sp.
			R	152 Corollithion kennedyi
			R	153 Zeugrhabdotus elegans

Key:

Nannofloral abundance (qualitative): H = High, M = Moderate

Nannofloral preservation: M = Moderate (identification of specimens with the light microscope not hampered by diagenetic etching and overgrowth of calcite).

Taxon abundance: A = Abundant (> 10 specimens/field of view)
C = Common (1–10 specimens/field of view)
F = Few (> 3 specimens/traverse)
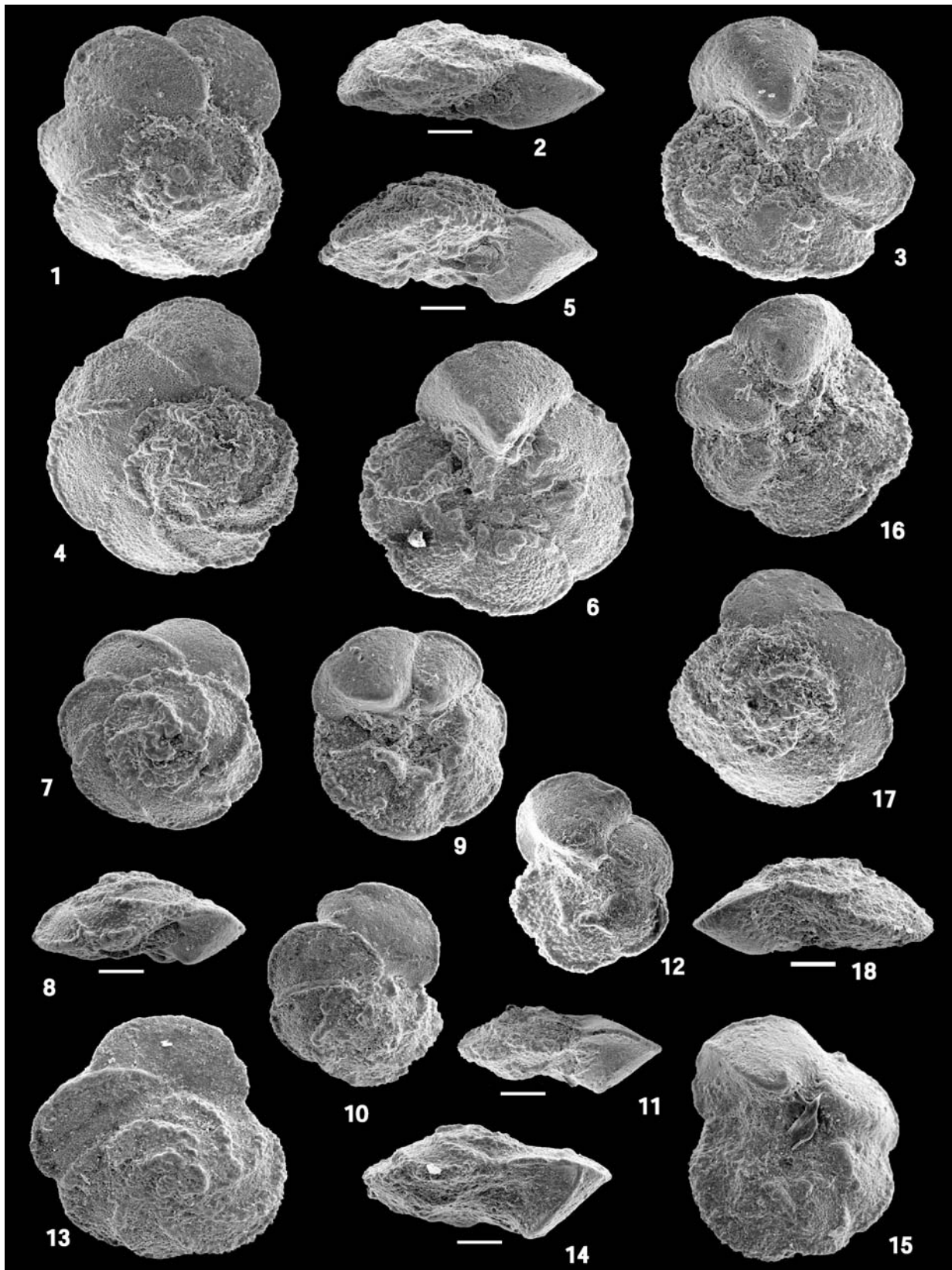*R = Rare (1–2 specimens/traverse)*

Figure 8 *Key planktonic foraminiferal taxa from the Global boundary Stratotype Section for the base of the Cenomanian Stage on the western flanks of Mont Risou, east of Rosans, Hautes-Alpes, France.*

1–3, Rotalipora appenninica (**Renz**), **BMNHS**, *–136 m;*

4–6, Rotalipora gandolfii **Luterbacher & Premoli-Silva**, *BMNHS, –38 m;*

7–9, Rotalipora tehamaensis **Marianos & Zingula**, *BMNHS, –27 m;*

10–12, Rotalipora globotruncanoides **Sigal**, *BMNHS, –36 m;*

13–15, Rotalipora globotruncanoides **Sigal**, *BMNHS, –23 m;*

16–18, Rotalipora ticinensis (**Gandolfii**), *BMNHS, –136 m.*　　　　　*(Bar scale is 100 microns)*

Carbon and oxygen stable isotope stratigraphy of the boundary interval

Oxygen isotopes

The $\delta^{18}O$ curve for the Mont Risou section (Figure 9) shows small-scale variation of 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, values rise to a maximum of −3.5‰. The possibility that these values have been 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 to a depth of up to several kilometers. The primary nature of these results is supported by several lines of evidence. SEM inspection of broken surfaces of various lithologies reveals little obvious cement: foraminiferan tests are empty, for example. The $\delta^{18}O$ values translate to give sea water surface temperatures of 26–27°C, using the equation of Anderson & Arthur (1983 SMOW 1.2‰) which are reasonable for this latitude in the Late Albian to Early Cenomanian interval (cf. Jenkyns, Gale & Corfield 1994). There is no correlation between lithology and $\delta^{18}O$ values; indeed, the highest part of the succession contains carbonate cemented beds, yet yields heavier oxygen isotope values — opposite to the predicted diagenetic trend. Finally, the very low level of variance is itself suggestive of a primary signal, because significantly altered successions are generally noisy as a result of the patchy distribution of cement. The oxygen isotope data thus indicates a slight cooling of about 1°C, beginning during the earliest Cenomanian.

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. However, the bacterial degradation of organic matter can have a marked effect on the $\delta^{13}C$ ratios of the dissolved bicarbonate reservoir, and may result in the formation of cements enriched in $\delta^{12}C$ (Scholle & Arthur 1980; Marshall 1992). Such cements are relatively common in deeper water organic-rich mudrocks (Marshall 1992) and are potentially important in interpretation of the d13C data from Mont Risou, because the deep-water marls at this locality contain up to 50% clay and have TOC values of 1–2% (Bréhéret & Delamette 1989, Fig. 2). The Niveau Breistroffer (containing laminated horizons) has the highest TOC values in the succession studied, and registers $\delta^{13}C$ values of the order of 1.5–1.9‰, which are not significantly lighter than values from coeval carbonate successions (e.g. Jenkyns et al. 1994). Additional evidence for a primary $\delta^{13}C$ signal in the Mont Risou section comes from the lack of correlation between lithology and carbon isotope values.

The carbon curve (Figures 9, 10) 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 Figure 10) 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 (see above). Peak B registers the highest values which pro-
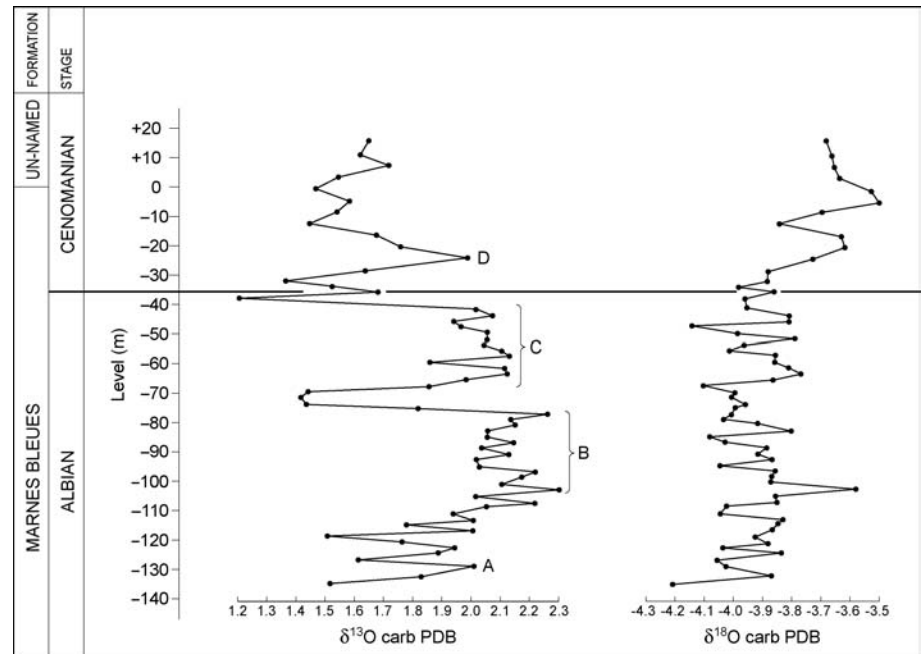

Figure 9 *The $\delta^{13}C$ and $\delta^{18}O$ curves across the Albian-Cenomanian boundary in the Global boundary Stratotype Section on the western flanks of Mont Risou, east of Rosans, Hautes-Alpes, France. Both $\delta^{13}C$ and $\delta^{18}O$ results are reproducible to better than ± 0.1‰. See Gale et al. (1996) for details of analytical procedures.*
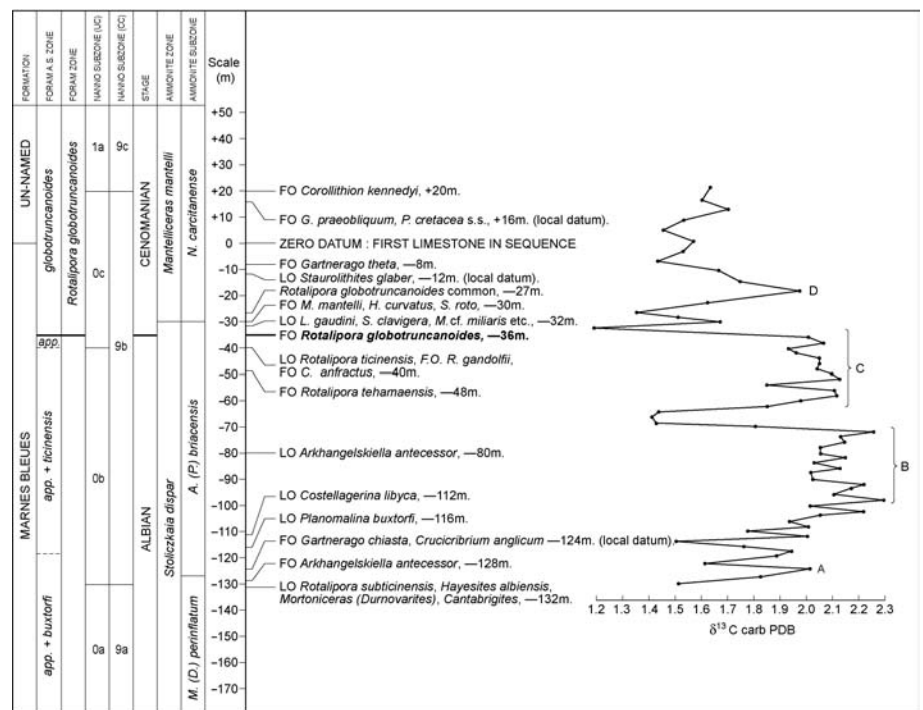

Figure 10 *The sequence of auxiliary markers, and the stable isotope curves across the Albian-Cenomanian boundary interval in the Marnes Bleues at the Global boundary Stratotype section for the base of the Cenomanian Stage on the western slopes of Mont Risou, Hautes-Alpes, France.*

gressively fall through C and D. However, to demonstrate convincingly the primary nature of the Risou $\delta^{13}C$ signature, it is necessary to find similar curves elsewhere (Scholle & Arthur 1980); Gale et al. (1996) compared carbon curves based on bulk carbonate analyses across Albian-Cenomanian boundary sections for Gubbio, Umbria Marche, Italy, (Jenkyns et al. 1994, Fig. 10) and for Speeton, Yorkshire, England (Mitchell & Paul 1994, Fig. 1) both based on whole-rock analyses. The Gubbio curve shows a small but discrete positive $\delta^{13}C$ spike including four minor peaks straddling the Albian-Cenomanian boundary as defined there by planktonic foraminifera. The Speeton curve shows a broad peak over 3–3.5 m of succession in unit RC2 of Mitchell & Paul (1994), made up of four individual sharp peaks and falls, with a total variance of about 0.8‰. The second peak is largest and reaches about 1.75‰; the two succeeding peaks are smaller. Mitchell & Paul place the Albian-Cenomanian boundary immediately beneath the highest of the four peaks, on evidence from calcitic macrofossils and calcitic and arenaceous microfossils.

The Speeton curve is very similar in overall shape, detail of ornament and variation range to that from Mont Risou. The Albian-Cenomanian boundary at Speeton falls in an identical position to that at Risou, immediately beneath the fourth minor $\delta^{13}C$ peak. Such a result is in line with data from the Cenomanian-Turonian boundary (Gale et al. 1993) where intricate details of the $\delta^{13}C$ spike can be interpolated with faunal and floral events and correlated on an intercontinental scale. However, the similarity between the Mont Risou and Speeton curves is perhaps even more remarkable because the thicknesses of the two sections differ by two orders of magnitude. The apparent lack of ornament on the Gubbio curve may be a result of the widely spaced sample intervals of 1 m taken by Jenkyns et al. (1994) from what is a thin succession. We conclude that the ornate $\delta^{13}C$ curve across the Albian-Cenomanian boundary established at Mont Risou provides a further secondary marker for the base of the Cenomanian Stage, which lies betweeen peaks C and D of the curve. Figure 10 summarizes the sequence of lithostratigraphic, biostratigraphic, and stable isotope markers across the boundary section.

Conclusions

The Global boundary Stratotype Section and Point for the base of the Cenomanian Stage at Mont Risou, near Rosans fulfils the following requirements set out by Remane et al. (1996):

There is exposure over an adequate thickness, and a sufficient time interval is represented by the section so that the boundary can also be determined by interpretation, using auxiliary markers close to the boundary.

There is continuous sedimentation across the boundary interval, with no evidence of sedimentary breaks or condensation.

The sedimentation rate was high, and successive events that straddle the boundary are widely separated.

The boundary interval is not disturbed by synsedimentary and significant tectonic disturbances. The Risou GSSP is terminated at its lower limit by a fault 100 m below the boundary level, and there is evidence of synsedimentary deformation 130 m above the boundary. The intervening interval includes minor faults with small displacements, in part of recent origin, but the boundary is not so disturbed.

There is no metamorphism, nor a strong diagenetic signal.

Well-preserved (if crushed) macrofossils, especially ammonites occur throughout the sequence, as do well-preserved and abundant micro- and nannofossils.

There are no vertical facies changes for 36 m above the boundary, and for more than 80 m below the boundary.

The pelagic facies, with cosmopolitan ammonite taxa, plus abundant planktonic micro- and nannofossils represents a favourable facies for long-distance correlation, as does the palaeogeographic setting of the GSSP, in the passage zone between the European Boreal and Tethyan Realms.

The GSSP preserves an excellent d13C and d18O record that provides an auxiliary marker of potential global application in the marine pelagic realm.

The GSSP is readily accessible by road, with free access.

The GSSP does not include potential chronometers for radiometric dating.

We lack a magnetostratigraphic profile for the GSSP, but note that the Albian-Cenomanian boundary falls within the Cretaceous Magnetic Quiet Zone.

Appendix I

Cretaceous Subcommission—Cenomanian Working Group Membership as at 31/3/97

E. Baraboschkin (Russia), P. Bengtson (Germany), J. Burnett (UK), M.M. Carmen (Romania), W. Christensen (Denmark), G. Csaszar (Hungary), A. Dhondt (Belgium), E. Erba (Italy), El M. Ettachfini (Morocco), A. Gale (UK), J. Gallemi (Spain), Gambashidze (Georgia), M. Gameil (Egypt), S. Gardin (France), Ghughunshivili (Georgia), J.M. Hancock (UK), J. Ion (Romania), J.W.M. Jagt (Netherlands), E.G. Kauffman (USA), W.J. Kennedy (UK), L.F. Kopaevich (Russia), M.A. Lamolda (Spain), G. Lopez (Spain), R. Martinez (Spain), T. Matsumoto (Japan), S. Monechi (Italy), F. Naji (Germany), H. Nestler (Germany), J. Obradovich (USA), E. Platon (Romania), J.M. Pons (Spain), I. Premoli-Silva (Italy), J. Rehánek (Czech Republic), K. von Salis (Switzerland), E. Seibertz (Germany), K.-A. Tröger (Germany), E. Urquhart (UK), C.J. Wood (UK).

Appendix II

Ammonites. A full account of the ammonite fauna of the sequence is given by Kennedy in Gale et al. 1996.

Nannofossils. The nannofossil sequence is described by Burnett in Gale et al. 1996. The revised nomenclature of Burnett (1998) is used here.

Planktonic foraminifera. Taxonomic notes on key species (Figure 8) are as follows:

Rotalipora tehamensis Marianos & Zingula, 1966: this species (Figure 8: 7-9) was identified in Tunisia by Gonzales-Donoso in Robaszynski et al. 1994, pp. 432, 457, illustrated in their pl. 20, Fig. 1, the stratigraphic range given in their text-fig. 36. This species differs from *R. ticinensis* (Figure 8: 16–18) in having a higher trochospire, a narrow umbilicus with periumbilical flanges on all chambers. It differs from *R. greenhornensis* by the absence of curved sutures on the spiral and umbilical faces.

Rotalipora gandolfii Luterbacher & Premoli-Silva, 1962: validly adopted by Robaszynski et al. 1979, pp. 81–84. This species (Figure 8: 4–6) evolved from *R. appenninica* (Figure 8: 1–3) by the development of a periumbilical flange and a more inflated umbilical face to the last two chambers.

Rotalipora globotruncanoides Sigal, 1948 (Figure 8: 10–12): a synonymy was published by Gonzalez-Donoso in Robaszynski et

al., 1994, p. 456. Caron herein, and in Gale et al., 1996 adopted a similar interpretation.

The taxonomy of *R. globotruncanoides* is complex, as summarised below.

- Sigal, 1948: two genera, *Rotalipora* Brotzen, 1942, and *Thalmanninella* gen. nov. recognised, as were two new species, *Rotalipora globotruncanoides* Sigal, 1948, and *Thalmanninella brotzen*i Sigal, 1948.

- Brönnimann & Brown, 1948: maintained *Thalmanninella* and *Rotalipora* as separate genera on the basis of the presence of a characteristic cover plate in *Thalmanninella.*

- Bolli, 1957: treated *Thalmanninella* as a junior synonym of *Rotalipora*, on the basis of the presence of sutural apertures in both.

- Sigal, 1958: *Thalmanninella* also regarded as a junior synonym of *Rotalipora.*

- Maslaskova, 1961-1963, Longoria, 1973: *Rotalipora* and *Thalmanninella* kept separate on morphological criteria.

- Wonders, 1978: keeled Rotaliporinae divided into three genera, *Rotalipora, Thalmanninella,* and *Pseudothalmanninella* Wonders, 1978.

- Robaszynski & Caron, 1979; Caron, 1985; Loeblich & Tappan, 1988: only *Rotalipora* recognised.

- Gonzalez-Donoso in Robaszynski et al., 1994 returned to the distinction of three phyletic groups within the rotaliporids, as recognised byWonders (1978), which he referred to *Rotalipora*, with *Thalmanninella* as a subgenus. He also (p. 456), referred to *brotzeni* Sigal, 1948, as a "synonyme subjectif postérieur" of *globotruncanoides* because Sigal (1948) introduced the name *globotruncanoides* on p. 100, and *brotzeni* on p. 102 of the same work. The term "synonym subjectif postérieur" does not appear in the fourth edition of the International Code of Zoological Nomenclature, while the names *globotruncanoides* and *brotzeni* are deemed to have been published simultaneously under the Rules (Article 24.2.2). The act of listing *brotzeni* Sigal, 1948, as a synonym of *globotruncanoides* Sigal, 1948, makes Gonzalez-Donoso (in Robaszynski et al., 1994, p. 456) "First Reviser" under the terms of Article 24.2.1 of the Code, and for those who believe *brotzeni* and *globotruncanoides* to be synonymous, the specific name *globotruncanoides* takes precedence.

- Robaszynski & Caron, 1995: recognised the genus *Rotalipora* only, accepted the act of Gonzalez-Donoso (1994), and afforded *globotruncanoides* precedence over *brotzeni.* This is the position adopted here.

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