The Turonian stage and substage boundaries

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Abstract

Formal definitions of the Cenomanian-Turonian and lower-middle Turonian boundaries are proposed, following discussions at the Second International Symposium on Cretaceous Stage Boundaries, held in Brussels, 8-16 September 1995. The Global boundary Stratotype Section and Point (GSSP, "golden spike") for the Cenomanian-Turonian boundary should be placed at the base of Bed 86 in a section at Rock Canyon Anticline, west of Pueblo, Colorado, USA, coincident with the first occurrence of the ammonite *Watinoceras devonense* WRIGHT & KENNEDY, 1981. A GSSP for the lower-middle Turonian boundary is proposed at the level of first occurrence of the ammonite *Collignoniceras woollgari* (MANTELL, 1822) in the same section (Bed 120). For the middle-upper Turonian boundary no GSSP can be proposed at present.

Key-words: Turonian, Upper Cretaceous, chronostratigraphy, biostratigraphy, cyclostratigraphy, carbon isotopes, ammonites, inoceramids, foraminifers, nannofossils, stratotypes, GSSP.

Résumé

Des définitions formelles sont proposées pour la limite Cénomanien-Turonien et pour la limite Turonien inférieur-moyen, suite aux discussions lors du "Second International Symposium on Cretaceous Stage Boundaries" (Bruxelles 8-16 septembre 1995). Le "Global boundary Stratotype Section and Point" (GSSP, "golden spike") pour la limite Cénomanien-Turonien devrait être placé dans une section à Rock Canyon Anticline, à l'ouest de Pueblo, Colorado, USA, à la base du Banc 86 qui coïncide avec la première apparition de l'ammonite *Watinoceras devonense* WRIGHT & KENNEDY, 1981. Comme GSSP pour la limite Turonien inférieur-moyen la première apparition de l'ammonite *Collignoniceras woollgari* (MANTELL, 1822) dans la même section (Banc 120) a été proposée. Pour la limite Turonien moyen-supérieur aucun GSSP ne peut être proposé pour le moment.

Mots-clefs: Turonien, Crétacé supérieur, chronostratigraphie, biostratigraphie, cyclostratigraphie, isotopes du carbone, ammonites, inocéramidés, foraminifères, nannofossiles, stratotypes, GSSP.

Туронский ярус и границы подъяруса: предложения Рабочей Группы Туронского яруса Подкомиссии Меловой Стратиграфии.

Резюме.
Формальное определение Сеномано-Туронской и нижне-средней Туронской границ было предложено после обсуждений, прошедших в течение второго Международного Симпозиума (Брюссель, 8-16 сентября 1995), посвящённого Границам Меловых Ярусов. «Global boundary Stratotype Section and Point» (GSSP, «golden spike») для Сеномано-Туронской границы должен быть определён в разрезе Rock Canyon Anticline, на западе Pueblo, Колорадо, США, в основании Слоя 86, совпадающего с первым появлением аммонита *Watinoceras devonense* (WRIGHT & KENNEDY, 1981). В качестве GSSP для нижне-средней Туронской границы было предложено первое появление аммонита *Collignonoceras woollgari* (MANTELL, 1822) того же разреза (Слой 120). Что касается средне–верхнего Турона, то на данный момент предложить какой-либо GSSP не представляется возможным.

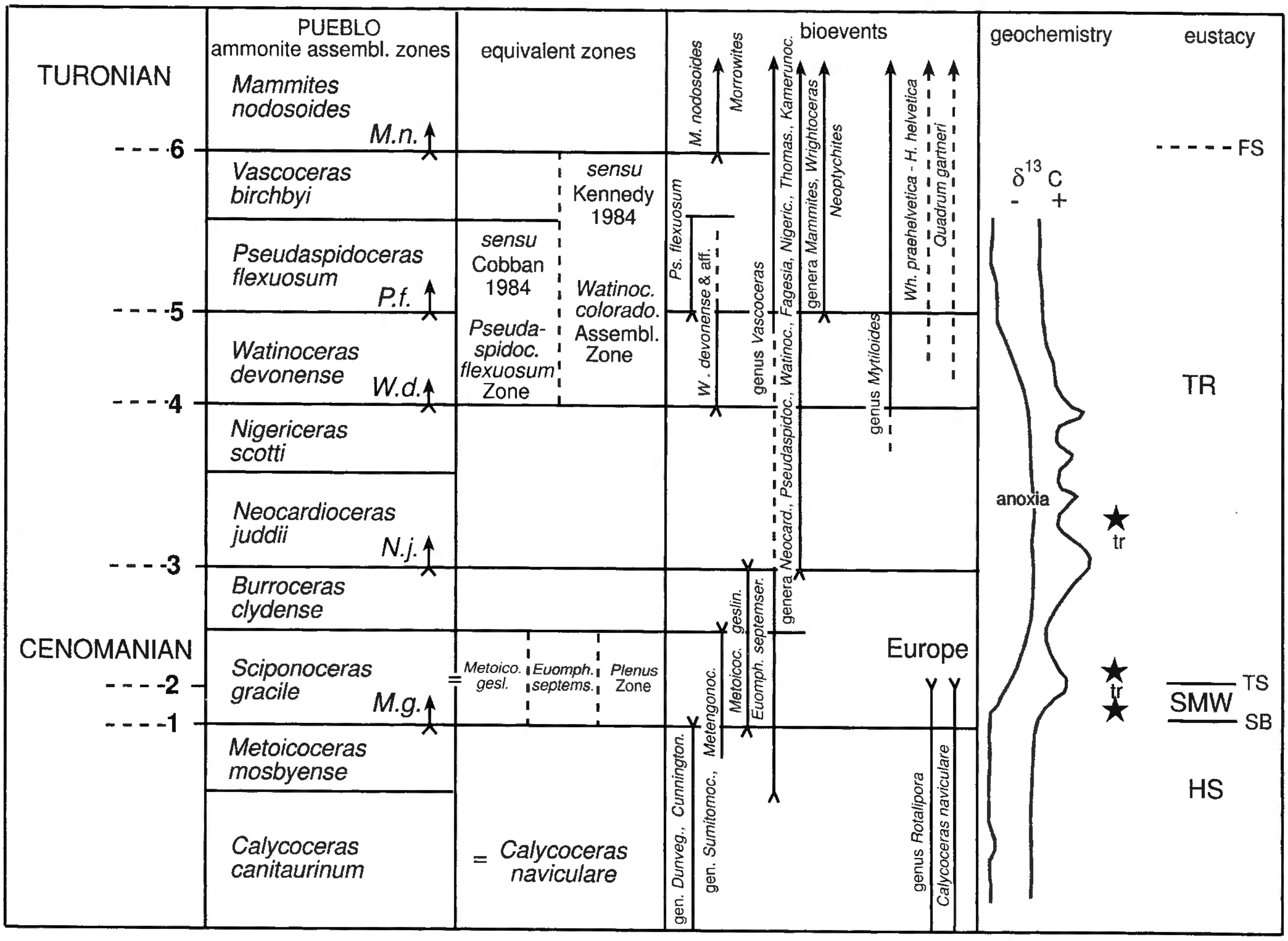
Ключевые слова: Туронский ярус, верхний мел, хроностратиграфия, биостратиграфия, циклостратиграфия, карбонические изотопы, аммониты, иноцерамы, фораминиферы, нанофоссилии, стратотипы, GSSP.

Introduction

The Turonian Working Group of the Subcommission on Cretaceous Stratigraphy has in recent years been primarily concerned with the definition of the bases of the Turonian substages. According to informal but well-established usage the Turonian Stage is best subdivided into three substages. Work has focused on agreeing about suitable chronostratigraphical levels for the bases of the lower, middle and upper Turonian substages, respectively, and on finding suitable boundary stratotypes in which these levels can be appropriately fixed through GSSPs (Global boundary Stratotype Sections and Points or, colloquially, golden spikes). The Cenomanian-Turonian boundary (i.e., the base of the [lower] Turonian) has become one of the least controversial among the Cretaceous stage boundaries. The reason for

[1] Stage (and substage) boundaries are chronostratigraphical datum planes and by definition globally isochronous. As biostratigraphical markers, such as first occurrences (FOs) of taxa or bases of biozones, are bound to be diachronous (no matter how insignificantly, geologically speaking) they cannot be used to define stage boundaries. The International Commission on Stratigraphy (REMANE 1995) recommends that stage boundaries should be defined by Global boundary Stratotype Sections and Points (GSSPs). Biostratigraphical or other markers in the rock record inferred to be nearly isochronous are then important instruments for the worldwide recognition of boundaries defined by GSSPs.

this is partly to be sought in the considerable international attention given to the Cenomanian-Turonian boundary in recent years, as a result of the discovery of a world-wide oceanic anoxic event and a possible mass extinction event near or at the boundary. In 1991, at Grenoble, France, an entire international symposium was devoted to the Cenomanian-Turonian boundary (cf. ROBASZYNSKI & GALE, 1993). The biostratigraphical "definition" [1] of the boundary has remained relatively stable during the past decade or so; this is also true of the lower-middle Turonian boundary, whereas the concept of the middle-upper Turonian boundary remains more elusive. The Turonian stage and substage boundaries are discussed here and proposals made for GSSPs for the Cenomanian-Turonian and lower-middle Turonian boundaries, respectively. These proposals are the main outcome of discussions at the Second International Symposium on Cretaceous Stage Boundaries, held in Brussels, 8-16 September 1995, and subsequent postal voting among the members of the Turonian Working Group.



Text-fig. 1 — Cenomanian-Turonian boundary stratigraphy, illustrated by the section at Rock Canyon Anticline, near Pueblo, Colorado, USA, showing six of the alternative levels for defining the boundary.

1. Base of the *Sciponoceras gracile-Metoicoceras geslinianum-Euomphaloceras septemseriatum-Actinocamax plenus* Assemblage Zone, with FO of *M. geslinianum* (D'ORBIGNY, 1850) and LOs of the genera *Dunveganoceras* and *Cunningtoniceras*. Commencement of $\delta^{13}C$ excursion. Sequence boundary.

2. LO of *Calycoceras naviculare* (MANTELL, 1822), approximately coincident with LO of the genus *Rotalipora*, notably *Rotalipora cushmani* (MORROW, 1934), at the transgressive surface, coincident with the first $\delta^{13}C$ maximum.

3. FOs of *Neocardioceras juddii* (BARROIS & DE GUERNE, 1878) and the genera *Pseudaspidoceras, Watinoceras, Fagesia*, etc. LOs of *M. geslinianum* and *E. septemseriatum* (CRAGIN, 1893), approximately coincident with the second $\delta^{13}C$ maximum.

4. FO of *Watinoceras devonense* WRIGHT & KENNEDY, 1981, approximately coincident with the FOs of the genus *Mytiloides* and *Quadrum gartneri* PRINS & PERCH-NIELSEN, 1977. $\delta^{13}C$ starts to fall.

5. FOs of *Pseudaspidoceras flexuosum* POWELL, 1963, and the genera *Mammites, Wrightoceras* and then *Neoptychites*.

6. FOs of *Mammites nodosoides* (SCHLÜTER, 1871) and the genus *Morrowites*. Flooding surface.

(Modified after ROBASZYNSKI & GALE, 1993, table 1.)

The Cenomanian-Turonian boundary (= base of the [lower] Turonian)

Historical review

A large number of biostratigraphical datums have been used historically and in more recent times as markers for the Cenomanian-Turonian boundary. In order to preserve continuity it is important that the boundary level to be chosen agree with the historical view as expressed by D'ORBIGNY (1850, 1852; see review by WRIGHT & KENNEDY 1981, p. 126). In terms of the traditional "standard" ammonite zonation this means that the boundary should be chosen so as to fall within the interval between the top of the *Metoicoceras geslinianum* ammonite Zone and the base of the *Mammites nodosoides* ammonite Zone as used by WRIGHT & KENNEDY (1981). Most of the boundary markers discussed at the first international meeting on Cretaceous stage boundaries, in Copenhagen 1983 (BIRKELUND *et al.*, 1984), fall within this interval (with a, g, h and possibly f lying below):

(a) Base of the *Metoicoceras geslinianum* ammonite Zone (or the slightly higher level of the FO of the ammonite *Euomphaloceras septemseriatum* [CRAGIN, 1893]).

(b) Base of the *Pseudaspidoceras flexuosum* ammonite Zone (or the FO of a vascoceratid such as *Vascoceras proprium* [REYMENT, 1954]).

(c) Base of the *Watinoceras coloradoense* ammonite Assemblage Zone.

(d) A definition based on the *Mytiloides* inoceramid lineage.

(e) The appearance of a flood of representatives of the genus *Mytiloides* at the base of the *Mammites nodosoides* ammonite Assemblage Zone.

(f) The FO of the nannofossil *Quadrum gartneri* PRINS & PERCH-NIELSEN, 1977 (in the *Neocardioceras juddii* ammonite Zone).

(g) The LO of the planktonic foraminifer genus *Rotalipora* in the *Metoicoceras geslinianum* ammonite Zone.

(h) The FO of the planktonic foraminifer *Whiteinella archaeocretacea* (PESSAGNO, 1967) in the middle of the *Metoicoceras geslinianum* ammonite Zone.

(i) The FO of the planktonic foraminifer *Helvetoglobotruncana helvetica* (BOLLI, 1945), although this datum is arguably diachronous and the presence of "*praehelvetica*" is ambiguous.

Alternative c, i.e. the base of the *Watinoceras coloradoense* Zone, was cited as the boundary level currently accepted by most European ammonite workers. This level was also said to be close to that of alternative b, the base of the *Pseudaspidoceras flexuosum* Zone (although KENNEDY & COBBAN [1991, p. 23] have shown that the base of the *W. coloradoense* Zone in sections exposed near Pueblo, Colorado [= base of *W. devonense* Zone], is actually at a much lower level than that of the *P. flexuosum* Zone). BIRKELUND *et al.* (1984) concluded that alternative b, i.e. the base of the *Pseudaspidoceras flexuosum* Zone, gained some support during the meeting (although the zonal index has a restricted geographical distribution). Important support for that boundary definition is the widespread appearance of early representatives of the inoceramid genus *Mytiloides*.

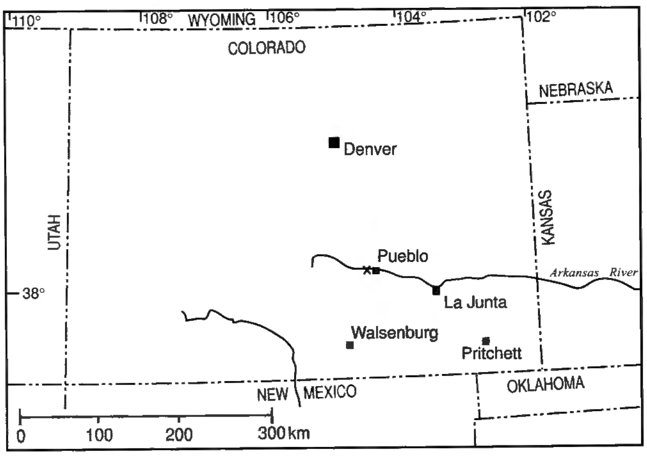
BIRKELUND *et al.* (1984) argued that a suitable boundary stratotype for alternative b should lie in Texas or Mexico, where both the *Pseudaspidoceras flexuosum* Zone and the underlying *Neocardioceras juddii* Zone are rich in ammonites. The section chosen should also contain *Mytiloides* and other groups such as planktonic foraminifers.

In the plenary session of the 1991 Grenoble meeting the boundary alternatives were discussed further and illustrated graphically by ROBASZYNSKI & GALE (1993; Text-fig. 1 herein). A section at Rock Canyon Anticline, near Pueblo, Colorado, USA, which had been studied in detail by KENNEDY & COBBAN (1991), was given serious thought as a possible boundary stratotype. Other sections mentioned, in the Niger Republic and Tunisia, were still incompletely known.

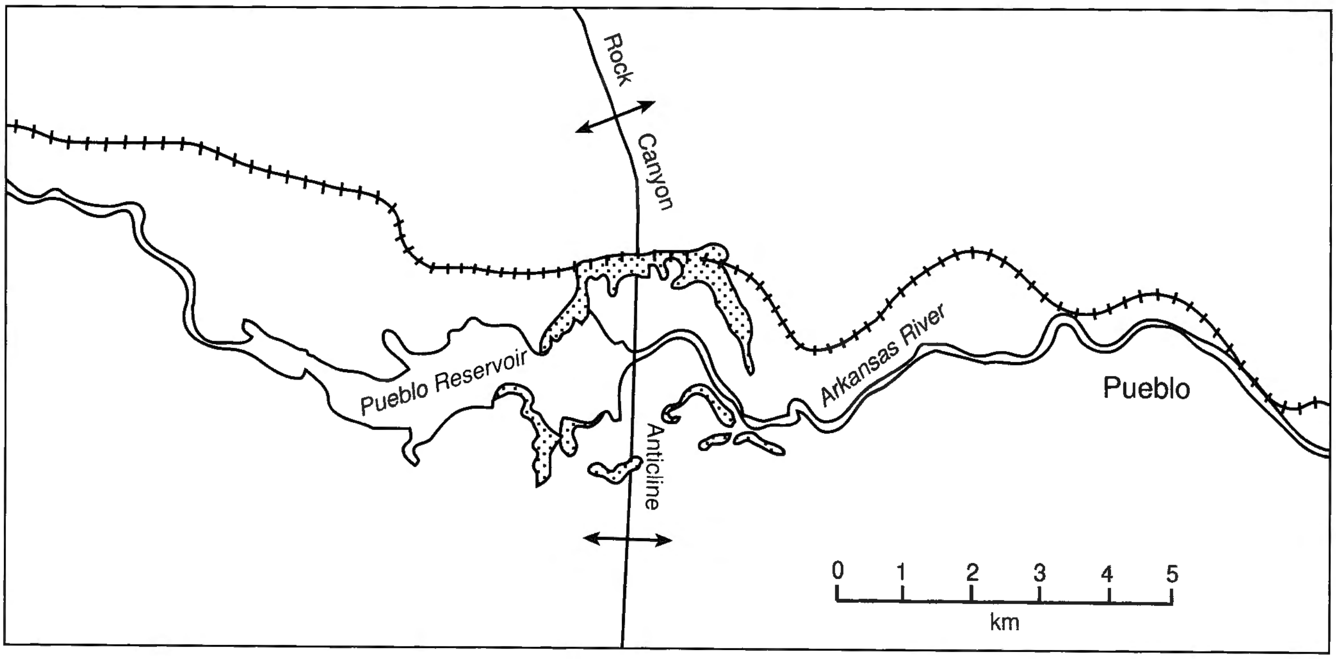
A detailed proposal for the section at Rock Canyon Anticline near Pueblo to be adopted as the Cenomanian-Turonian boundary stratotype and for the boundary point to be placed in this section at the FO of the ammonite species *Watinoceras devonense* WRIGHT & KENNEDY, 1981, was submitted by W. A. Cobban (Denver), A. S. Gale (London) and W. J. Kennedy (Oxford) (unpublished report, 1995; cf. REYMENT, 1995) and circulated among the members of the Turonian Working Group before the Brussels meeting.

The section at Rock Canyon Anticline, near Pueblo, Colorado

A suitable section for the Cenomanian-Turonian boundary should include as many of the biostratigraphical



Text-fig. 2 — Location of the section at Rock Canyon Anticline, near Pueblo, Colorado, and other important Cenomanian-Turonian boundary sections in Colorado (from KENNEDY & COBBAN, 1991, fig. 1).



Text-fig. 3 — Sketch map of the area west of Pueblo showing outcrops (stippled) of the Cenomanian-Turonian boundary sequence around the axis of the Rock Canyon Anticline (from KENNEDY & COBBAN, 1991, fig. 7).

marker horizons listed above as possible, comprise a non-condensed succession without obvious gaps, be well-documented with respect to geochemical and isotope data and should furthermore be dated numerically. The section should also be well exposed, permanent and easily accessible. The section at Rock Canyon Anticline near Pueblo, Colorado (Text-figs 2-3), proposed herein, fulfils many of these criteria. The following description is largely adapted from KENNEDY & COBBAN (1991) and from the written proposal by W. A. Cobban *et al.* (unpublished report, 1995) to the Turonian Working Group.

The Rock Canyon Anticline section is known since the last century (e.g., STANTON, 1894). It was mapped by SCOTT (1964, 1970) and the ammonite faunas have been documented by COBBAN & SCOTT (1973), COBBAN (1985), COBBAN *et al.* (in press), ELDER (1985) and KENNEDY & COBBAN (1991). The inoceramid bivalves have been documented by ELDER (1991) and KENNEDY & COBBAN (1991), planktonic foraminifers by EICHER & DINER (1985), calcareous nannofossils by WATKINS (1985) and BRALOWER (1988), stable isotopes by PRATT (1981, 1983, 1984, 1985), PRATT & THRELKELD (1984) and PRATT *et al.* (1993), iridium anomalies by ORTH *et al.* (1988), and isotopic dating of correlative sections has been carried out by OBRADOVICH (1994). ELDER (1985, 1987), HARRIES & KAUFFMAN (1990) and HARRIES (1993) discussed extinctions across the Cenomanian-Turonian boundary. Additional information was given by PRATT *et al.* (1985).

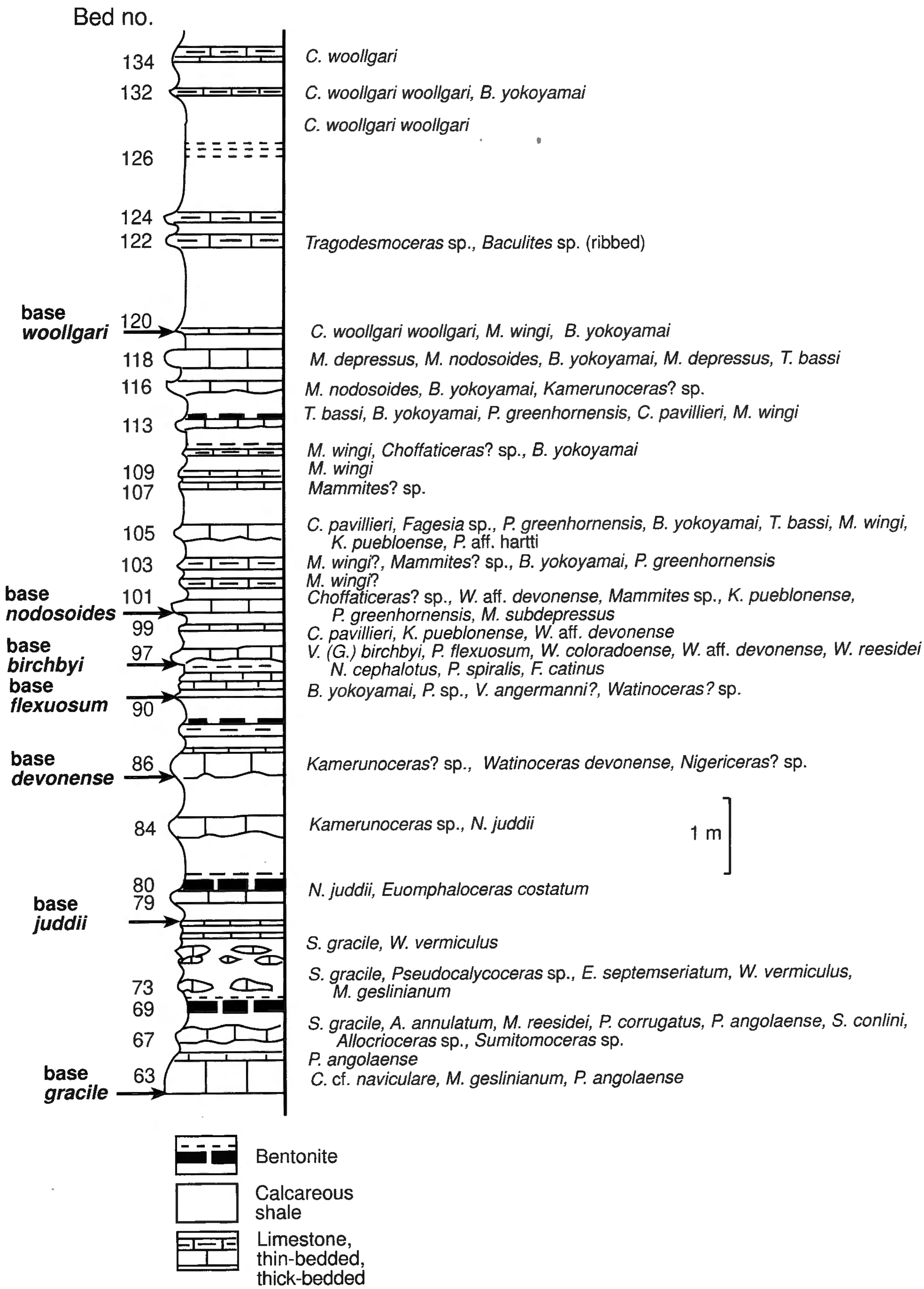
The sequence exposed at Rock Canyon Anticline shows no obvious signs of condensation or non-sequence across the boundary interval. It consists of diagenetically modified limestone-marl cycles and individual limestone and marl beds corresponding to the lower part of the Bridge Creek Member of the Greenhorn Limestone. Individual Milankovich couplets can be traced across a distance of 700 km into Kansas (e.g. HATTIN, 1971).

The proposed stratotype is in the Rock Canyon Anticline, west of Pueblo, where the Arkansas River cuts through the Cretaceous succession (Text-fig. 3). The construction of a dam and the development of a state park (the Pueblo Reservoir State Recreation Area) provide easy access by metalled roads. The section is permanent and lies in an area of natural badlands. Fossil collecting from natural outcrops in the state park is not permitted; however, relocation of the adjacent Denver and Rio Grande Western Railroad (Text-fig. 3) has provided several kilometres of fresh cuts through the boundary succession.

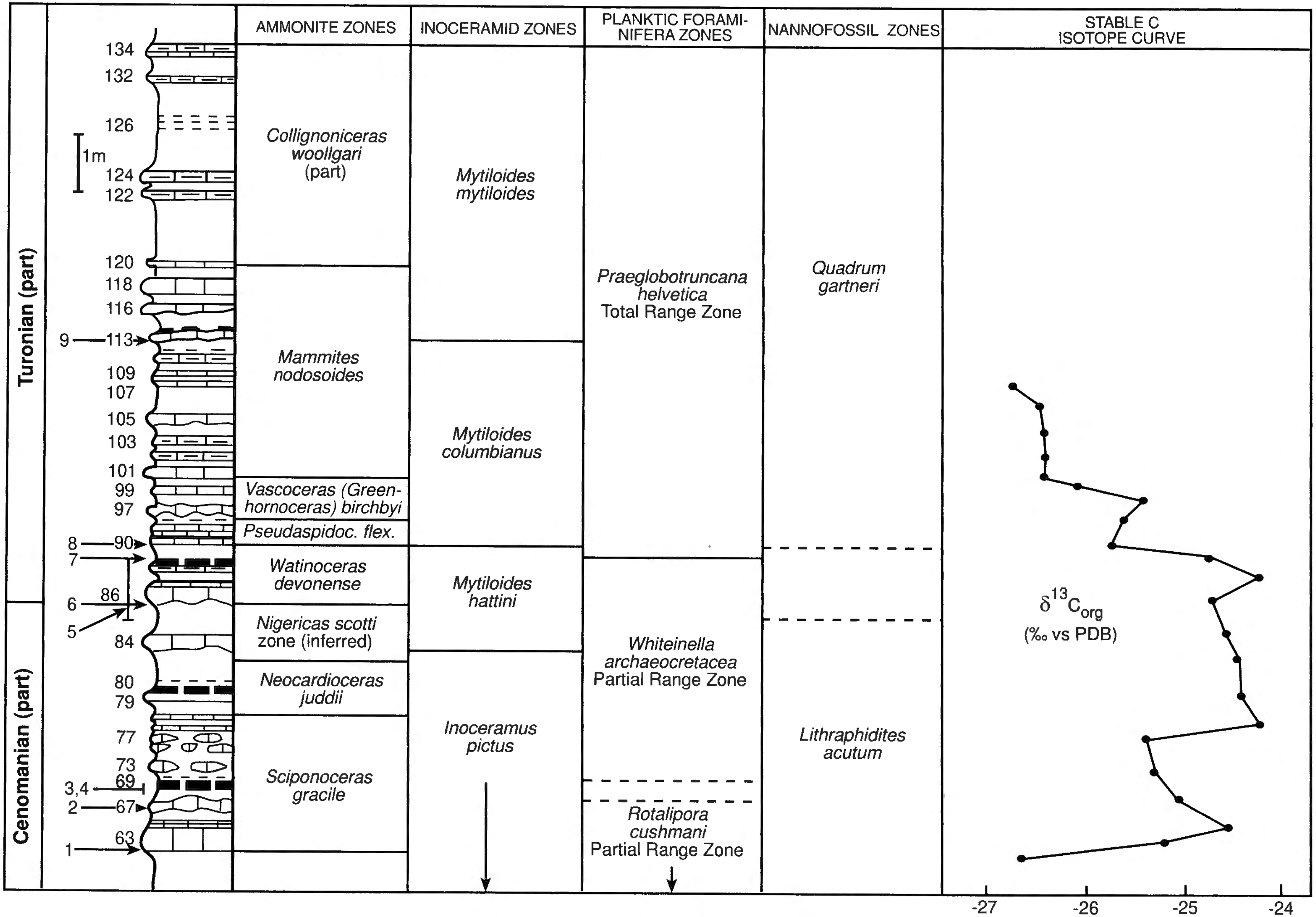
The ammonite zonation and succession at Rock Can-

ZONE	SUBSTAGE
Mammites nodosoides	LOWER TURONIAN
Vascoceras (Greenhornoceras) birchbyi	
Pseudaspidoceras flexuosum	
Watinoceras devonense	
Nigericeras scotti	UPPER CENOMANIAN (part)
Neocardioceras juddii	
Burroceras clydense	
Sciponoceras gracile	

Text-fig. 4 — The succession of ammonite zones across the Cenomanian-Turonian boundary in the southern U.S. Western Interior (from KENNEDY & COBBAN, 1991, fig. 2).



Text-fig. 5 — Stratigraphical chart of the part of the Rock Canyon Anticline sequence referred to the Cenomanian-Turonian boundary interval (beds 63-134), showing ammonite zonal boundaries and levels of species occurrences (after KENNEDY & COBBAN, 1991, fig. 8).


Turonian (part)
Cenomanian (part)
1m
134
132
126
124
122
120
118
116
9
113
109
107
105
103
101
99
97
8
90
7
6
86
5
84
80
79
77
73
3,4
69
2
67
63
1
AMMONITE ZONES
Collignoniceras woollgari (part)
Mammites nodosoides
Vascoceras (Greenhornoceras) birchbyi
Pseudaspidoc. flex.
Watinoceras devonense
Nigericas scotti zone (inferred)
Neocardioceras juddii
Sciponoceras gracile
INOCERAMID ZONES
Mytiloides mytiloides
Mytiloides columbianus
Mytiloides hattini
Inoceramus pictus
PLANKTIC FORAMINIFERA ZONES
Praeglobotruncana helvetica Total Range Zone
Whiteinella archaeocretacea Partial Range Zone
Rotalipora cushmani Partial Range Zone
NANNOFOSSIL ZONES
Quadrum gartneri
Lithraphidites acutum
STABLE C ISOTOPE CURVE
δ13Corg
(‰ vs PDB)
-27
-26
-25
-24

yon Anticline are shown in Text-figs 4 and 5, respectively.

Few well-documented alternatives to the section at Rock Canyon Anticline for a Cenomanian-Turonian boundary stratotype have been suggested, none of which formally. Candidates were mainly the Tunisian sections and the Oyubari section in Hokkaido (HASEGAWA *in* REYMENT, 1995); however, these were considered less satisfactory in comparison with the Rock Canyon Anticline section. An alternative boundary point was also considered by the Working Group at the Brussels meeting (see below).

PROPOSAL FOR A CENOMANIAN-TURONIAN GSSP

Arguments in favour of the section at Rock Canyon Anticline near Pueblo, Colorado, to be chosen as the Cenomanian-Turonian boundary stratotype section have been outlined above. W. A. Cobban *et al.* (unpublished report, 1995) suggested that the boundary point should be placed at the FO of the ammonite *Watinoceras devonense* WRIGHT & KENNEDY, 1981, in the Rock Canyon Anticline section. This level (the base of the *Watinoceras devonense* Zone) coincides with the base of Bed 86 (nomenclature and numbering system of COBBAN & SCOTT, 1973), according to current state of knowledge. It is close to the FOs of the planktonic foraminifer *Helvetoglobotruncana helvetica* (BOLLI, 1945) (cf. EICHER & DINER, 1985, p. 64) and the nannofossil *Quadrum gartneri* PRINS & PERCH-NIELSEN, 1977, and to the LO of the last *Rotalipora* morphotypes. *Watinoceras devonense* is an easily recognisable species and both this species and the potential boundary proxies *H. helvetica* and *Rotalipora* are geographically widespread taxa, which should facilitate correlation of the boundary. Alternative boundary levels were suggested by E. G. Kauffman (Boulder, Colorado) and E. Seibertz (Braunschweig, Germany), viz. the FOs of the inoceramid species *Mytiloides hattini* ELDER, 1991 (= *M.* aff. *sackensis* of authors) and *M. wiedmanni* LOPEZ, 1992 (SEIBERTZ, 1995), respectively, both appearing first in shale Bed 85 in the Rock Canyon Anticline section (but see below).

The original proposal by W. A. Cobban *et al.* (unpublished report, 1995) gained the most support, although as primary boundary marker the base of Bed 86 was preferred rather than the coincident FO of *Watinoceras devonense*. The Cenomanian-Turonian boundary point proposed here was thus selected primarily on cyclostratigraphical grounds. (With present-day biostratigraphical knowledge of the Rock Canyon Anticline section the result is, however, the same as if the biostratigraphical marker *W. devonense* had determined the choice.)

ARGUMENTS IN FAVOUR OF THE PROPOSED BOUNDARY POINT

The following main circumstances and arguments support the proposal of the base of Bed 86 in the section at Rock Canyon Anticline, near Pueblo, Colorado, as the Cenomanian-Turonian boundary point.

— The base of Bed 86 can be correlated cyclostratigraphically over tens of thousands of square kilometres of the U.S. Western Interior (across up to 700 km into Kansas).
— The ammonite *Watinoceras devonense* and other species of *Watinoceras* appear (FOs) at the base of Bed 86; *W. devonense* is easily recognisable, widely spread, and the type material is fully accessible in the collections of the Natural History Museum (London), which makes the FO of this and other *Watinoceras* species outstanding secondary markers and prime biostratigraphical markers and correlation tools.
— The planktonic foraminifer *Helvetoglobotruncana helvetica* appears (FO) less than 1 m above the base of Bed 86.
— The inoceramid bivalves *Mytiloides hattini* and *M. wiedmanni* appear (FOs) in the shales less than 1 m below the base of Bed 86 (ELDER, 1991, fig. 1; E. Seibertz, personal communication, 1996).
— The last *Rotalipora* morphotypes disappear (LO) near but below the base of Bed 86.

←

Text-fig. 6 — Integrated ammonite, inoceramid, planktonic foraminifer and nannofossil zonation of the Bridge Creek Limestone Member in the Rock Canyon Anticline section with bases of zones indicated and the plot of the $\delta^{13}C$ organic carbon excursion (stable carbon isotope curve) from a nearby core (PRATT & THRELKELD, 1984).
1. FO of *Metoicoceras geslinianum* (d'ORBIGNY, 1850);
2. FO of *Euomphaloceras septemseriatum* (CRAGIN, 1893);
3. LO of *Rotalipora cushmani* (MORROW, 1934) as well as of other *Rotalipora* morphotypes;
4. FO of *Whiteinella archaeocretacea* (PESSAGNO, 1967);
5. Interval containing FO of *Quadrum gartneri* PRINS & PERCH-NIELSEN, 1977, *fide* WATKINS (1985), although there is conflicting evidence (KENNEDY & COBBAN, 1991, p. 18);
6. Base of *Watinoceras devonense* Zone at the base of Bed 86, corresponding to the FOs of *Watinoceras devonense* WRIGHT & KENNEDY, 1981, and *Watinoceras* spp.; the proposed Cenomanian-Turonian boundary level;
7. FO of *Praeglobotruncana helvetica* (BOLLI, 1945) (= *Helvetoglobotruncana helvetica* herein);
8. Base of *Pseudaspidoceras flexuosum* Zone;
9. Flood of *Mytiloides mytiloides* (MANTELL, 1822). (After KENNEDY & COBBAN, 1991, Fig. 9, and Cobban *et al.*, unpublished report, 1995.)

	HEBERT 1864–1866	BARROIS 1878	DE GROSSOUVRE 1901	KENNEDY & HANCOCK 1976	AMEDRO *in* ROBASZYNSKI *et al.* 1980	KENNEDY, HANCOCK & WRIGHT 1983		AMEDRO *et al.* 1983		recommendations of the Colloque sur le Turonien (1981) 1983	
CONIACIAN *pars*	*Micraster cortestudinarium*	*Micraster cortestudinarium*	*Barroisiceras haberfellneri*		*Peroniceras tricarinatum*	*Reesideoceras petrocoriense*		*Peroniceras tridorsatum* A.Z.		*Peroniceras tricarinatum* I.Z *Reeside. petrocoriense* I.Z.	CONIACIAN *pars*
TURONIAN	*Micraster breviporus*	*Micraster breviporus*	*Romaniceras deverianum*	*Subprionocyclus neptuni*	*Subprionocyclus neptuni* A.Z.	*Subprionocyclus neptuni*	upper	*Subprionocyclus neptuni* A.Z *Romaniceras deverianum* A.Z.	upper	*Subprionocyclus neptuni* I.Z *Romaniceras deverianum* I.Z.	U. TURONIAN
	Rhynchonella cuvieri *Echiniconus subrotundus*	*Terebratulina gracilis*	*Romaniceras ornatissimum* *Romaniceras bizeti*	*Collignoniceras woollgari*	*Collignoniceras woollgari* A.Z.	*Collignoniceras woollgari*	middle	*Romaniceras ornatissimum* A.Z. *Romaniceras kallesi* A.Z. *Kamerunoceras turoniense* A.Z.	middle	*Collignoniceras woollgari* I.Z. *Romaniceras ornatissimum* I.Z. *Romaniceras kallesi* I.Z. *Kamerunoceras turoniense* P.R.Z.	MIDDLE TURONIAN
	Inoceramus labiatus	*Inoceramus labiatus*	*Mammites nodosoides*	*Mammites nodosoides* *(Watinoceras coloradoense)*	*Mammites nodosoides* A.Z.	*Mammites nodosoides* *Watinoceras coloradoense*	lower	*Mammites nodosoides* A.Z.	lower	*Mammites nodosoides* T.R.Z. *Watinoceras coloradoense* I.Z.	L. TURONIAN
U.CENOMANIAN	*Belemnites plenus*	*Belemnites plenus*	*Acanthoceras rhotomagense*	*Sciponoceras gracile* *Eucalycoceras pentagonum*	*Metoicoceras geslinianum*	*Neocardioceras juddii* *Metoicoceras geslinianum*		*Metoicoceras geslinianum* A.Z.		*Neocardioceras juddii* I.Z. *Metoicoceras geslinianum* I.Z.	U.CENOMANIAN

— There is a carbon isotope peak ca. 0.5 m above the base of Bed 86.
— The faunal association of the Rock Canyon Anticline section is neither typically Boreal nor Tethyan but rather a mixed assemblage, which enhances its correlation potential.
— The ammonite fauna of Bed 86 at Rock Canyon Anticline has recently been described and illustrated (COBBAN *et al.*, in press).

An integrated biozonation for the Cenomanian-Turonian boundary beds of the Rock Canyon Anticline section was presented by KENNEDY & COBBAN (1991, fig. 9) with minor amendments by COBBAN *et al.* (unpublished report, 1995); it is reproduced herein as Text-fig. 6. It should be noted that, as a result of different taxonomic opinions the base of their *Mytiloides hattini* Zone (originally *M.* aff. *sackensis* Zone) lies at a lower level than the FO of the species, *sensu* ELDER (1991), KAUFFMAN *et al.* (1994) and HARRIES *et al.* (1996). A more detailed inoceramid zonation for the entire Western Interior Basin was presented by KAUFFMAN *et al.* (1994, figs 7-8); a revised inoceramid zonation is also in preparation by E. Seibertz (personal communication, 1996); cf. also HARRIES *et al.* (1996).
The presence of bentonites in the Rock Canyon Anticline section which can be dated radiometrically adds to the value of the section. The time interval spanning the "proxies" listed above is estimated at approximately 25,000 years, which lies near the limits of biostratigraphical resolution.

The lower-middle Turonian boundary (base of the middle Turonian)

Widespread usage has been to place the lower-middle Turonian boundary at the FO of the widely distributed ammonite *Collignoniceras woollgari* (MANTELL, 1822). This was also the recommendation of the 1981 colloquium on the Turonian (ROBASZYNSKI, 1983a, p. 210, fig. 1, reproduced as Text-fig. 7 herein; ROBASZYNSKI, 1983b), although it was noted that the phylogenetic origin of *C. woollgari* was uncertain. In a written report to the Turonian Working Group before the Brussels meeting, W. J. Kennedy (unpublished report, 1995) proposed that usage should be formalised and that the section at Rock Canyon Anticline near Pueblo should be chosen as the boundary stratotype. The phylogenetic origins of *C. woollgari* can now be seen to lie in the lower Turonian genus *Cibolaites* COBBAN & HOOK, 1983.

In the Rock Canyon Anticline section *C. woollgari* appears first in Bed 120 (Text-figs 5 and 6). This level is coincident with the FOs of the widely spread inoceramid species *Mytiloides hercynicus* (PETRASCHECK, 1903) and *Inoceramus cuvierii* J. Sowerby, 1814 (KAUFFMAN *et al.*, 1994, p. 430, fig. 6; but see HARRIES *et al.*, 1996). The proposed boundary point lies within the *Helvetoglobotruncana helvetica* planktonic foraminifer Total Range Zone and the *Quadrum gartneri* nannofossil Zone.

The Rock Canyon Anticline section near Pueblo and the FO of *Collignoniceras woollgari* in this section are here proposed as a GSSP for the lower-middle Turonian boundary. Additional microfossil data will be required for the subsequent formal submission to the ICS.

←
Text-fig. 7 — Recommendations of the 1981 colloquium on the Turonian, with historical zonations for France for comparison (from ROBASZYNSKI, 1983a, fig. 1).

The middle-upper Turonian boundary (base of the upper Turonian)

To define the base of the upper Turonian is a less straightforward matter than for the other two Turonian substages (cf. Text-fig. 7). In ammonite terms two views prevail: (1) the FO of *Romaniceras deverianum* (d'ORBIGNY, 1841) and (2) the FO of *Subprionocyclus neptuni* (GEINITZ, 1849). Neither of these species has a worldwide occurrence, although *S. neptuni* is widely distributed. The main problem lies, however, in the fact that the relative positions of the FOs of the two species are uncertain, as they rarely co-occur. The 1981 colloquium on the Turonian suggested that for western Europe *R. deverianum* might be used as a provisional boundary marker (ROBASZYNSKI, 1983a, p. 212).

Further taxonomic and biostratigraphical work is required before a GSSP for the middle-upper Turonian boundary can be formally proposed. It may be that ammonites are less suitable as a basis for a boundary point. An alternative might be the FO of *Inoceramus costellatus* WOODS, 1912 (SEIBERTZ, 1995), which lies near the FO of *S. neptuni*.

No suitable potential stratotype is known at present, which underscores the need for further investigations. An informal working group of inoceramid specialists led by K.-A. Tröger (Freiberg, Germany) was set up at the Brussels symposium, with the purpose of finding a suitable inoceramid datum close to the FOs of *R. deverianum* and *S. neptuni* and to recommend on a GSSP.

Conclusions

The proposals of the Turonian Working Group of the Subcommission on Cretaceous Stratigraphy for Global boundary Stratotype Sections and Points are as follows:

Cenomanian-Turonian boundary: The base of Bed 86 in the section at Rock Canyon Anticline west of Pueblo, Colorado, USA, exposing the Bridge Creek Member of the Greenhorn Limestone. According to current state of knowledge this level coincides with the first occurrence of the ammonite *Watinoceras devonense* WRIGHT & KENNEDY, 1981, in the section.

Lower-middle Turonian boundary: The first occurrence of the ammonite *Collignoniceras woollgari* (MANTELL, 1822) in the section at Rock Canyon Anticline west of Pueblo, Colorado, exposing the Bridge Creek Member of the Greenhorn Limestone. According to current state of knowledge this level lies within Bed 120 and coincides with the first occurrence of the inoceramid bivalves *Mytiloides hercynicus* (PETRASCHECK, 1903) and *Inoceramus cuvierii* J. SOWERBY, 1814, in the section.

Middle-upper Turonian boundary: No proposal for a GSSP is possible at present. Work should be concentrated on finding a suitable boundary section and on increasing the biostratigraphical knowledge of the inoceramid bivalves and ammonites, in particular.

Acknowledgements

The proposals and conclusions presented herein are the results of a joint effort by several members of the Turonian Working Group. The preparatory work leading up to the discussions at the Second International Symposium on Cretaceous Stage Boundaries in Brussels, in September 1995, was coordinated by Richard A. Reyment (Uppsala). A written proposal for the definition of the Cenomanian-Turonian boundary was submitted for this meeting by W.A. Cobban (Denver, Colorado), A. S. Gale (London) and W.J. Kennedy (Oxford); in addition, W.J. Kennedy and E. Seibertz (Braunschweig) circulated reviews of the middle and upper Turonian substages.

At the Brussels meeting 28 out of 39 Working Group members were present. The result of the subsequent postal voting on the proposal for a Cenomanian-Turonian GSSP as presented herein was 34 votes in favour (including the ballots not returned), 3 votes against the proposal and 2 abstentions. Two of the negative voters argued that the boundary stratotypes should be selected in Europe where the historical stage stratotypes are and that the proposed Rock Canyon Anticline section in Colorado belongs to another palaeobiogeographical region, which may lead to diachronism in correlation of boundary stratotypes and stage stratotypes. The third negative voter considered the proposed Rock Canyon Anticline section to be still too poorly known, in particular with respect to the microfossil stratigraphy. The proposal for a GSSP for the lower-middle Turonian boundary received 33 votes in favour (including the ballots not returned), 4 votes against the proposal and 2 abstentions. The reasons given for the negative votes were the same as for the stage boundary proposal.

Working Group members who have contributed to the elaboration of this proposal (other than through mere voting) are listed as contributors below the title of the article. In particular the assistance by W.J. Kennedy in providing data for this report is gratefully acknowledged. Additional data on the inoceramids were contributed by E. Seibertz (Braunschweig) and on the planktonic foraminifers by M. A. Lamolda (Bilbao, Spain).

The graphical work was done by Rolf Koch (Geologisch-Paläontologisches Institut, Heidelberg).

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