BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 66-SUPP.: 81-94, 1996
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 66-SUPP.: 81-94, 1996

The Coniacian stage and substage boundaries

by Erle G. KAUFFMAN (compiler), W. Jim KENNEDY & Christopher J. WOOD,

with contributions by Annie V. Dhondt, Jake M. Hancock, Ludmila F. Kopaevich, Ireneusz Walaszczyk

Abstract

The Coniacian Working Group of the Cretaceous Subcommission on Stratigraphy has recommended the First Occurrence (FO) of the inoceramid bivalve *Cremnoceramus rotundatus* (*sensu* Tröger *non* Fiege) as criterion for recognising the Turonian-Coniacian boundary. This boundary lies between the LO of the ammonite *Prionocyclus germari* (uppermost Turonian of Eurasia and North America), and the FOs of the ammonites *Forresteria (Harleites) petrocoriensis* (Europe) and *F. peruana* and *F. brancoi* (North America), thus preserving the sense of the original ammonite definition of the boundary.

The working group further recommends that:

– the Lower-Middle Coniacian substage boundary be drawn at the FO of the inoceramid *Volviceramus koeneni* and, where ammonites are preserved, at or near the FO of *Peroniceras* (*Peroniceras*) *tridorsatum*,

– the Middle-Upper Coniacian boundary be drawn at the FO of the cosmopolitan inoceramid, *Magadiceramus subquadratus*.

The Coniacian Working Group unanimously recommended the Salzgitter-Salder Quarry section, near Salzgitter-Salder, Lower Saxony, Germany, as the Turonian-Coniacian boundary stratotype. The T-C boundary at this quarry is placed in bed MK-47 of the Wood *et al.* (1984) section, above the *Didymotis* ecoevent II and the flood occurrence of *Cremnoceramus? waltersdorfensis waltersdorfensis*.

No stratotype sections were recommended for the Coniacian substages because the data in support of any one of the two candidates have not yet been fully developed. Under study are the lower Austin Chalk of the Dallas-Fort Worth area of Texas, and the Seaford Head exposures of the Upper Chalk in southern England.

Key-words: Coniacian, Upper Cretaceous, biostratigraphy, ammonites, inoceramids, stratotypes.

Résumé

Le Groupe de Travail Coniacien de la Sous-Commission de Stratigraphie du Crétacé recommande que la première apparition du bivalve inocéramidé *Cremnoceramus rotundatus (sensu* Tröger *non* Fiege) soit reconnue comme critère pour la limite Turonien-Coniacien. Cette limite se situe entre l'extinction de l'ammonite *Prionocyclus germari* (Turonien tout à fait supérieur de l'Eurasie et d'Amérique du Nord) et l'apparition des ammonites *Forresteria (Harleites) petrocoriensis* (en Europe) et *F. peruana* et *F. brancoi* (en Amérique du Nord); ainsi la limite reste définie à un endroit proche de celui désigné à l'origine sur base des ammonites.

Le Groupe de Travail recommande aussi que:

– la limite entre les sous-étages Coniacien Inférieur et Moyen soit placée à l'apparition de l'inocéramidé *Volviceramus koeneni* et, quand il y a des ammonites, à ou près de l'apparition de *Peroniceras (Peroniceras) tridorsatum*,

– la limite entre les sous-étages Coniacien Moyen et Supérieur corresponde à l'apparition de l'inocéramidé cosmopolite *Magadiceramus subquadratus*.

Unanimement le Groupe de Travail recommande la carrière Salzgitter-Salder, près de Salzgitter-Salder, Basse Saxe, Allemagne, comme stratotype de la limite Turonien-Coniacien. Dans cette carrière, la limite T-C est placée dans le niveau MK 47 de la coupe décrite par Wood *et al.*, 1984; ce niveau se situe au-dessus du *Didymotis* "ecoevent II" et de l'apparition en masse de *Cremnoceramus waltersdorfensis waltersdorfensis*.

Pour les limites des sous-étages du Coniacien, aucun stratotype n'a été désigné parce que les données des deux coupes-candidates ne sont pas assez bien connues. L'Austin Chalk inférieur des environs de Dallas-Fort Worth au Texas et des affleurements de l'Upper Chalk de Seaford Head dans le sud de l'Angleterre sont à l'étude.

Mots-clefs: Coniacien, Crétacé supérieur, biostratigraphie, ammonites, inocéramidés, stratotypes

Определение Туроно-Коньякской границы.

Резюме.

Рабочая Группа Коньякского Яруса Стратиграфической Меловой Подкомиссии рекомендует признать первое появление иноцерамного двустворчатого моллюска *Cremnoceramus rotundatus* (*sensu* Tröger *non* Fiege) в качестве критерия для определения Туроно-Коньякской границы. Последняя располагается между границей исчезновения аммонита *Prionocyclus germari* (самый верхний Турон Евразии и Северной Америки) и появлением аммонитов *Forresteria (Harleites) petrocoriensis* (в Европе) и *F. peruana* и *F. brancoi* (в Северной Америке), предохраняя таким образом подлинное значение аммонитового определения границы.

Рабочая Группа также рекомендует:

- определять границу между подъярусами Нижнего и Среднего Коньяка при первом появлении иноцерама *Volviceramus koeneni* или, в том случае если аммониты сохранены, при первом появлении *Peroniceras tridorsatum*,

- определять границу между подъярусами Верхнего и Среднего Коньяка при первом появлении распространённого иноцерама, *Magadiceramus subquadratus*.

Рабочая Группа Коньякского Яруса единогласно рекомендует разрез в карьере Salzgitter-Salder, недалеко от Salzgitter-Salder, (Нижняя Саксония, Германия), в качестве стратотипа для Туроно-Коньякской границы. В этом карьере Туроно-Коньякская граница определена в слое МК-47 разреза WOOD et al., (1984; рис.4), над *Didymotis ecoevent* II и появлением множества *Cremnoceramus? waltersdorfensis waltersdorfensis*.

Что касается подъярусов Коньяка, то учёные не рекомендовали ни один разрез в качестве стратотипа, так как данные в поддержку каждого из двух вариантов не были ещё достаточно рассмотрены. В настоящий момент специалисты изучают Lower Austin Chalk в районе

Dallas-Fort Worth (Техас), а также отложения Seaford Head на юге Англии (Upper Chalk).

Ключевые слова: Коньякский ярус, верхний мел, биостратиграфия, аммониты, иноцерамы, стратотипы.

Introduction

The Coniacian is the shortest Cretaceous stage, enhancing the dynamic aspect of major changes in ocean-climate systems and their marine biotas. Based on ^{40}Ar-^{39}Ar radiometric dating of bentonites in the Western Interior Basin of North America, OBRADOVICH (1994) estimated a 2.4 Ma duration for the Coniacian, and presented new ages of 86.92 $\pm$ 0.39 Ma for a bentonite in the Late Coniacian ammonite biozone of *Protexanites bourgeoisianus*, and 88.34 $\pm$ 0.6 Ma for a bentonite in the *Scaphites preventricosus* Zone, Early Coniacian in age as a result of the recommendations of the Coniacian Working Group in Brussels.

Defining stage and substage boundaries: historical perspectives and recommendations

The Turonian-Coniacian (T-C) boundary

The Coniacian stage was introduced by COQUAND (1857 b). The type locality of the Coniacian is at the Richemont Seminary, near Cognac, Charente, France [COQUAND, 1857 a (p. 84), 1857 b (p. 748); SÉRONIE-VIVIEN, 1972, 1980; BIRKELUND *et al.*, 1984; KENNEDY, 1984 a, b], where a prominent regional disconformity separates Turonian rudistid-bearing limestones, capped by a hardground, from basal Coniacian glauconitic sands (which are unfossiliferous, apart from oysters); biostratigraphically important groups like the Inoceramidae and ammonites are absent (KENNEDY, 1984 a, b).

Therefore, BIRKELUND *et al.* (1984) proposed other possible candidates for the Turonian-Coniacian (T-C) boundary stratotype, including:

(a) The ''Priesener Schichten'' in the Czech Republic, which have a diverse ammonite and inoceramid fauna, as well as facies suitable for microbiotic analyses (= Brezno Fm., *sensu* CECH *et al.*, 1980); and

(b) the El Kef section in Tunisia with its high potential for micro- and nannofossil recovery.

Neither of these sections has been subsequently proposed or specifically favoured by members of this committee as the best stratotype, however, although both remain valid candidates.

WOOD *et al.* (1984) described the Salzgitter-Salder Quarry, in Lower Saxony (Germany), as a regional reference section for the Turonian and Lower Coniacian, and formally proposed that it should be regarded as an international standard section.

During the course of preliminary communications of the working group and at the Brussels meeting (KAUFFMAN, 1995; subsequently discussed, unpublished) a fourth stratotype candidate, in the Fort Hays Limestone Member, Niobrara Formation, near Wagon Mound, New Mexico, USA, was formally proposed by E. G. Kauffman.

Five additional Turonian-Coniacian sequences were informally proposed for consideration by the Working Group in correspondence leading up to the Brussels meeting (subsequently discussed), but none of these was formally presented at or before the meeting.

Criteria for the definition of the Turonian-Coniacian boundary presented at the Copenhagen meeting are as follows (BAILEY *et al*, 1984; BIRKELUND *et al.*, 1984):

(a) The first occurrence (FO) of the ammonite Forresteria (Harleites) petrocoriensis (Coquand) (= *Barroisiceras haberfellneri,* of authors, recorded from the Charente by de GROSSOUVRE, 1894 to SÉRONIE-VIVIEN, 1972; KENNEDY, 1984 a, b). Other ammonites are rare, so that this boundary definition relies heavily on the occurrence of a single species, *Forresteria (H.) petrocoriensis* (see: KENNEDY, 1984 a, b).

This definition received the greatest support in the Copenhagen meeting (BIRKELUND *et al.*, 1984).

(b) The FO of Cremnoceramus deformis (Meek) and/or Cr. schloenbachi (Boehm), as discussed by BAILEY *et al.* (1984), TRÖGER (1981), and especially as shown at the cement quarry near Erwitte, eastern Westphalia.

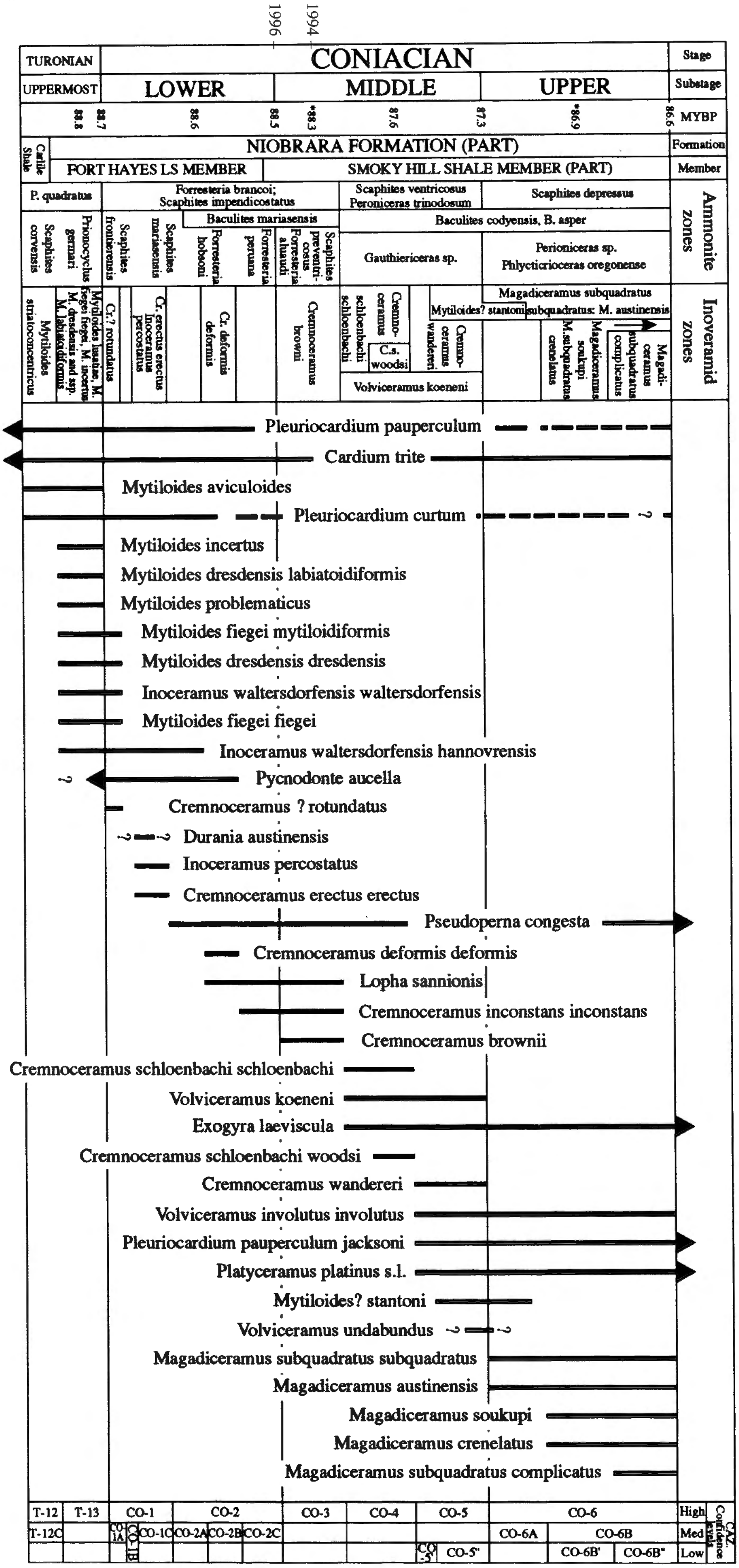
(c) The FO of Cremnoceramus rotundatus (sensu Tröger non Fiege).

The FO of *Cremnoceramus rotundatus* as described in TRÖGER, 1967, p. 110-114.

This FO is found in bed MK 47 at the Salzgitter-Salder Quarry, Lower Saxony, Germany (WOOD *et al.*, 1984; BAILEY *et al.*, 1984).

→

Fig. 1 — Standard Coniacian ammonite-inoceramid bivalve, biostratigraphic zones for the Western Interior of North America (modified after KAUFFMAN *et al.*, 1994) matched to radiometric and calculated ages (left columns) and composite range zones for biostratigraphically useful bivalve species. Radiometric ages (*) from OBRADOVICH (1994); calculated ages from KAUFFMAN *et al.*. (1994). Composite assemblage zones (CAZ: right) divided into high-, medium-, and low-confidence- level zones based on number of coeval FOs and LOs at zone boundaries. Key: 1994 - defines the boundary between the Early and Middle Coniacian selected by KAUFFMAN *et al.* (1994) for North America; 1996 - Early-Middle Coniacian substage boundary as recommended by members of the Coniacian Working Group of the Cretaceous Subcommission on Stratigraphy at Brussels. (For *Peroniceras trinodosum* read *Pe. tridorsatum*)


1996
1994
TURONIAN
CONIACIAN
Stage
UPPERMOST
LOWER
MIDDLE
UPPER
Substage
88.8
88.7
88.6
88.5
•88.3
87.6
87.3
•86.9
86.6
MYBP
Carlile Shale
NIOBRARA FORMATION (PART)
Formation
FORT HAYES LS MEMBER
SMOKY HILL SHALE MEMBER (PART)
Member
P. quadratus
Forresteria brancoi; Scaphites impendicostatus
Scaphites ventricosus Peroniceras trinodosum
Scaphites depressus
Baculites mariasensis
Baculites codyensis, B. asper
Scaphites corvensis
Prionocyclus germari
Scaphites frontierensis
Scaphites mariasensis
Forresteria hobsoni
Forresteria peruana
Forresteria alluaudi
Scaphites preventricosus
Gauthiericeras sp.
Perionicerass sp.
Phlycticrioceras oregonense
Ammonite zones
Mytiloides striatoconcentricus
Mytiloides fiegei fiegei, M. dresdensis and sp.
M. labiatoidiformis
Mytiloides lusatiae, M. incertus
Cr.? rotundatus
Inoceramus percostatus
Cr. erectus erectus
Cr. deformis deformis
Cremnoceramus browni
Cremnoceramus schloenbachi
C.s. woodsi
Cremnoceramus wandereri
Volviceramus koeneni
Magadiceramus subquadratus
Mytiloides? stantoni
subquadratus: M. austinensis
M. subquadratus crenelatus
Magadiceramus soukupi
Magadiceramus subquadratus complicatus
Inoceramid zones
Pleuriocardium pauperculum
Cardium trite
Mytiloides aviculoides
Pleuriocardium curtum
Mytiloides incertus
Mytiloides dresdensis labiatoidiformis
Mytiloides problematicus
Mytiloides fiegei mytiloidiformis
Mytiloides dresdensis dresdensis
Inoceramus waltersdorfensis waltersdorfensis
Mytiloides fiegei fiegei
Inoceramus waltersdorfensis hannovrensis
Pycnodonte aucella
Cremnoceramus ?rotundatus
Durania austinensis
Inoceramus percostatus
Cremnoceramus erectus erectus
Pseudoperna congesta
Cremnoceramus deformis deformis
Lopha sannionis
Cremnoceramus inconstans inconstans
Cremnoceramus brownii
Cremnoceramus schloenbachi schloenbachi
Volviceramus koeneni
Exogyra laeviscula
Cremnoceramus schloenbachi woodsi
Cremnoceramus wandereri
Volviceramus involutus involutus
Pleuriocardium pauperculum jacksoni
Platyceramus platinus s.l.
Mytiloides? stantoni
Volviceramus undabundus
Magadiceramus subquadratus subquadratus
Magadiceramus austinensis
Magadiceramus soukupi
Magadiceramus crenelatus
Magadiceramus subquadratus complicatus
T-12
T-13
CO-1
CO-2
CO-3
CO-4
CO-5
CO-6
High
T-12C
CO-1A
CO-1B
CO-1C
CO-2A
CO-2B
CO-2C
CO-6A
CO-6B
Med
CO-5'
CO-6B'
CO-6B"
Low
CAZ Confidence

(d) The FOs of the echinoids Micraster decipiens (Bayle) and/or M. normanniae Bucaille at the base of the Western European *M. cortestudinarium* zone were suggested by POMEROL (1983) and POMEROL *et al.* (1983) as a means of defining the base of the Coniacian. The boundary, so defined, is especially well preserved at Saint-Julien-du-Sault, near Sens (Yonne, France). The localised occurrences of these echinoids, problems in taxonomic definition of the species, their possible occurrences with both Upper Turonian and Lower Coniacian ammonites, and the probability of strong ecological and preservational control on their occurrence, led BIRKELUND *et al.* (1984) and BAILEY *et al.* (1984) to reject the use of these biostratigraphic criteria in defining the T-C boundary.

(e) The FO of Marthasterites furcatus (Deflandre) has commonly been used by nannofossil specialists as the base of the Coniacian. But this FO lies well within the range of typical Upper Turonian ammonites such as *Subprionocyclus neptuni* (Geinitz), and below the acme-zone of this species (BAILEY *et al.*, 1984). This boundary definition thus does not honour the original concept of the Turonian-Coniacian boundary near Cognac.

(f) The FO of the foraminifera Marginotruncana of the M. sinuosa group, together with the evolution of the Dicarinella primitiva-concavata group can be used (BIRKELUND *et al.*, 1984; MARKS, 1984) to distinguish the Coniacian from the Turonian.

(g) The FO of the foraminifers Lingulogavelinella sp. cf. L. vombensis (Brotzen) (*i.e. Gavelinella arnagerensis Soliakus*), *Reussella kelleri* (*Vassilenko*), *and Stensioina spp.* (e.g. *S. granulata levis* Koch). BAILEY *et al.* (1984) present arguments against these criteria for the Turonian-Coniacian boundary; the FOs of these taxa are highly discrepant between localities, suggesting that the species may be subject to strong ecological controls on occurrence; the first two foraminiferid taxa are also known to co-occur with *Subprionocyclus neptuni*, *Didymoceras saxonicum* (Schlüter) and *Scaphites geinitzii* (d'Orbigny), implying Upper Turonian FOs as well as a Lower Coniacian range for these species of foraminifera.

Criteria suggested for the definition of the Turonian-Coniacian boundary at the Brussels meeting are as follows:

(1) The first occurrence (FO) of the ammonite Forresteria (Harleites) petrocoriensis (Coquand) had strong support in Brussels and in correspondence leading up to that meeting. In particular, E. Seibertz expressed preference for a single ammonite entry level, that of *F.* (*H.*) *petrocoriensis*, as a basis for defining the Turonian-Coniacian boundary. W. J. Kennedy emphasised at the meeting that the final definition of the Turonian-Coniacian boundary should honour the placement of *F. (H.) petrocoriensis* in the Lower Coniacian [as was also proposed by MATSUMOTO (1984) for Japan and by ROBASZYNSKI (1984) for France], and below it the occurrence of *Prionocyclus germari* (Reuss) in the Upper Turonian .

[The approximately equivalent FO in North America maybe that of *F. (E.) peruana* (Brüggen, 1901) and/or *F. (F.) brancoi* (Solger, 1904) (KAUFFMAN *et al.*, 1994; Fig. 1 herein)].

In the Münster Basin of Germany (KAPLAN & KENNEDY, 1994; KAPLAN & KENNEDY, in press; KENNEDY, unpublished report to the Coniacian Working Group, 1995), it has been noted that the earliest appearance of the typical Coniacian inoceramid lineage of *Cremnoceramus* [e.g. *Cr. rotundatus* (*sensu* Tröger *non* Fiege)], lies below the FOs of *Forresteria (H.) petrocoriensis*, and above the LO of *Prionocyclus germari.*

The choice of the FO of *Cr. rotundatus* (*sensu* Tröger *non* Fiege) as the Turonian-Coniacian boundary marker by the Coniacian Working Group in Brussels honours KENNEDY's request, but places the T-C boundary significantly below the FO of *F.* (*H.*) *petrocoriensis* in Europe.

In the Western Interior of North America (KAUFFMAN *et al.*,1994 and herein) the FO of *Cr. rotundatus* lies below the FOs of *F. (E.) peruana* and/or *F. (E.) brancoi*, respectively (Fig. 1) and at the boundary level utilised in the Western Interior of North America (KAUFFMAN *et al.*, 1994: Fig. 1 herein) and previously tentatively throughout Europe and the Caribbean Province, where ammonites are relatively rare (KAUFFMAN, 1978 a, b).

(2) The FO of Cremnoceramus deformis (Meek) and/or Cr. schloenbachi (Boehm). KAPLAN & KENNEDY (1994) and KENNEDY (unpublished report to the Coniacian Working Group, 1995) both noted that the FO of *Forresteria* (*Harleites*) *petrocoriensis* is at, or slightly below, or slightly above, the first appearance of *Cremnoceramus erectus* (Meek), the second oldest Lower Coniacian biozone, and thus well below the occurrence of either *Cr. deformis* or *Cr. schloenbachi*.

In the Western Interior of North America (KENNEDY & COBBAN, 1991; KAUFFMAN *et al.*, 1994: Fig. 1 herein), the first appearance of *Cremnoceramus deformis sensu* Meek, lies several metres above the FOs of *Forresteria peruana*, *F. brancoi*, *Cr. erectus*, and *Cr. rotundatus*, all regarded as Lower Coniacian taxa. *Cr. schloenbachi* first appears above the *Cr. deformis* zone in this area, in the lower Middle Coniacian as defined by KAUFFMAN *et al.* (1994).

Criterion 2 is thus considered invalid.

[Editor's note: in Europe, following WALASZCZYK (1992), Cremnoceramus schloenbachi (Boehm, 1912) has been replaced by its earlier synonym Cr. crassus (Petrascheck, 1903)].

(3) The FO of Cremnoceramus rotundatus (sensu Tröger non Fiege).
I. Walaszczyk and C. J. Wood, written comm., May 1996 and Figures 4 and 5 herein, confirm the position of the FO of *Cr. rotundatus*; it approaches the criterion for definition of the T-C boundary established at Brussels.

Below the *Cr. rotundatus* bed at Salzgitter-Salder (WOOD *et al.*, 1984), in levels MK 45 and KM 46, is the flood occurrence of small forms of *Cr. waltersdorfensis hannovrensis* (Heinz) [now considered to be conspecific with the type concept of *Cr. waltersdorfensis waltersdorfensis* (I. Walaszczyk and C. J. Wood, written comm., May 1996)] together with abundant *Didymotis* in the upper *Didymotis* event and the unique specimen of *Cremnoceramus* sp. aff. *Cr. rotundatus (sensu* Tröger *non* Fiege) [this inoceramid is now considered a transitional form between *Cr. waltersdorfensis waltersdorfensis* (Andert) and *Cr. rotundatus* (Tröger non Fiege), I. Walaszczyk and C. J. Wood, written comm., May 1996]. These two levels (MK 45 -KM 46) are correspondingly reassigned to the uppermost Turonian (I. Walaszczyk and C. J. Wood, written comm., May 1996).

Further, despite the successful regional tracing of these flood occurrences in Germany, Bohemia, (Czech Republic) (CECH, 1989) northern Spain (KÜCHLER & ERNST, 1989) and even to England (WOOD *et al.*, 1984), on a more global scale their epiboles could be environmentally regulated at different times in different places, and thus not be inter-regional bioevents s.s.

In the Münster Basin of Germany (KAPLAN & KENNEDY, 1994; KENNEDY, unpublished report to the Coniacian Working Group, 1995), it has been noted that the earliest appearance of the typical Coniacian inoceramid lineage of *Cremnoceramus* [e.g. *Cr. rotundatus* (*sensu* Tröger *non* Fiege)], lies below the FOs of *Forresteria (H.) petrocoriensis*, and above the LO of *Prionocyclus germari.*

The choice of the FO of *Cr. rotundatus* (*sensu* Tröger *non* Fiege) as the Turonian-Coniacian boundary marker by the Coniacian Working Group in Brussels honours KENNEDY's request, but places the T-C boundary significantly below the FO of *F.* (*H.*) *petrocoriensis* in Europe.

In the Western Interior of North America (KAUFFMAN *et al.*,1994 and herein) the FO of *Cr. rotundatus* lies below the FOs of *F. (E.) peruana* and/or *F. (E.) brancoi*, respectively (Fig. 1, herein), at the base of the *Forresteria brancoi-Scaphites impendicostatus* assemblage biozone, the boundary level utilised in the Western Interior of North America (KAUFFMAN *et al.*, 1994). This assemblage is associated with rare *Didymotis*, and *Cremnoceramus? waltersdorfensis* (Andert) in the upper part of its range zone. The regional LOs of several species of uppermost Turonian *Mytiloides* [*M? lusatiae* (Andert), *M. incertus* (Jimbo), *M. dresdensis labiatoidiformis* (Tröger), *M. problematicus* (Schlotheim)] also occur at this boundary in North America. These are predominantly cosmopolitan inoceramid species with high correlation potential.

An alternative ammonite/inoceramid zonation was presented for the Western Interior of North America by KENNEDY & COBBAN (1991), using scaphitids and fewer inoceramid zones than in the KAUFFMAN *et al.*, 1978 scheme. KENNEDY & COBBAN (1991) clearly state that *Scaphites (Sc.) impendicostatus* Cobban, 1952 is restricted to the *Inoceramus deformis* Zone and thus occurs above *Forresteria brancoi*. They tied their zonation in with the French Coniacian.

The FOs of *Cr. rotundatus* and *Didymotis* spp. were recently proposed as criteria for defining the base of the Coniacian Stage in Germany and Spain (KÜCHLER & ERNST, 1989), and in the Brandenberg Basin, Austria (HERM *et al.*, 1979).

L. F. Kopaevich (Moscow State University) noted (personal communication, 1995) that the base of the Coniacian in Russia, Daghestan, Kazakhstan, and central Europe, which had traditionally been drawn at the FO of *Cremnoceramus deformis* (now known to be later Early Coniacian in age: KAUFFMAN *et al.*, 1994; Fig. 1 herein), has now been redefined to coincide with the FOs of *Cr. rotundatus, Forresteria petrocoriensis*, the foraminifera *Ataxophragmium nautiloides* (Brotzen, 1936), and *Gavelinella praeinfrasantonica* (Mjatluik, 1947), and the LOs of *Globorotalites hangensis* Vassilenko, 1956 and *Gavelinella moniliformis* (Reuss, 1845). Collectively, this boundary definition seems to fit the favoured European boundary criteria well (e.g. BAILEY *et al.*, 1984; KENNEDY, 1984 b and unpublished report to the Coniacian Working Group, 1995).

Selected Turonian-Coniacian boundary marker

By a vote of 24 to 0, with 3 abstentions, the Coniacian Working Group in Brussels approved criterion 3 (discussed above) for definition of the Turonian-Coniacian boundary.

Thus, the boundary will lie between the LO of *Prionocyclus germari* and the FO of *Forresteria* (*Harleites*) *petrocoriensis*, and at the FO of *Cremnoceramus rotundatus* (*sensu* Tröger *non* Fiege).

The use of other biostratigraphic data, chronostratigraphic event surfaces, and climate cycle deposits in helping to bracket and define the Turonian-Coniacian boundary was encouraged.

These criteria are well represented at the chosen boundary stratotype, the Salzgitter-Salder Quarry in Lower Saxony (WOOD *et al.*, 1984; subsequently discussed): the FO of *Cremnoceramus rotundatus* occurs at the base of the Coniacian, in a regionally correlatable shale-limestone bedding sequence, just above two regional bioevents - the second *Didymotis* ecoevent and a flood occurrence of *Cr.? waltersdorfensis waltersdorfensis,* as described by WOOD *et al.* (1984), shown in Figures 4 and 5, and adjusted by I. Walaszczyk & C. J. Wood, written comm., 1996. Ammonites (scaphitids and baculitids) occur at several levels below and above this boundary, but are not found at the boundary; *Scaphites kieslingswaldensis doylei* ranges across the boundary, while the first unequivocal Coniacian ammonites, i.e. *Sc. kieslingswaldensis kieslingswaldensis* and *Scalarites turoniensis* first appear significantly above the boundary. There is a regional planktonic foraminiferal change at or near the boundary, which is marked particularly by a significant increase in *Globotruncana paraventricosa* (Hofker) (BRÄUTIGAM, 1962). The boundary is also bracketed by numerous regionally correlated cyclostratigraphic and event beds or faunas (Figures 4 and 5).

Defining Coniacian substages.

Substage division of the Coniacian has been attempted by a number of past authors. DE GROSSOUVRE (1901) proposed a two-fold division of the Coniacian in parts of France based on ammonite zones; a lower *Barroisiceras haberfellneri* Zone, and an upper *Mortoniceras emscheris* Zone.

But as KENNEDY (1984 b) pointed out, neither of these species actually occurs in France. KENNEDY (1984 b) proposed a three-fold substage division of the Coniacian for large areas of France, as follows:

(1) a Lower Coniacian *Forresteria* (*Harleites*) *petrocoriensis* Zone;
(2) a Middle Coniacian *Peroniceras* (*Peroniceras*) *tridorsatum* Zone;
(3) a sequence of two ammonite zones (*Gauthiericeras margae* Zone below, *Paratexanites serratomarginatus* Zone above) referred to the Upper Coniacian.

KENNEDY (1984 b) discussed these divisions and listed additional ammonite taxa in each; his proposed substage boundaries are marked by the FOs of the ammonite taxa characterizing the overlying zone. As KENNEDY (KENNEDY & COBBAN, 1991) subsequently pointed out, however, it is not possible at present to define Coniacian substages internationally using ammonites because cosmopolitan taxa are not common, and ammonites, in general, are too rare, or absent, in most sections (also KENNEDY, unpublished proposal to the Coniacian Working Group, 1995).

KAUFFMAN *et al.* (1978) formally proposed substage divisions for the Late Albian through the Coniacian in the Western Interior of North America based on assemblage biozones composed of largely endemic ammonites and cosmopolitan inoceramid bivalves.

In this work, the base of the Lower Coniacian was defined by the FOs of *Cremnoceramus rotundatus* (Fiege), *Pycnodonte aucella* (Roemer), and *Forresteria* spp. , the base of the Middle Coniacian was defined by the FO of *Inoceramus (= Cremnoceramus) browni* (Cragin), and the base of the Upper by the FO of *Magadiceramus subquadratus* (Schlüter). This has subsequently been applied more widely in the Western Hemisphere (KAUFFMAN, 1978 b).

At the Brussels meeting, it was agreed that no internationally consistent definition of Coniacian substages and substage boundaries has yet been developed. Further, the most comprehensive published substage divisions, those of KENNEDY (1984 b) based on European ammonites, and of KAUFFMAN *et al.* (1994) for the Western Interior of North America, based on assemblage biozones consisting of largely endemic ammonites and mainly cosmopolitan inoceramid bivalves (Fig. 1) are not completely similar and cannot be compared in detail on the basis of ammonite zonation. Ammonites are poorly preserved in many Coniacian sequences, especially in fine-grained carbonates, and the American ammonite indices are largely endemic, insofar as they are currently known. Thus ammonites do not provide the best biostratigraphic basis for definition of the Turonian-Coniacian boundary.

After much debate, the Coniacian Working Group, by an 18 to O vote, 6 abstentions, approved the FO of the inoceramid genus *Volviceramus*, and specifically *Vo. koeneni, as the criterion for defining the Lower-Middle Coniacian Stage boundary.*

Although KENNEDY (1984 b) proposed for the Middle-Upper Coniacian an ammonite boundary (FO of *Gauthiericeras margae*) for parts of Europe, he acknowledged that ammonites are too rare in this interval to be useful, as currently known, in regional to global correlation of the Middle-Upper Coniacian substage boundary (unpublished report to the Coniacian Working Group, 1995). He also favoured the FO of *Magadiceramus subquadratus* to define the substage boundary.

This was the only boundary criterion discussed for the Middle-Upper Coniacian boundary by the working group at Brussels, and was approved by a 16 to 0 vote, 4 abstentions.

Boundary stratotype proposals

All aspects of the Coniacian and its stage and substage boundaries were discussed at the Brussels meeting, resulting in a number of recommendations to the Subcommission on Cretaceous Stratigraphy.

Turonian-Coniacian Boundary Stratotype. – Because neither of the Turonian-Coniacian boundary sections suggested as possible stratotype candidates [the Priesener Schichten (= Brezno Formation of present day stratigraphy) in the Czech Republic, and the El Kef section in Tunisia] at the Copenhagen meeting by BIRKELUND *et al.* (1984) has subsequently been studied in detail, published, and supported by a formal proposal to the Coniacian Working Group they could not be considered as viable candidates at the Brussels meeting.

Despite a rich and varied fossil record, the T-C boundary is below outcrop level at the proposed Czech stratotype (and, moreover it lies within the Teplice Formation rather than within the Brezno Formation – see CECH, 1989); the El Kef section lacks a significant macrofauna, and access may be limited in the future.

Three new proposals for the Turonian-Coniacian boundary stratotype were presented at the Brussels meeting, and in correspondence leading up to that meeting, and an additional five informal proposals were made in correspondence, but were not pursued further at the meeting. The three Brussels proposals were as follows:

(1) The Vistula River section in central Poland, which contains an excellent Upper Turonian through upper Lower Coniacian (*Cremnoceramus deformis* Zone) macrofossil record, including ammonites and inoceramid and *Didymotis* bivalves (WALASZCZYK, 1992) and which shows little diagenesis, suggesting the potential for good microfossil recovery;

(2) The Wagon Mound, New Mexico (USA) section (COLLOM, 1991; KAUFFMAN, 1995) an easily accessible, well exposed, road-cut section of cyclically bedded calcareous shale and hemipelagic limestone (Milankovitch climate cycle deposits) with excellent preservation of foraminifers and inoceramid bivalves, detailed geochemical data (stable isotope and organic carbon profiles), and scattered ammonites;

(3) The Salzgitter-Salder Quarry section in Lower Saxony, Germany, originally studied in detail by WOOD *et al.* (1984) and proposed as a regional reference section and possible boundary stratotype for the T-C boundary. This section is well exposed, accessible, documented at very high levels of resolution, and contains a rich foraminifer, nannofossil, inoceramid and didymotid bivalve record, scattered ammonites, and numerous regionally persistent event marker beds (WOOD *et al.*, 1984; Figs. 2, 3, 4 herein). BURNETT (pers. comm.) placed the base in nannofossil zone CC 138 (defined by the FO of *Lithastrinus septenarius*. A preliminary $\delta^{13}C$ curve was published by ERNST & WOOD (1995); more detailed stable isotope data will be published by VOIGT & HILBRECHT (in prep.).

During the two-year deliberations of the working group, a number of regional stratotype sections for the Turonian-Coniacian boundary were informally proposed, but not formally presented at the Brussels meeting; these included:

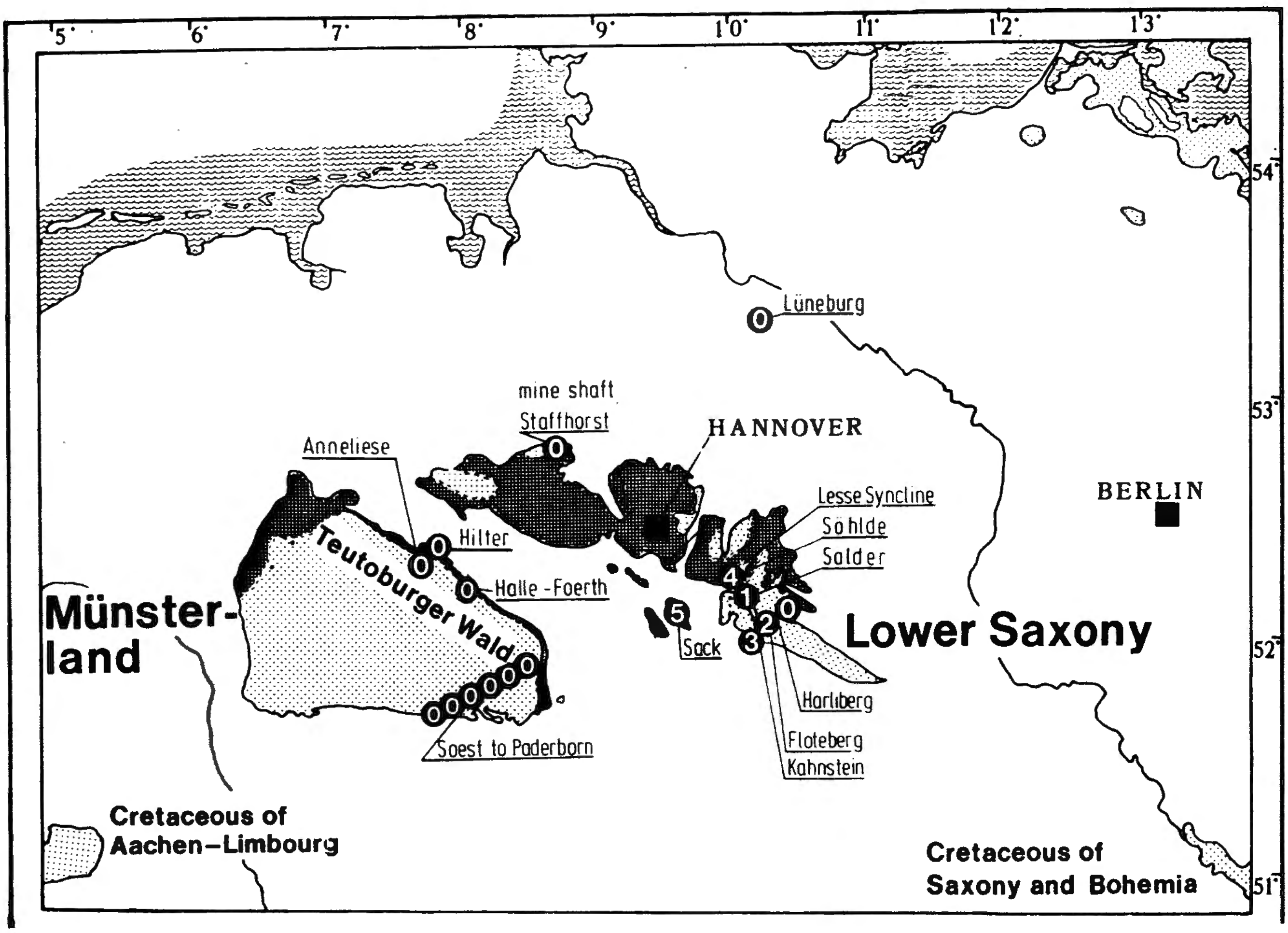


Fig. 2 — Locality map of Lower Saxony, Germany, showing the position of the Salzgitter-Salder Quarry (see Salder), the site of the stratotype section for the Turonian-Coniacian boundary recommended by the Coniacian Working Group at Brussels (After WOOD *et al.*, 1984).

Fig. 3 — Photograph of the Turonian-Coniacian boundary stratotype section at the Salzgitter-Salder Quarry, Lower Saxony, Germany. The arrow designates the T-C boundary (see Figure 4) at the base of bed MK-47. (Photograph courtesy of C. J. Wood).

(1) T. Matsumoto (Fukuoka, Japan) proposed that the best reference sections for the Turonian-Coniacian boundary in Japan may be the Pombets (Ponbetsu)-Gono-sawa section in the Ikushambets (or "Mikasa") area of central Hokkaido (MATSUMOTO, 1984). The integrated micro- and macropalaeontology, and event stratigraphy of this boundary sequence is described in detail in TOSHIMITSU *et al.* (1995). The systematics and biostratigraphy of the Early Coniacian *Inoceramus (Cremnoceramus) deformis* group from the Obira area, northwestern Hokkaido, critical to the definition of the T-C boundary, has been completed recently by NODA (in press).

(2) W. A. Cobban (U. S. Geological Survey, Denver, USA), suggested that the Fort Hays Limestone section at Pueblo, Colorado, might be a good Turonian-Coniacian stratotype because *Forresteria* spp. are more abundant in the Lower Coniacian limestones there than at Wagon Mound, New Mexico (North American reference section proposed by E. G. Kauffman), and they may occur closer to the T-C boundary. A rich and diverse inoceramid bivalve fauna also spans the boundary here, but is not as well preserved as to the south. The interval is widely exposed, well preserved, and fully accessible within a Colorado State Recreation Area.

However, this boundary sequence is more condensed than in New Mexico or at the Salzgitter-Salder Quarry, and thus may contain some omission surfaces. Further, the Pueblo section has much thinner and more weathered marl and shale intervals between the limestones, which yield a depleted and somewhat poorly preserved microbiota. For these reasons, this T-C boundary section was withdrawn from consideration before the Brussels meeting.

(3) Ludmila F. Kopaevich (Moscow State University, Moscow, Russia) recommended three possible T-C stratotype sections, as follows:

(a) the Shakh-Bogota section, northern Mangyshlak, Kazakhstan; this is a complete and well exposed, fossiliferous section where the base of the Coniacian is marked by the FO of *Cremnoceramus? waltersdorfensis*, the benthic foraminifers *Gavelinella* sp. cf. *G. vombensis* (Brotzen)

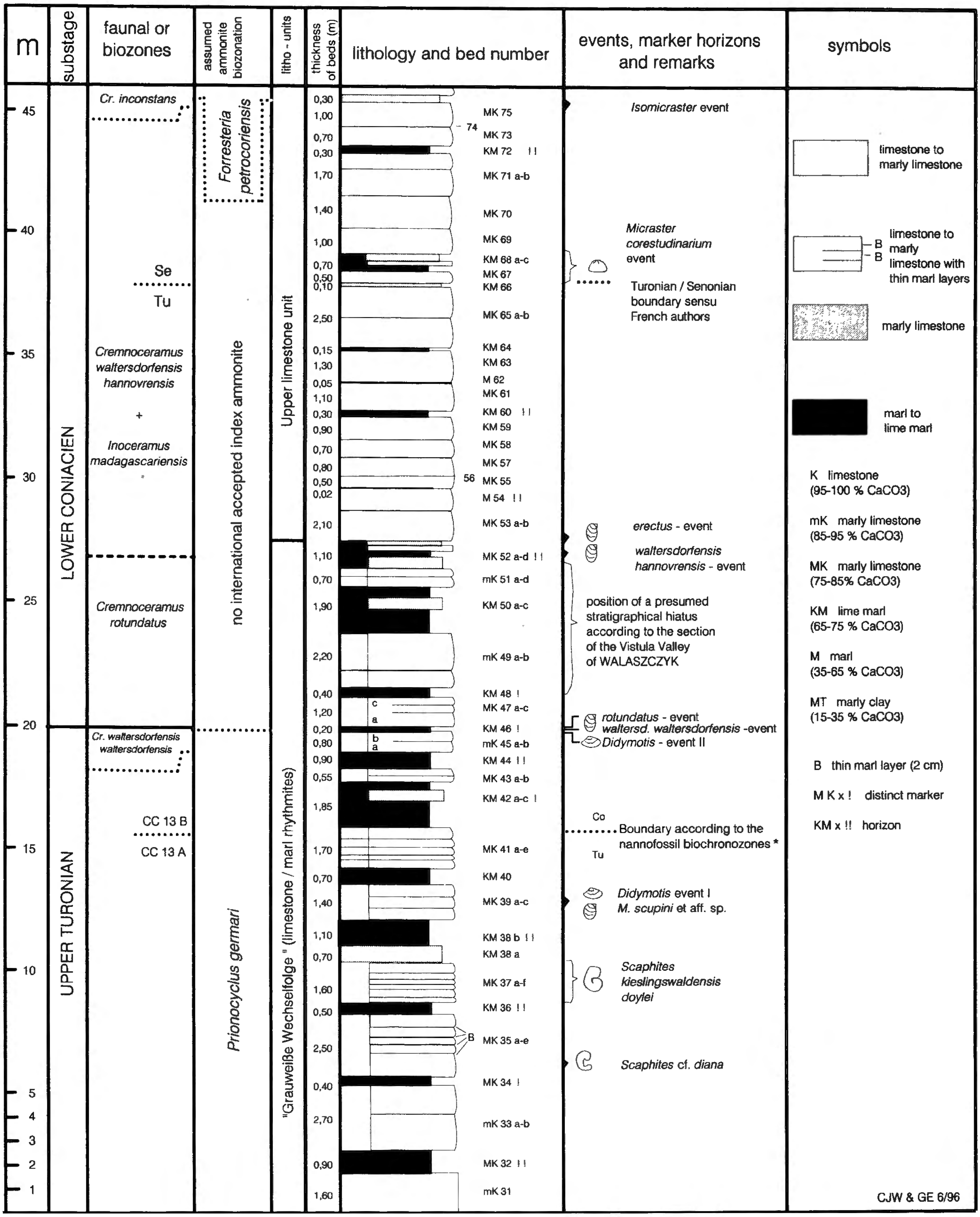


Fig. 4 — Detailed litho- and event stratigraphy of the Turonian-Coniacian stratotype boundary sequence, of the proposed international standard section Salzgitter-Salder Quarry (Lower Saxony, Germany) modified after Wood *et al.*, 1984.

and *Stensioina* sp. ex. gr. *S. granulata* (Olbertz), as well as a flood occurrence of planospiral marginotruncanid foraminifers (NAIDIN *et al.*, 1984);

(b) a bentonite between Turonian and Coniacian strata marks the boundary on the Voronezh High (Russia), Central part of Russian platform (KOPAEVICH *et al.*, 1995)

(c) abundant inoceramids, brachiopods, foraminifers, coccoliths, and numerous regional bioevents across the T-C boundary at the Aksu-dere section in southwest Crimea, The Ukraine (KOPAEVICH & WALASZCZYK, 1990).

The Mangyshlak section was proposed as the T-C boundary stratotype in preliminary communications.

Because formal proposals for the Vistula River Section, the Hokkaido section, the Pueblo section, the Kazakh, the Russian and the Ukrainian sections were not presented at the Brussels meeting (e.g. proposals including high-resolution stratigraphic, geochemical, and biostratigraphic data as well as justifications for choosing this stratotype section), and the mandate of the Coniacian Working Group was to decide at this meeting on criteria for defining the Turonian-Coniacian boundary, Coniacian substage boundaries, and boundary stratotypes, these proposals were subsequently withdrawn from consideration.

The Coniacian Working Group did endorse the concept of further documenting these sequences as regional reference sections for the T-C boundary.

Arguments were presented in favour of the Wagon Mound, New Mexico, USA, and of the Salzgitter-Salder, Lower Saxony, Germany sections; the latter was chosen as the new boundary stratotype of the Turonian-Coniacian boundary.

The Wagon Mound section (New Mexico, USA) section. – KAUFFMAN (1995) proposed the Wagon Mound, New Mexico (USA) locality of the Fort Hays Limestone Member, Niobrara Formation, as a candidate for the Turonian-Coniacian stratotype boundary. Data from this locality were obtained from the graduate thesis work of LAFERRIERE (1987 a) and COLLOM (1991), publications of LAFERRIERE (1987 b), LAFERRIERE *et al.* (1987), LAFERRIERE & HATTIN (1989), and subsequent field work by E. G. Kauffman in 1995. According to E.G. Kauffman this section meets all the requirements of an acceptable boundary stratotype. Detailed biostratigraphic continues on this section by E.G. Kauffman and students.

The Salzgitter-Salder Quarry Section, Lower Saxony, Germany. – WOOD *et al.* (1984) proposed the Salzgitter-Salder Quarry exposure as the best Turonian-Coniacian boundary reference section for northern Europe, and a possible candidate for the T-C boundary stratotype. Figure 3 shows the exposure of the boundary interval (arrow marks the position of the T-C boundary, as defined by criteria approved by the Coniacian Working Group at Brussels), and a detailed stratigraphic section, with regional marker beds noted, is shown in Figure 4.

The quarry is situated near the village of Salzgitter-Salder in Lower Saxony, Germany. It lies on the southeastern margin of the asymmetrical Lesse Syncline, just to the north of the Lichtenberg inversion structure. The quarry section comprises over 230 m of continuously exposed Middle Turonian through Lower Coniacian strata, dipping N at 70°, which have been documented in very high-resolution stratigraphic detail by WOOD *et al.* (1984, and references therein) (Figures 4 and 5). The sequence is richly fossiliferous, and especially through the Upper Turonian - Lower Coniacian interval; inoceramid bivalves dominate the macrofaunas, and calcareous plankton are well preserved.

The proposed Turonian-Coniacian boundary in the Salzgitter-Salder Quarry (Figs. 3, 4) is situated near the top of the ''Grauweisse Wechselfolge'' lithostratigraphic unit, at an horizon 207 m above the base of the WOOD *et al.* (1984) measured section and 61 m above the inter-regionally persistent tuff TF. The boundary (revised from the position taken in WOOD *et al.*, 1984) is drawn at the base of bed MK 47 (Figure 4), coincident with the FO of *Cremnoceramus rotundatus* (*sensu* TRÖGER *non* FIEGE), above the second flood occurrence of the bivalve *Didymotis* cf. *costatus* (FRIC) [*Didymotis* II] and above an acmezone of *Cremnoceramus waltersdorfensis waltersdorfensis*; these bioevents collectively constitute an inter-regional event-bundle (I. Walaszczyk & C.J. Wood, written communication, May 1966). This revised interpretation places both the two main *Didymotis* events into the terminal Turonian and agrees with the recorded LO of the upper Turonian zonal index ammonite *Prionocyclus germari* in and immediately above *Didymotis* II in the Bohemian Cretaceous Basin (cf. CECH, 1989).

The T-C boundary approximates to a minor negative $\delta^{13}C$ peak at the culmination of an overall broadly negative excursion (see ERNST & WOOD, 1995, fig. 4.5, and VOIGT & HILBRECHT, in prep.) beginning with the *Hyphantoceras* event. The boundary between nannofossil zones CC 13A and CC 13B based on the FO of *Lithastrinus septenarius* lies between middle Bed MK 41c and middle Bed KM 42a, i.e. ca 5-7 m below the T-C boundary (Burnett, unpublished data).

A distinctive set of discretely bundled, thickening upwards shale-limestone bedding couplets (Fischer bundles?) is present in the 50 m sequence underlying the T-C boundary (WOOD *et al.*, 1984, figs 2, 3); current work (KRÖGER, in prep.) seeks to demonstrate whether or not these couplets are orbitally controlled (Milankovitch rhythms) and the extent to which they can be used for high resolution regional correlation. In addition, several event beds and/or event-bundles bound the Turonian/ Coniacian boundary (Figures 4 and 5). These are, in ascending order:

– (1) an interregionally persistent event-bundle (see WRAY & WOOD, 1995) comprising tuff TF, marl MF and the *Micraster* bioevent marl MG (acme-occurrence of advanced *Micraster* of the *bucailli* lineage), 58 m below the T-C boundary;

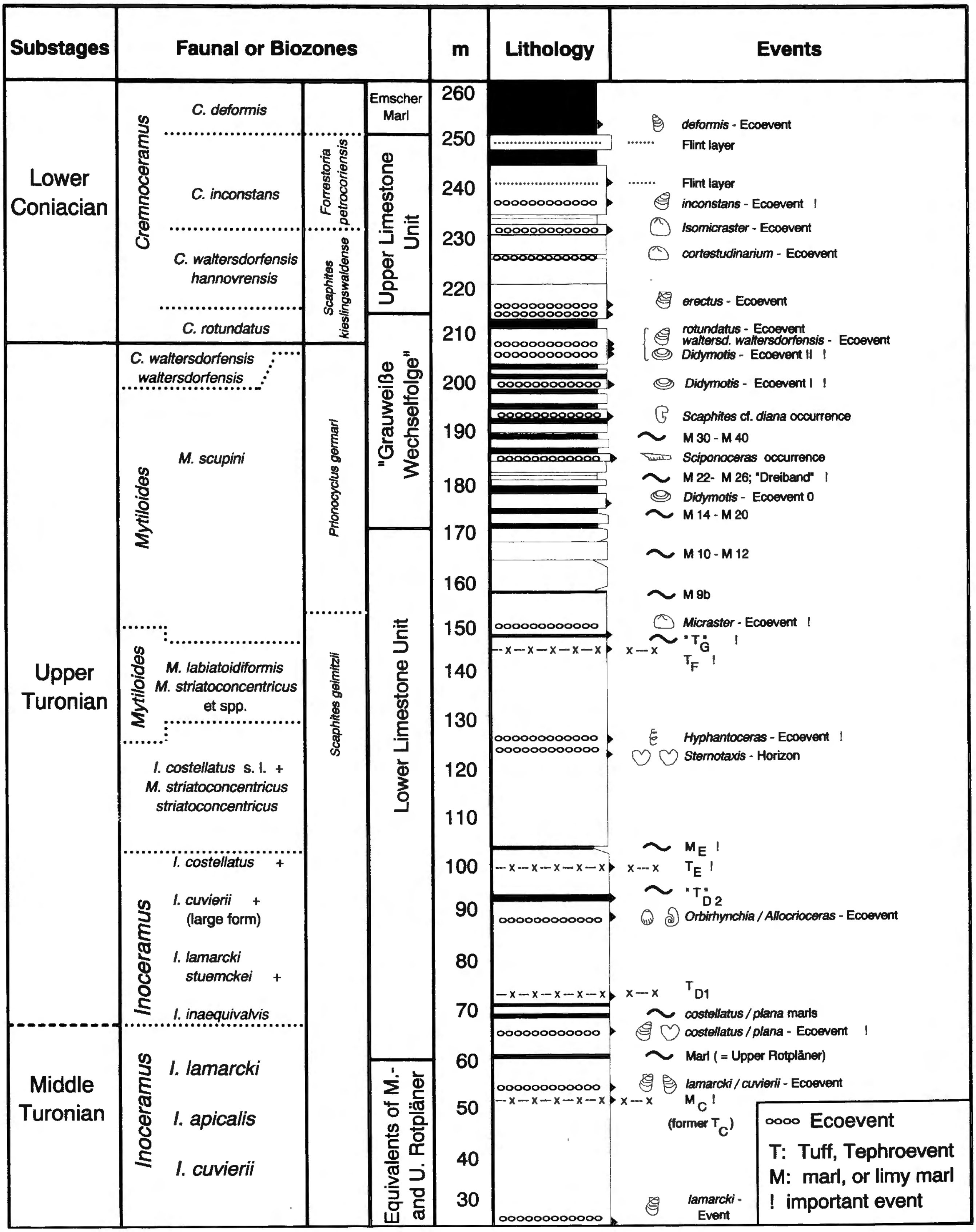


Fig. 5 — Bio- and event stratigraphy of the Upper Turonian and Lower Coniacian of the Salzgitter-Salder limestone Quarry (Lower Saxony, Germany).

– (2) a (recently) discovered *Didymotis* event in Bed mK 19 (Kröger, in prep.);
– (3) a *Sciponoceras* occurrence bed (mK 29), 23 m below the T-C boundary;
– (4) a *Scaphites* aff. *diana* occurrence bed (mK 35a), 14 m below the T-C boundary;
– (5) a *Sc. kieslingswaldensis doylei* [formerly *Sc. lamberti*] occurrence bed (37), 10-11 m below the T-C boundary;
– (6) the *Didymotis* ecoevent I (Bed MK 39b), 7.5 m below the T-C boundary, comprising a flood occurrence of *Didymotis* cf. *costatus* associated with a *Mytiloides scupini* zone assemblage comprising *M. scupini* (Heinz), *M. herbichi* (Atabekian) and *Inoceramus lusatiae* (Andert);
– (7) an event bed (Bed MK 41c), 5.3 m below the T-C boundary, with the same inoceramid assemblage as *Didymotis* I, but without *Didymotis* records;
– (8) the *Didymotis* ecoevent II in the limestone bed (MK 45b), 0.5 m below the T-C boundary, with a flood occurrence of *Didymotis* cf. *costatus* associated with a near-monospecific inoceramid assemblage conspecific with Andert's (1911) type material of *Cremnoceramus waltersdorfensis waltersdorfensis* [previously recorded by Wood *et al.*, 1984 as small forms of *C. waltersdorfensis hannovrensis* (Heinz)];
– (9) a flood occurrence of crushed, bivalved *C. waltersdorfensis waltersdorfensis* associated with rare large *Didymotis* sp. in the marl bed (KM 46), 0-0.2 m below the T-C boundary;
– (10) the FO of *Cremnoceramus rotundatus* (*sensu* Tröger *non* Fiege) and its bioevent (acmezone), associated with forms transitional to *C. erectus* (Meek) and rare *Didymotis* sp. in the limestone bed (MK 47a): the base of this event bed is taken as the base of the Coniacian Stage;
– (11) the FO and bioevent (acmezone) of *Cremnoceramus waltersdorfensis hannovrensis* in Bed KM 52b, 7 m above the T-C boundary; and a *Cremnoceramus erectus* bioevent (acmezone) in Bed MK 53a, 8.5 m above the T-C boundary.

There are many advantages to this section as the Turonian-Coniacian boundary stratotype, as reviewed by Wood *et al.* (1984) and as presented in the Brussels Symposium:

• it is a thick, continuously exposed, depositional sequence across the boundary without obvious hiatuses;
• it has numerous event and cycle marker beds at and bracketing the T-C boundary with proven regional correlation potential (e.g. Wood *et al.*, 1984, Figures 4 and 5);
• it is richly fossiliferous, especially in inoceramid bivalves, which form the basis for biostratigraphic determination of Coniacian Stage and Substage boundaries; sufficient ammonites and echinoids are known from the section to provide independent biostratigraphic tie-points to other zonal schemes;
• diverse planktic microfossils are preserved in the sequence;
• utilizing bivalve (especially inoceramid) shell material, a detailed chemostratigraphic profile can be constructed for the section $\delta^{13}C$ (Ernst & Wood, 1995; Voigt & Hilbrecht, in press); whole rock analysis may be more difficult considering the tectonic deformation and resulting carbonate diagenesis of the strata;
• the section is accessible, continuously exposed, with fresh rock surfaces, and is still partially quarried with steep cliff faces that will remain relatively unweathered for the foreseeable future.

The only significant disadvantages relate to the diagenetic alteration of the carbonate, which makes fossils (especially microfossils) difficult to extract, and the paucity of ammonites.

By a 16 to 3 vote (no abstentions) the Coniacian Working Group proposed the Salzgitter-Salder Quarry section in Lower Saxony as the stratotype for the Turonian-Coniacian boundary, with the position of the T-C boundary there placed at the FO of *Cremnoceramus rotundatus* (*sensu* Tröger *non* Fiege), above the first flood occurrence of *Cremnoceramus? waltersdorfensis waltersdorfensis*, and above the second flood occurrence of *Didymotis* sp. cf. *D. costatus* associated with a significant regional turnover in planktonic foraminifers (Figures 4 and 5).

In making this decision, the working group cited three major advantages of the Salzgitter-Salder Quarry section over other candidates, as follows:

• this is the best studied of the proposed boundary stratotypes, with exceptionally high-resolution stratigraphic data already published (e.g. Wood *et al.*, 1984), and a detailed chronology based on integrated event marker beds and mollusc-foraminifer biozones. Collectively, these event horizons and biozone boundaries allow precise correlation, and location of the boundary interval, over much of Europe;
• the quarry contains one of the richest and most persistent records of inoceramid bivalves in Europe, including *Cremnoceramus rotundatus*, the FO of which coincides with other widely distributed bioevent horizons (see above), and which has been chosen as the main criterion for internationally defining the T-C boundary. (Inoceramids are the principal basis for refined biostratigraphic zonation and regional to global correlation in the Coniacian because they are well preserved in hemipelagic and pelagic carbonate facies, which otherwise show a preservational bias against ammonites). There is a major turnover in the species composition of the calcareous foraminifer assemblage coincident with the FO of *Cr. rotundatus* and the T-C boundary at Salzgitter-Salder; and
• the Salzgitter-Salder Quarry is still somewhat active, with steep clean walls, and is not likely to be filled or deeply weathered in the near future.

Substage stratotypes: Whereas two possible stratotype sections were discussed for the Lower-Middle Coniacian boundary, none were considered well enough known at present to make a final selection. The membership did approve, however, by a vote of 16-0, with 4 abstentions, to encourage research teams from the Coniacian Working Group to document in detail possible boundary stratotypes in the following areas, with a report due back to the committee in 1996:
(1) the Dallas-Fort Worth area of Texas, in the Lower Austin Chalk (A. S. Gale, E. G. Kauffman, P. Larson, and colleagues);
(2) the Seaford Head exposures of the Upper Chalk in southern England (R. Mortimore, C. J. Wood, A. S. Gale and colleagues);

Each of these sections has excellent exposures, a rich inoceramid fauna and microbiota, some ammonites, and rock/fossils amenable to geochemical analysis. Volcanic ash layers (bentonites) for possible radiometric dating and refined chronostratigraphic correlation occur in the Texas sections. At the time this manuscript was completed, none of these groups had completed their regional studies.

No stratotype sections were proposed by the working group for the Middle-Upper Coniacian boundary, but the three general areas listed above for the Lower-Middle Coniacian boundary are all being investigated as potential candidates.

References

Bailey, H. W., Gale, A. S., Mortimore, R. N., Swiecicki, A., & Wood, C. J., 1984. Biostratigraphical criteria for the recognition of the Coniacian to Maastrichtian stage boundaries in the Chalk of north-west Europe, with particular reference to southern England. *Bulletin of the Geological Society of Denmark*, **33**: 31-39.

Birkelund, T., Hancock, J. M., Hart, M. B., Rawson, P. F., Remane, J., Robaszynski, F., Schmid, F. & Surlyk, F., 1984. Cretaceous stage boundaries - Proposals. *Bulletin of the Geological Society of Denmark*, **33**: 3-20.

Bräutigam, F., 1962. Zur Stratigraphie und Paläontologie des Cenomans und Turons im nordwestlichen Harzland. Thesis TH Braunschweig. 261 pp.

Cech, S., 1989. Upper Cretaceous *Didymotis* Events from Bohemia. *In:* Wiedmann, J., Ed.: Cretaceous of the Western Tethys, Schweizerbart'sche Verlagsbuchhandlung, pp. 657-676.

Cech, S., Klein, V., Kriz, J. & Valecka, J., 1980. Revision of the Upper Cretaceous stratigraphy of the Bohemian Cretaceous Basin. *Vestnik ustredniho ustavu geologickeho* **55:** 227-296.

Collom, C. J., 1991. High-resolution stratigraphic and paleoenvironmental analysis of the Turonian-Coniacian stage boundary interval (Late Cretaceous) in the lower Fort Hays Limestone Member, Niobrara Formation, Colorado and New Mexico. Unpublished M. Sc. Thesis, Brigham Young University, USA, 371 pp.

Coquand, H., 1857a. Notice sur la formation crétacée du département de la Charente. *Bulletin de la Société géologique de France* (2), **14**: 55-98.

Coquand, H., 1857b. Position des *Ostrea columba* et *biauriculata* dans le groupe de la craie inférieure. *Bulletin de la Société géologique de France* (2), **14**: 745-766.

Ernst, G. & Wood, C.J., 1995. Exkursion B. Die tiefere Oberkreide des subherzynen Niedersachsens (Raum Hildesheim-Salzgitter-Vienenburg). Faziesgeschichte, Beckendynamik, Events und Sequenzen. *In:* Boetzkes, M. & Vespermann, J. Exkursionsführer der 65. Jahrestagung der Paläontologischen Gesellschaft Hildesheim, 25-30 September 1995. pp. 41-84.

Grossouvre, A. de, 1894. Recherches sur la craie supérieure, 2. Paléontologie. Les ammonites de la craie supérieure. *Mémoires du Service de la Carte géologique detaillée de la France*. 264 pp.

Grossouvre, A. de, 1901. Recherches sur la craie supérieure, 1. Stratigraphie générale. *Mémoires du Service de la Carte géologique detaillée de la France*. vii + 1013 pp.

Herm, D., Kauffman, E. G. & Wiedmann, J., 1979, The age and depositional environment of the 'Gosau'-Group (Coniacian-Santonian), Brandenberg/Tirol, Austria. *Mitteilungen Bayerische Staatssammlung für Paläontologie und historische Geologie*, **19**: 23-92.

Kaplan, U. & Kennedy, W. J., 1994. Ammoniten des westfälischen Coniac. *Geologie und Paläontologie in Westfalen* **31**: 155 pp.

Kaplan, U. & Kennedy, W. J., in press. Upper Turonian and Coniacian Ammonite Stratigraphy of Westphalia, NW-Germany.

Kauffman, E. G., 1978 a. British middle Cretaceous inoceramid biostratigraphy. *In*: Reyment, R. A. & Thomel, G. (eds.), Mid-Cretaceous Events: Reports on the Biostratigraphy of Key Areas. *Annales du Muséum d'Histoire Naturelle de Nice*, **4**: IV-1 - IV-12 (imprint 1976).

Kauffman, E. G., 1978 b. Middle Cretaceous bivalve zones and stage implications in the Antillean Subprovince, Caribbean Province. *In:* Reyment, R. A., & Thomel, G. (eds.), Mid-Cretaceous Events: Reports on the Biostratigraphy of Key Areas. *Annales du Muséum d'Histoire Naturelle de Nice*, **4:** XXX-1 - XXX-10 (imprint 1976).

Kauffman, E. G., 1995. Proposed Turonian-Coniacian boundary stratotype, Wagon Mound, northern New Mexico, USA. Abstracts, Second International Symposium on Cretaceous Stage Boundaries, Sept. 8-16, 1995, Brussels, Belgium: p. 174.

Kauffman, E. G., Cobban, W. A., & Eicher, D. L., 1978. Albian through Lower Coniacian strata, biostratigraphy, and principal events in the Western Interior, United States. *In:* Reyment, R. A. & Thomel, G. (eds.), Mid-Cretaceous Events: Reports on the Biostratigraphy of Key Areas. *Annales du Muséum d'Histoire Naturelle de Nice*, **4**: XXIII-1 - XXIII-49 (imprint 1976).

Kauffman, E. G., Sageman, B. B., Kirkland, J. I., Elder, W. P., Harries, P. J., & Villamil, T., 1994, Molluscan Biostratigraphy of the Cretaceous Western Interior Basin, North America. *In:* CALDWELL, W. G. E., & KAUFFMAN, E. G. (eds.), Evolution of the Western Interior Basin. *Geological Association of Canada, Special Paper*, **39:** 397-434.

KENNEDY, W. J., 1984a. Systematic palaeontology and stratigraphic distribution of the ammonite faunas of the French Coniacian. *Special Papers in Palaeontology*, **31**: 160 pp.

KENNEDY, W. J., 1984b. Ammonite faunas and the 'standard zones' of the Cenomanian to Maastrichtian Stages in their type areas, with some proposals for the definition of the stage boundaries by ammonites. *Bulletin of the Geological Society of Denmark*, **33**: 147-161.

KENNEDY, W.J. & COBBAN, W. A., 1991. Coniacian ammonite faunas from the United States Western Interior. *Special Papers in Palaeontology* **45:** 96 pp.

KOPAEVICH, L. F., OLFERIEV, A. G., OSIPOVA, L.M., 1995. Turonian/Coniacian boundary on the Russian Platform. Abstracts, Second International Symposium on Cretaceous Stage Boundaries, Sept. 8-16, 1995, Brussels, Belgium: p. 69

KOPAEVICH, L. F. & WALASZCZYK, I., 1990. An integrated inoceramid-foraminiferal biostratigraphy of the Turonian and Coniacian strata in south-western Crimea, Soviet Union. *Acta geologica polonica*, **40** (1-2): 83-96.

KÜCHLER, T. & ERNST, G., 1989. Integrated biostratigraphy of the Turonian-Coniacian transition interval in Northern Spain with comparison to NW Germany. *In:* WIEDMANN, J., Ed.: Cretaceous of the Western Tethys, Schweizerbart'sche Verlagsbuchhandlung, pp. 161-190

LAFERRIERE, A. P.,1987a. Regional analysis of rhythmic bedding in the Fort Hays Limestone Member, Niobrara Formation (Upper Cretaceous), U. S. Western Interior. Unpublished Ph. D. Thesis, Indiana University, 278 pp.

LAFERRIERE, A. P., 1987 b. Cyclic sedimentation in the Fort Hays Limestone Member, Niobrara Formation (Upper Cretaceous) in northeastern New Mexico and southeastern Colorado. *New Mexico Geological Society Guidebook, 38th Field Conference, NE New Mexico,* p. 249-254

LAFERRIERE, A. P., HATTIN, D. E., & ARCHER, A. W., 1987, Effects of climate, tectonics, and sea-level changes on rhythmic bedding patterns in the Niobrara Formation (Upper Cretaceous), U. S. Western Interior. *Geology*, **15**: 233-236.

LAFERRIERE, A. P., & HATTIN, D. E., 1989. Use of rhythmic bedding patterns for locating structural features, Niobrara Formation, United States Western Interior. *American Association of Petroleum Geologists Bulletin*, **73, 5**: 630-640.

MARKS, P., 1984. Proposal for the recognition of boundaries between Cretaceous stages by means of planktonic foraminiferal biostratigraphy. *Bulletin of the Geological Society of Denmark*, **33**: 163-169.

MATSUMOTO, T., 1984, The so-called Turonian-Coniacian boundary in Japan. *Bulletin of the Geological Society of Denmark*, **33**: 171-181.

NAIDIN, D.P., BENYAMOVSKY, V. N. & KOPAEVICH, L. F., 1984. Methods of transgression and regression study exemplified by Late Cretaceous Basins of west Kazakhstan. 162 pp. Moscow University Press, Moscow (in Russian)

OBRADOVICH, J., 1994. A Cretaceous time scale. *In:* CALDWELL, W. G. E., & KAUFFMAN, E. G. (eds.), Evolution of the Western Interior Basin. *Geological Association of Canada, Special Paper*, **39**: 379-396.

POMEROL, B., 1983. The correlation of the Turonian-Senonian boundary in the Senonian stratotype area and southern England. *In:* BIRKELUND, T., BROMLEY, R., CHRISTENSEN, W. K., HAAKANSSON, E., & SURLYK, F. (eds.), Symposium on Cretaceous Stage Boundaries, Copenhagen, Denmark, p. 161-165.

POMEROL, B., DAMOTTE, R., FOURAY, M., & MONCIARDINI, C., 1983, Précisions biostratigraphiques sur la limite Turonien-Sénonien dans la région stratotypique de Sens (Yonne). *Comptes Rendus Académie Sciences, Paris*, **297**, II: 421-424.

ROBASZYNSKI, F., 1984, The Albian, Cenomanian and Turonian Stages in their type-regions. *Bulletin of the Geological Society of Denmark*, **33**: 191-198.

SÉRONIE-VIVIEN, M., 1972, Contribution à l'étude du Sénonien en Aquitaine septentrionale. Les stratotypes: Coniacien, Santonien, Campanien. *Les stratotypes français,* **2**, 195 pp. , éditions C.N.R.S.

SÉRONIE-VIVIEN, M. 1980, Coniacien, Santonien. *In:* Les étages français et leurs stratotypes. *Mémoires Bureau Recherches Géologiques et Minières*, **109:** 150-160.

TOSHIMITSU, S., MATSUMOTO, T, NODA, M., & NISHIDA, T., 1995. Toward an integrated mega-, micro- and magneto-stratigraphy of the Upper Cretaceous in Japan, *Journal of the Geological Society of Japan*, **101**, 1: 19-29.

TRÖGER, K.-A., 1967. Zur Paläontologie, Biostratigraphie und faziellen Ausbildung der unteren Oberkreide (Cenoman bis Turon). Teil I. Paläontologie und Biostratigraphie der Inoceramen des Cenomans bis Turons Mitteleuropas. *Abhandlungen des Staatlichen Museums für Mineralogie und Geologie zu Dresden*, **12**: 13-207.

TRÖGER, K.-A., 1981, Zur Problemen der Biostratigraphie der Inoceramen und der Untergliederung des Cenomans und Turons in Mittel- und Osteuropa. *Newsletters of Stratigraphy*, **9**: 139-156.

VOIGT, S. & HILBRECHT, H. (in press). Stable carbon isotope stratigraphy of the European Boreal and Tethyan Upper Cretaceous. *Palaeogeography, Palaeoclimatology, Palaeoecology.*

WALASZCZYK, I., 1992. Turonian through Santonian deposits of the Central Polish Uplands; their facies development, inoceramid palaeontology and stratigraphy. *Acta geologica polonica,* **42:** 1-122.

WOOD, C. J., ERNST, G., & RASEMANN, G., 1984, The Turonian-Coniacian stage boundary in Lower Saxony (Germany) and adjacent areas: the Salzgitter-Salder Quarry as a proposed international standard section. *Bulletin of the Geological Society of Denmark*, **33**: 225-238.

WRAY, D. S. & WOOD, C. J., 1995. Geochemical identification and correlation of tuff layers in Lower Saxony, Germany. *Berliner geowissenschaftliche Abhandlungen*, **E 16** (Gundolf Ernst Festschrift): 215-225.

Correspondence to:
Erle G. KAUFFMAN,
Department of Geological Sciences,
University of Colorado, Boulder,
CO, 80309-0250 USA