Newsl. Stratigr.	24 (1/2)	1–33	15 Fig.	Berlin · Stuttgart, 25. 4. 1991

Stratigraphy and interregional correlation of the Cenomanian-Turonian transition in the Western Interior of the United States near Pueblo, Colorado, a potential boundary stratotype for the base of the Turonian stage

by W. J. Kennedy and W. A. Cobban*

with 15 figures

Abstract. The Cenomanian-Turonian boundary sequence at Pueblo, Colorado, is represented by the lower part of the Bridge Creek Member of the Greenhorn Limestone. Upper Cenomanian ammonite zones are, from oldest to youngest, those of *Sciponoceras gracile* and *Neocardioceras juddii*, while the position of the base of a succeeding Cenomanian *Nigericeras scotti* zone is inferred from correlation with sections in southeast Colorado. The base of the Turonian in ammonite terms is drawn at the base of the *Watinoceras devonense* zone, a new biostratigraphic unit for the Western Interior sequence; this is succeeded by zones of *Pseudaspidoceras flexuosum*, *Vascoceras (Greenhornoceras) birchbyi* and *Mammites nodosoides*; the base of the succeeding *Collignoniceras woollgari* zone marks the base of the middle Turonian.

Four inoceramid zones are recognized; the *Inoceramus pictus* zone spans the *S. gracile* to *N. scotti* zones; the base of the *Mytiloides* aff. *sackensis* zone is just below the base of the *W. devonense* zone; the base of the *Mytiloides columbianus* zone correponds to the base of the *Pseudaspidoceras flexuosum* zone; the base of the *Mytiloides mytiloides* zone lies some way above the base of the *Mammites nodosoides* zone.

Nine horizons suggested as possible boundary markers at the 1984 Copenhagen Symposium on Cretaceous Stage Boundaries can be recognized within this sequence which, together with the presence of bentonites that are amenable to absolute dating, makes the Pueblo sequence a strong candidate for consideration as a boundary stratotype of the Turonian Stage.

The Pueblo succession is correlated with that in southern England, where ten horizons recognized in Colorado can also be recognized in the interval from the base of the *Metoicoceras geslinianum* zone to the base of the *Collignoniceras woollgari* zone; these are in the same relative position in each region.

1 Introduction

The position of, and biostratigraphic sequences across the boundary between the Cenomanian and Turonian Stages has attracted considerable attention in recent years. At the Symposium on Cretaceous stage boundaries arranged by the Subcommission on Cretaceous Stratigraphy and held in Copenhagen in 1983, no less than nine possible boundary positions were discussed, involving such disparate groups as ammonites, inoceramid bivalves, coccoliths and planktonic

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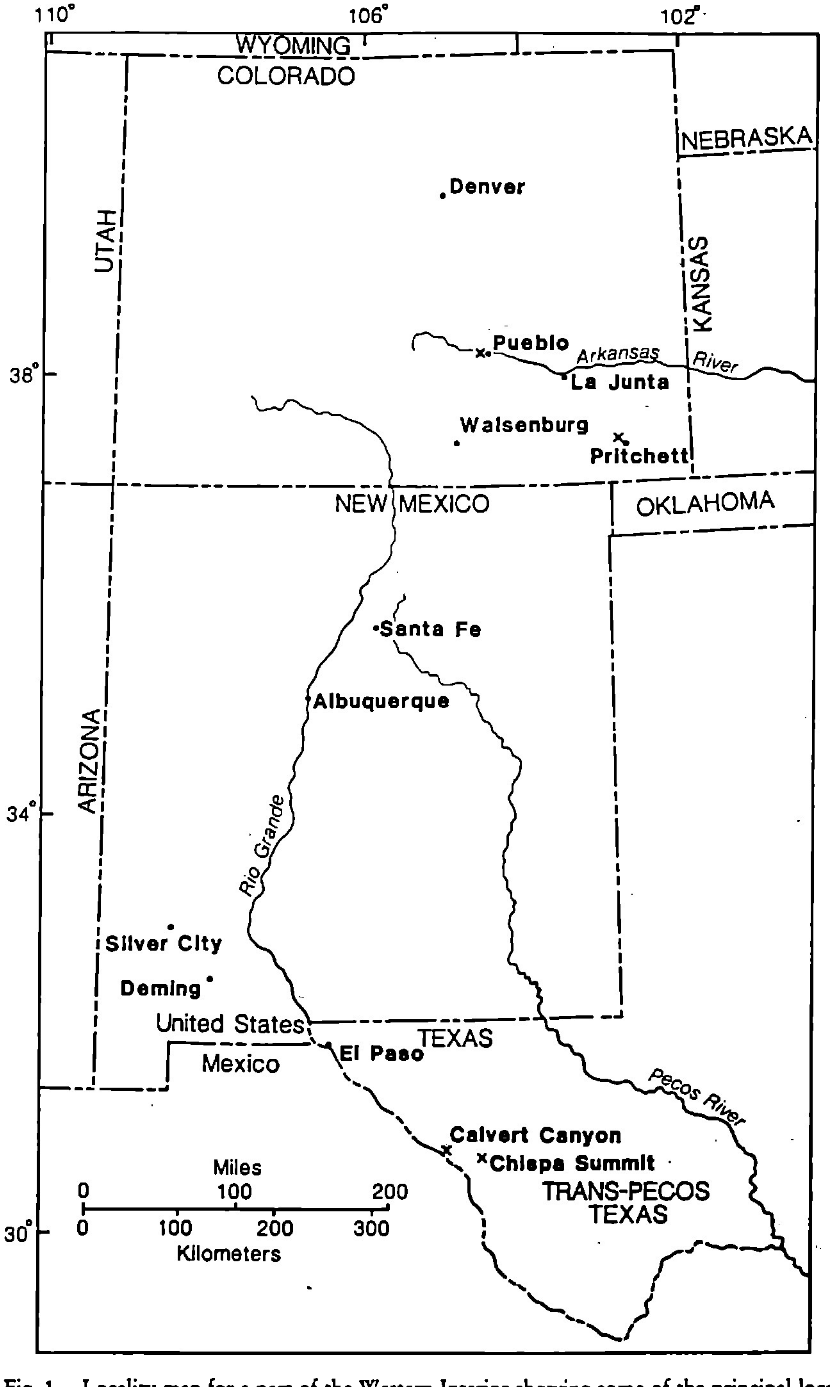


Fig. 1. Locality map for a part of the Western Interior showing some of the principal localities mentioned in the text.

foraminifers (BIRKELUND et al., 1984: 12). Of more general significance at this level in the Cretaceous is the development of a short-lived oceanic anoxic event (the BONARELLI Event) which is reflected by a significant positive ^{13}C heavy excursion in the carbon isotopic values of organic matter and carbonate and, in appropriate settings, the development of organic carbon-rich and sometimes anoxic sediments (SCHLANGER & JENKYNS, 1976; GRACIANSKY et al., 1984; HERBIN et al., 1986; HART & BALL, 1986; SCHLANGER, ARTHUR, JENKYNS & SCHOLLE, 1987; ARTHUR, DEAN & PRATT, 1988). Furthermore, other workers claim a major Cenomanian-Turonian extinction event (RAUP & SEPKOSKI, 1982; KAUFFMAN, 1984; ELDER, 1985, 1987).

We here document the stratigraphy of this boundary interval in the Bridge Creek Member of the Greenhorn Limestone at Rock Canyon anticline near Pueblo in Pueblo Country, southeastern Colorado, in the Western Interior of the United States. These data are supplemented by a stratigraphic section near Pritchett in Baca Country farther southeast in Colorado (Fig. 1). Together these sections provide the most complete ammonite and inoceramid record across the boundary that can be correlated with recently published data on the calcareous nannofossils (WATKINS, 1985; BRALOWER, 1988), planktonic foraminifers (EICHER & DINER, 1985), molluscan fossils (ELDER, 1989), and carbon stable isotope excursion (PRATT, 1981, 1983, 1984, 1985). The Bridge Creek Member is in a rhythmically bedded limestone/shale facies (periodite facies of European workers; EINSELE, 1982) that records climatically driven variations in sedimentation, or as frequently termed, MILANKOVITCH cycles. Individual beds together with beds of bentonite across the boundary interval can be correlated over tens of thousands of square kilometers of the Western Interior, from northeastern Arizona to central Kansas (HATTIN, 1971, 1975, 1979, 1985; ELDER, 1985, 1987, 1988). The origin of this cyclicity was first recognized by GILBERT (1895: see review in FISCHER, HERBER & PREMOLI SILVA, 1985). The periodicity of these cycles can be used to speculate on evolutionary rates and species duration across the boundary interval. Furthermore, the sequence includes bentonites that are of even greater areal extent than individual marls and limestones, and have the potential for both correlation and absolute dating across the boundary interval.

We compare the Pueblo sequence with representative boundary sections in southern England. The precision of correlation is such that we believe the southeastern Colorado sequence merits serious consideration as a boundary stratotype for the base of the Turonian Stage, as suggested by HANCOCK (1984).

2 Cenomanian-Turonian ammonite zonation in the Western Interior of the United States

COBBAN (1984) provided a recent review of middle Cenomanian to upper Turonian ammonite zonation in the Western Interior. In this section of the present paper, we confine our discussion to those zones that encompass the boundary interval. Ammonites are of erratic occurrence in the rocks of the Western Interior. They sometimes occur by the hundreds in concretions or crushed in shale and limestone; other intervals are barren. Certain assemblages are of limited geographic distribution and thus of limited value in correlation. Their absence elsewhere may reflect original distribution or post-mortem destruction. Other zones can be traced across the Western Interior and beyond and are of great value in interregional correlation. In addition, there is marked geographic limitation on certain groups, even at levels where ammonite occurrence and preservation is widespread and alternative zonal indices have been used in the northern and southern parts of the Western Interior. Thus, as COBBAN (1984) notes, genera such as *Dunveganoceras* and *Scaphites* have a typically northern range, whereas genera such as *Vascoceras, Nigericeras, Romaniceras* and *Thomasites* that are of great value for correlation with Tethyan sequences, are mostly confined to the southernmost part of the Western Interior.

In general, the zones used here are assemblage zones, recognized by the occurrence of more than one species. The zonal indices are commonly, but not invariably confined to their eponymous zones. Because the environment in the Western Interior seaway deteriorated during the Cenomanian-Turonian boundary interval, diversity drops considerably, and the highest Cenomanian zone recognized, that of *Nigericeras scotti*, generally yields the index species only and is known only from southwestern Colorado and northeastern and southwestern New Mexico.

The zonal sequence recognized in southeastern Colorado is set out in Fig. 2. Details are as follows (author names and dates, included as parts of species names, are not included in the references).

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

Fig. 2. The succession of ammonite zones across the Cenomanian-Turonian boundary in the southern Western Interior (see text for details).

2.1 *Sciponoceras gracile* zone

The base of the zone is marked by the appearance of a diverse ammonite assemblage. Floods of *Sciponoceras gracile* (SHUMARD, 1860) are characteristic. *Euomphaloceras septemseriatum* (CRAGIN, 1893), *Calycoceras naviculare* (MANTELL, 1822), *Pseudocalycoceras angolaense* (SPATH, 1931), *Sumitomoceras bentonianum* (CRAGIN, 1894), *S. conlini* WRIGHT & KENNEDY, 1981, *Metoicoceras geslinianum* (D'ORBIGNY, 1850), *Metaptychoceras reesidei* (COBBAN & SCOTT, 1972), *Puebloites corrugatus* (STANTON, 1894) and *Allocrioceras annulatum* (SHUMARD,

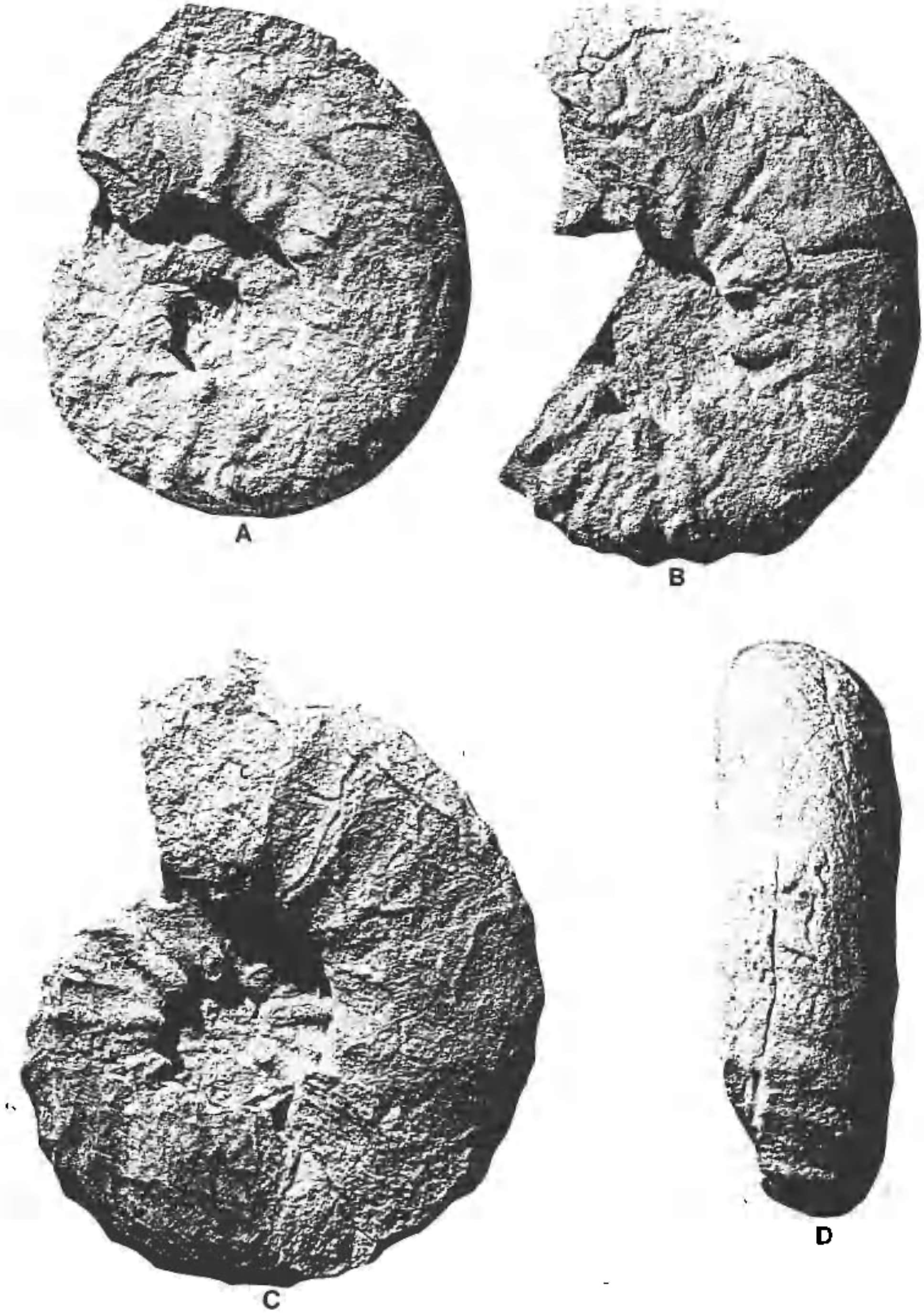


Fig. 3. *Nigericeras scotti* Cobban, 1971. A, USNM 166403; B, USNM 166407; C, D, USNM 166396: Bridge Creek Member of Greenhorn Limestone, *Nigericeras scotti* zone at USGS Mesozoic locality D6756, spillway of check dam in the SE1/4 sec. 14, T. 29 S., R. 49 W., Baca County, Colorado.

1860) are restricted to this zone and occur widely in the Western Interior. *Nannometoicoceras acceleratum* HYATT, 1903 is restricted to the zone, but known only from northeast Texas. *Borissiakoceras orbiculatum* STEPHENSON, 1955, *Moremanoceras scotti* (Moreman, 1942), *Metengonoceras dumbli* (CRAGIN, 1893), *M. acutum* HYATT, 1903 and *Anisoceras* sp. nov. aff. *plicatile* (J. SOWERBY, 1819) have their last appearance in the zone. *Placenticeras (Karamaites) cumminsi* CRAGIN 1893, *Allocrioceras dentonense* (MOREMAN, 1942), *A. larvatum* (CONRAD, 1855), and *Worthoceras vermiculus* (SHUMARD, 1860) first appear in the zone, but range higher. We have seen rare *Sciponoceras* from as high as the *Neocardioceras juddii* zone in southwestern New Mexico that appear to be late survivors of *S. gracile*.

Preliminary observations on the sequence in southwestern New Mexico suggested the *S. gracile* zone might be divided into a lower subzone of *Vacoceras diartianum* (D'ORBIGNY, 1850) and an upper subzone of *Euomphaloceras septemseriatum* (COBBAN, 1984). This must be abandoned, because the *V. diartianum* occurrence is within the top part of the underlying *Metoicoceras mosbyense* zone in association with *Euomphaloceras euomphalum* (SHARPE, 1855) and *Eucalycoceras pentagonum* (JUKES-BROWNE, 1896).

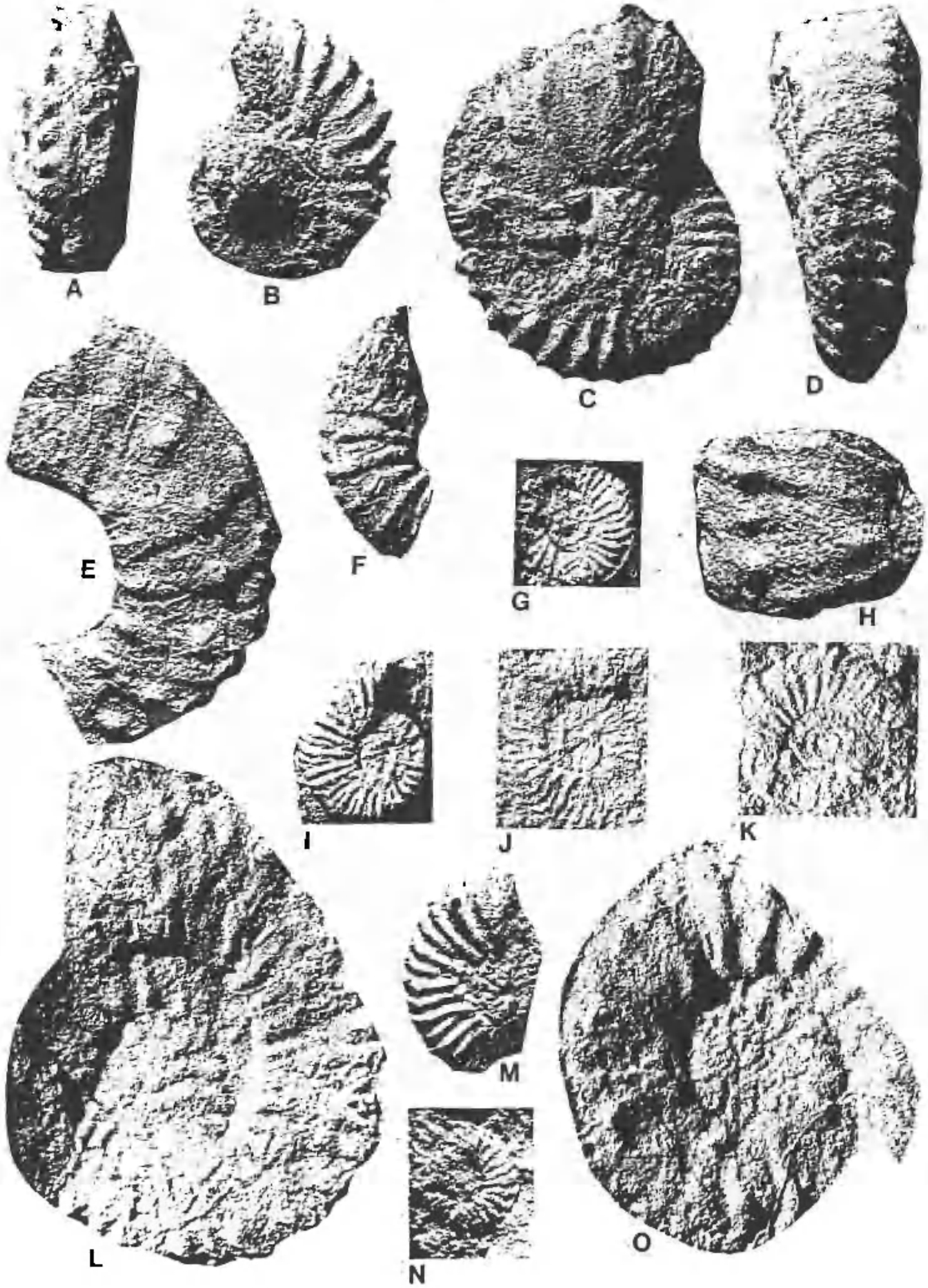
2.2 *Burroceras clydense* zone

This zone, previously referred to as the zone of *Vasoceras cauvini* (COBBAN, 1984), is known only from southwestern New Mexico. The ammonites from that area that were considered as *V. cauvini*, are now assigned to *V. barcoicense exile* COBBAN, HOOK & KENNEDY (1989). Species restricted to this zone include the following new forms described by COBBAN, HOOK & KENNEDY (1989): *Burroceras clydense, Paraburroceras minutum* and *Hamites pygmaeus*. Species that range on up from the underlying zone of *Sciponoceras gracile* are *S. gracile, Worthoceras vermiculus* and *Placenticeras (Karamaites) cumminsi*. *Vascoceras* is abundant and represented by *V.* cf. *gamai* CHOFFAT, *V. barcoicense exile* and two other forms.

2.3 *Neocardioceras juddii* zone

The zonal index is widespread from Trans-Pecos Texas northward to the Canadian border. A diverse associated assemblage is present in New Mexico and Trans-Pecos Texas. In southwestern New Mexico (Deming-Silver City area), this assemblage includes *N. juddii* (BARROIS & GUERNE, 1875), *Pseudaspidoceras pseudonodosoides* (CHOFFAT, 1898), *Vascoceras silvanense* (CHOFFAT, 1899), *V. (V.) hartti* WHITE, 1887, *Rubroceras* spp. and *Euomphaloceras costatum*

Fig. 4. Ammonites from the basal Turonian of the Western Interior and southern England. A–O are all *Watinoceras coloradoense praecursor* WRIGHT & KENNEDY, 1981. A, B are paratype OUM K9463; C, D are the holotype, IGS Zn 9152; F is paratype BMNH C82246; H is SMC B91215; I is paratype IGS Zn 9158; M is paratype BMNH C82245; all from the base of the *Watinoceras coloradoense* zone Middle Chalk on the coast between Axmouth and Humble Point, Devon, England. E is USNM 441438, from USGS Mesozoic locality D6123 in the NE1/4 sec. 2, T. 21 S., R. 66 W., Pueblo County, Colorado; G, J, K, N are USNM 441439 to 441441, 441443 from USGS Mesozoic locality D12715, NE1/4SE1/4 sec. 1, T. 30 S., R. 50 W., Baca County, Colorado; L, USNM 441442 from USGS Mesozoic locality D12460, NE1/4 sec. 25, T. 20 S., R. 66 W., Pueblo County, Colorado; O, USNM 441444 from USGS Mesozoic locality D3975, SW1/4 sec. 30, T. 20 S., R. 65 W., Pueblo County, Colorado. Specimens E–O are all from bed 86 of the Greenhorn Limestone, *Watinoceras devonense* zone.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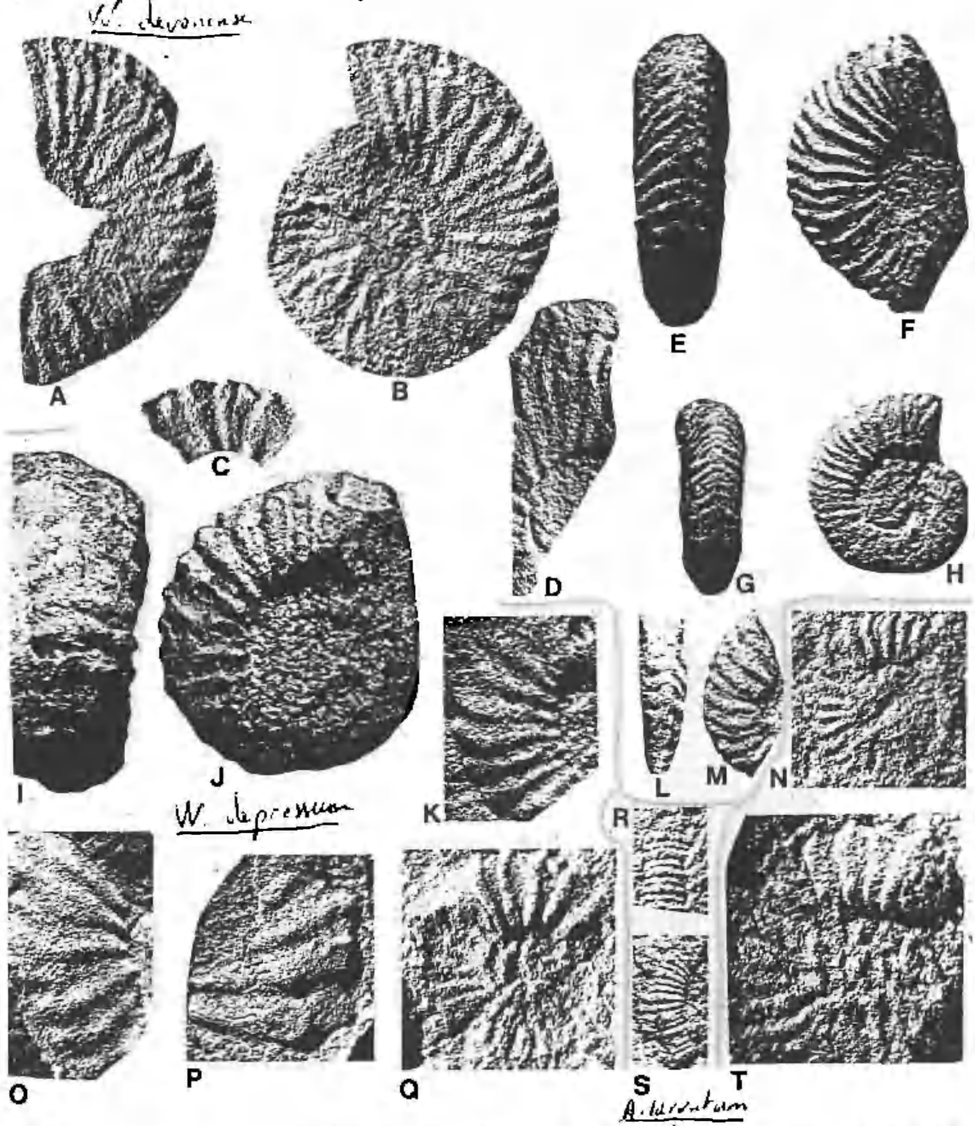


Fig. 5. Ammonites from the basal Turonian of the Western Interior and southern England. A-H, L, M, *Watinoceras devonense* WRIGHT & KENNEDY, 1981; E, F, holotype BMNH C82259, from the basal Middle Chalk, *Watinoceras coloradoense* zone, Shapwick Grange, Devon, England; G, H, paratype BMNH C82250 from the same horizon at Humble Point, Devon, England. A, B, D, USNM 441445, 441447 from USGS Mesozoic locality D3975, SW1/4 sec. 30, T. 20 S., R. 65 W., Pueblo County, Colorado; C, USNM 441446 from USGS Mesozoic locality D10176, center of sec. 25, T. 20 S., R. 66 W., Pueblo County, Colorado; L, M, USNM 441449 from USGS Mesozoic locality D12715, west-flowing tributary of Freezout Creek in NE1/4SE1/4 sec. 1, T. 30 S., R. 50 W., Baca County, Colorado; all specimens are from bed 86 of the Greenhorn Limestone, *Watinoceras devonense* zone. I–K, N–Q, T, *Watinoceras depressum* WRIGHT & KENNEDY, 1981. I, J, holotype, OUM K10109, basal Middle Chalk, *Watinoceras coloradoense* zone, Humble Point, Devon; K, N–Q, T, USNM 441448, 441450–441453, 441456, from the same horizon and locality as the original of L and M. R, S, *Allocrioceras larvatum* (CONRAD, 1855), from the same horizon and locality as L and M, USNM 441454, 441455.

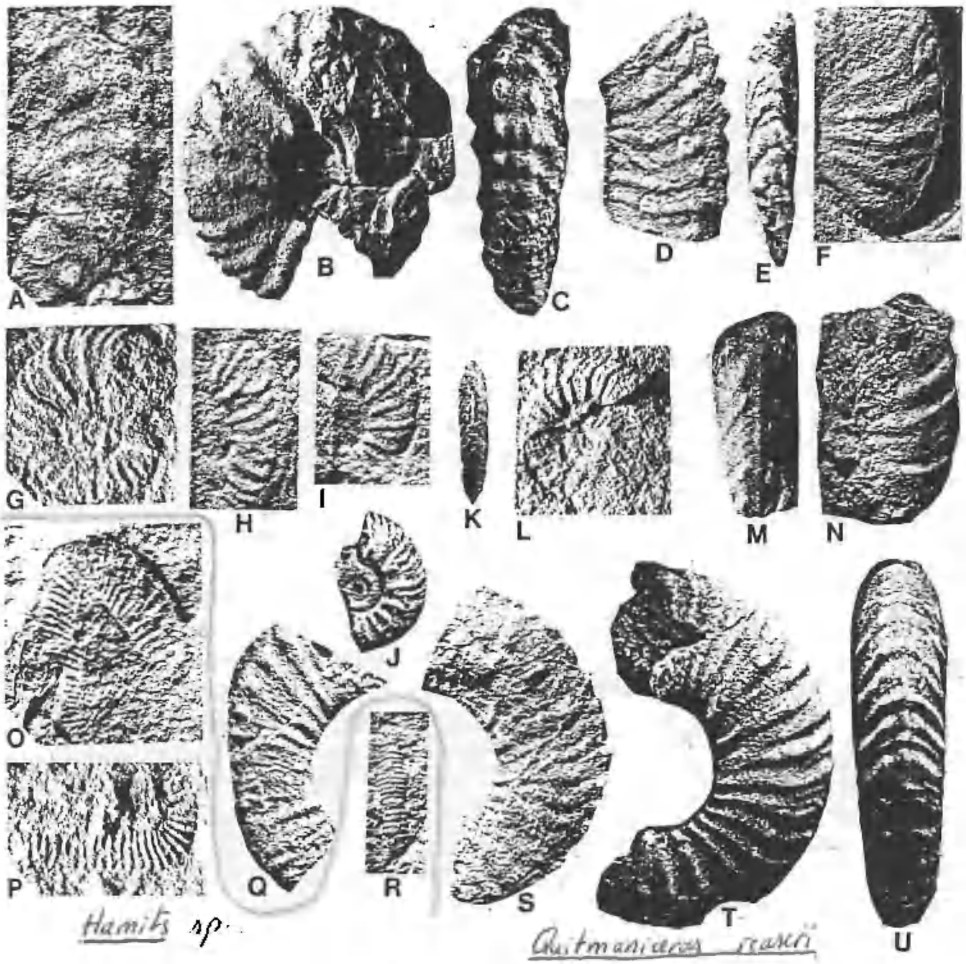


Fig. 6. Ammonites from the basal Turonian of the Western Interior and Trans-Pecos Texas. A–N, S–U, *Quitmaniceras reaseri* POWELL, 1963. A, D–I, L, Q, S, USNM 441457 to 441463, 441466, 441468, from USGS Mesozoic locality D12715, west-flowing tributary of Freezout Creek in NE1/4SE1/4 sec. 1, T. 30 S., R. 50 W., Baca County, Colorado, and from bed 86 of the Greenhorn Limestone, *Watinoceras devonense* zone. B, C. OUM KT590; J. K, TMM30917; M, N, OUM KT517; T, U, TMM36272, the holotype, all specimens from the *Pseudaspidoceras flexuosum* zone of Calvert Canyon, Hudspeth County, Texas (Figs. B, C, M, N) and Dos Alamos in Arroyo Alamos, Chihuahua, Mexico. O, P, R, *Hamites* sp. USNM 441464 to 441465, 441467, from the same horizon and locality as A–D.

COBBAN, HOOK & KENNEDY, 1989, which are confined to the zone. Other, longer-ranging species include occasional specimens of *Worthoceras vermiculus* and *Sciponoceras gracile*. At Chispa Summit in Trans-Pecos Texas (Fig. 1), the assemblage includes *Neocardioceras juddii, Thomelites* sp. nov.; *Euomphaloceras* sp. nov.; *Pseudaspidoceras pseudonodosoides, Nigericeras gadeni* (CHUDEAU), 1909) *Thomasites koulabicus* (KLER, 1908), and *Thomasites* sp.

2.4 *Nigericas scotti* zone

This zone yields abundant specimens at its type locality (Fig. 3) in southeastern Colorado, where it is associated with rare *Thomasites*. Elsewhere *N. scotti* is rare and known from single specimens in northeastern and southwestern New Mexico. It is here regarded as the uppermost Cenomanian ammonite zone.

2.5 *Watinoceras devonense* zone

This is a new biostratigraphic unit; it is the level of *Watinoceras* n. sp. of COBBAN (1985, fig. 1). The *Watinoceras* can now be referred to European species. The fauna is: *Watinoceras devonense* WRIGHT & KENNEDY, 1981, *W. depressum* WRIGHT & KENNEDY, 1981, *W. coloradaense praecursor* WRIGHT & KENNEDY, 1981, *Quitmaniceras reaseri* POWELL, 1963, *Quitmaniceras* sp. nov., *Allocrioceras larvatum* (CONRAD, 1855) and *Hamites* sp. Typical examples of these species are shown alongside type or topotype material of the species concerned in Figs. 4, 5 and 6.

2.6 *Pseudaspidoceras flexuosum* zone

This assemblage is best known in Trans-Pecos Texas, and was revised by KENNEDY, WRIGHT & HANCOCK (1987). The assemblage is: *Quitmaniceras reaseri* POWELL, 1963, *Kamerunoceras calvertense* POWELL, 1963, *Pseudaspidoceras flexuosum* POWELL, 1963, *Mammites powelli* KENNEDY, WRIGHT & HANCOCK, 1987, *Vascoceras proprium* REYMENT, 1954, *Fagesia catinus* (MANTELL, 1822), *Neoptychites* sp. *Wrightoceras munieri* (PERVINQUIÈRE, 1907), *Thomasites adkinsi* (KUMMEL & DECKER, 1954), *Allocrioceras dentonense* MOREMAN, 1942, *A. larvatum* (CONRAD, 1855), *Sciponoceras* sp. and *Worthoceras* sp. A limited representative of the zonal assemblage occurs along the Arizona-New Mexico boundary, and the index species occurs with *Q. reaseri*, *F. catinus* and *Watinoceras* sp. in southwestern New Mexico. *Quitmaniceras reaseri* is also known from the Greenhorn Member of the Cody Shale of southern Montana, where it was recorded as *Pseudotissotia (Choffaticeras)* sp.? (REESIDE, 1923).

2.7 *Vascoceras (Greenhornoceras) birchbyi* zone

The zonal index occurs a few metres above specimens of *Pseudaspidoceras flexuosum* in southwestern New Mexico, establishing the relative position of the two zones. The zonal index is known farther to the northeast from a single correlative bed of limestone in eastern Colorado, central Kansas, and northeastern New Mexico. Associated ammonites are *Watinoceras coloradoense coloradoense* (HENDERSON, 1908), *W.* spp., *Neoptychites cephalotus* (COURTILLER, 1860). *Fagesia catinus*, and *Puebloites spiralis* (COBBAN & SCOTT, 1972). There are a number of species in common in the zones of *P. flexuosum* and *V. birchbyi* in the Pueblo section, including *P. flexuosum (=Ampakabites collignoni* COBBAN & SCOTT, 1972) and *Mytiloides columbianus* (HEINZ, 1935) suggesting that the two zones may in part be coeval.

2.8 *Mammites nodosoides* zone

This zone yields a diverse fauna in the southern part of the Western Interior, and some elements extend north to Wyoming and Montana. The southern assemblage includes: *Trago-*

desmoceras bassi (MORROW, 1935, *T. socorroense* COBBAN & HOOK, 1983, *T.* sp., *Placenticeras (Karamaites) cumminsi* CRAGIN, 1983, *Kamerunoceras turoniense* (D'ORBIGNY, 1850), *Morrowites wingi* (MORROW, 1935), *M. depressus* (POWELL, 1963), *M. subdepressus* COBBAN & HOOK, 1983, *M.* cf. *dixeyi* (REYMENT, 1957), *Mammites nodosoides* (SCHLÜTER, 1871), *Neoptychites cephalotus* (COURTILLER, 1860), *Vascoceras* sp., *Choffaticeras pavillieri* (PERVINQUIÈRE, 1907), *Fagesia superstes* (KOSSMAT, 1897), *Cibolaites molenaari* COBBAN & HOOK, 1983, *Puebloites greenhornensis* COBBAN & SCOTT, 1972, and *Baculites yokoyamai* TOKUNAGA & SHIMIZU, 1926.

3 The Cenomanian-Turonian boundary sequence at Rock Canyon anticline, Pueblo, Colorado

3.1 Introduction

This section lies to the west of Pueblo, Colorado, where the Arkansas River cuts through the Rock Canyon anticline (Fig. 7). The presence of fossiliferous mid-Cretaceous rocks was known to STANTON (1894, p. 27, 28), but careful bed-by-bed collecting only commenced in 1957, when COBBAN and G. R. SCOTT began a biostratigraphic study of the sequence. Maps of the area were published by SCOTT (1964, 1970), and the litho- and biostratigraphy and ammonite fauna were documented by COBBAN & SCOTT (1972). At that time the area was poorly accessible, but later a dam was constructed on the Arkansas River and the river valley downstream was developed into a state park, the Pueblo Reservoir State Recreation Area. Vehicular access to sections is now simple, and relocation of the Denver and Rio Grande Western Railroad has provided several kilometers of fresh cuts through the Bridge Creek Member of the Greenhorn Limestone in addition to the extensive natural outcrops both in the State Park

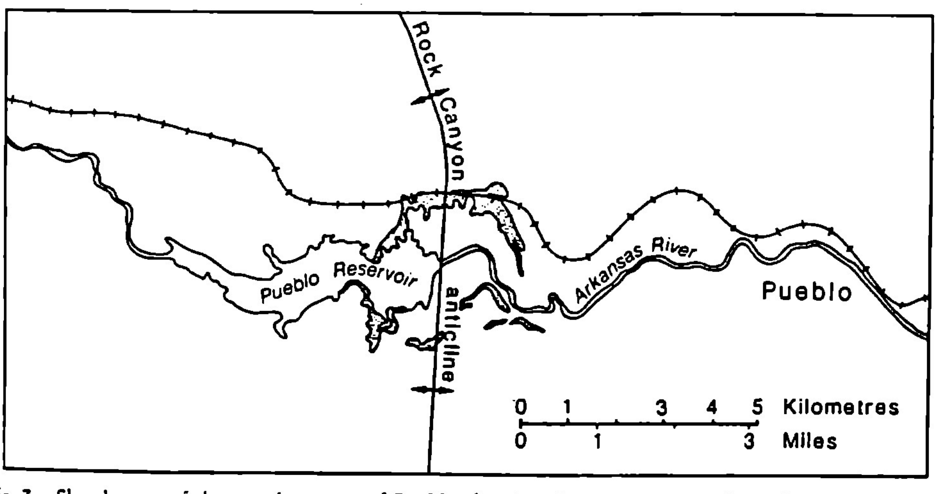


Fig. 7. Sketch map of the area just west of Pueblo showing the outcrops (stippled) of the Greenhorn Limestone around the axis of the Rock Canyon anticline at Pueblo Reservoir State Recreation Area (modified from SCOTT, 1964). The railroad tracks are those of the Denver and Rio Grande Western Railroad, the cuts of which provide fresh outcrops of the boundary interval.

(where fossil collecting without a permit is forbidden) and outside of the park. The sequence described below is thus available in any number of permanent outcrops.

Since original publication of the sequence, some additional data on ammonite occurrences are given by COBBAN (1985) and ELDER (1985).

Figure 8 shows the sequences in that part of the section that spans the Cenomanian-Turonian boundary with lists of the ammonites that have been collected as well as the position of the base of the ammonite zones recognized. Bed numbers correspond to the original account of COBBAN & SCOTT (1972). Because identificable ammonites are generally restricted to the limestones (they are present but crushed and often unidentifiable in the shales), zonal bases generally correspond to the bases of limestones.

3.2 The macrofossil sequence

The base of the *Sciponoceras gracile* zone is drawn at the base of bed 63, which is the basal bed of the Bridge Creek Member (Fig. 8). It is the thickest bed of limestone (46 cm) in the sequence, is fairly hard, and forms a conspicuous white ledge. The bed is burrow-mottled and poorly fossiliferous. Fragments of *Inoceramus pictus* J. DE C. SOWERBY, 1829 occur in the upper part, as well as an occasional fragment of *Calycoceras* cf. *naviculare* and *Metoicoceras geslinianum*. An external mould of an ammonite that is probably *Pseudocalycoceras angolaense* was observed on a large block of limestone submerged in Pueblo Reservoir.

Bed 67 is referred to as the "Sciponoceras bed." A concretionary appearance and yellowish-grey-weathering characterize this highly fossiliferous unit, which attains a thickness of 15 cm. Megafossils are more diverse in bed 67 than in any of the other Bridge Creek beds. Large echinoids (*Holaster feralis* COOKE, 1953) are present in addition to a small undetermined form. *Inoceramus pictus* and a small *Entolium* are abundant. Sparse gastropods have been recorded (COBBAN & SCOTT, 1972, p. 24). The ammonite fauna, however, is the most conspicuous feature of bed 67. Species collected to date are *Sciponoceras gracile*, *Metaptychoceras reesidei*, *Allocrioceras annulatum*, *Puebloites corrugatus*, *Pseudocalycoceras angolaense*, *Sumitomoceras conlini* (WRIGHT & KENNEDY, 1981), *Euomphaloceras septemseriatum*, and *Metoicoceras geslinianium*. This typical *S. gracile* zone assemblage includes several species that are known from countries in Europe, parts of Africa, Mexico and Japan.

Bed 73 is concretionary but softer and a little thinner (13 cm) than bed 67. Some unusual spiral burrows were observed in this bed at one locality. The bed contains small echinoids, gastropods, and bivalves (mainly *Inoceramus pictus*, a small *Pycnodonte*, and a small *Entolium*). Ammonites include *Sciponoceras gracile*, *Euomphaloceras septemseriatum*, *Pseudocalycoceras* sp., *Sumitomoceras* sp., and *Worthoceras vermiculus*.

Bed 77 is referred to as the "*Scaphite* bed" and is the highest of the concretionary beds in the *S. gracile* zone. The bed is very hard, weathers light brown and has a thickness of 7.5–15 cm. Fossils are sparse and poorly preserved but include *Sciponoceras gracile* and *Worthoceras vermiculus*. A rare find was most of a fossil fish.

There is no faunal evidence for the *Burroceras clydense* zone in the Pueblo sequence.

The base of the *Neocardioceras juddii* zone is drawn at the base of the upper shale subunit in bed 78, on the basis of the record of a single specimen in ELDER (1985, fig. 7), although the species becomes a little more common only in bed 79, some 25 cm higher.

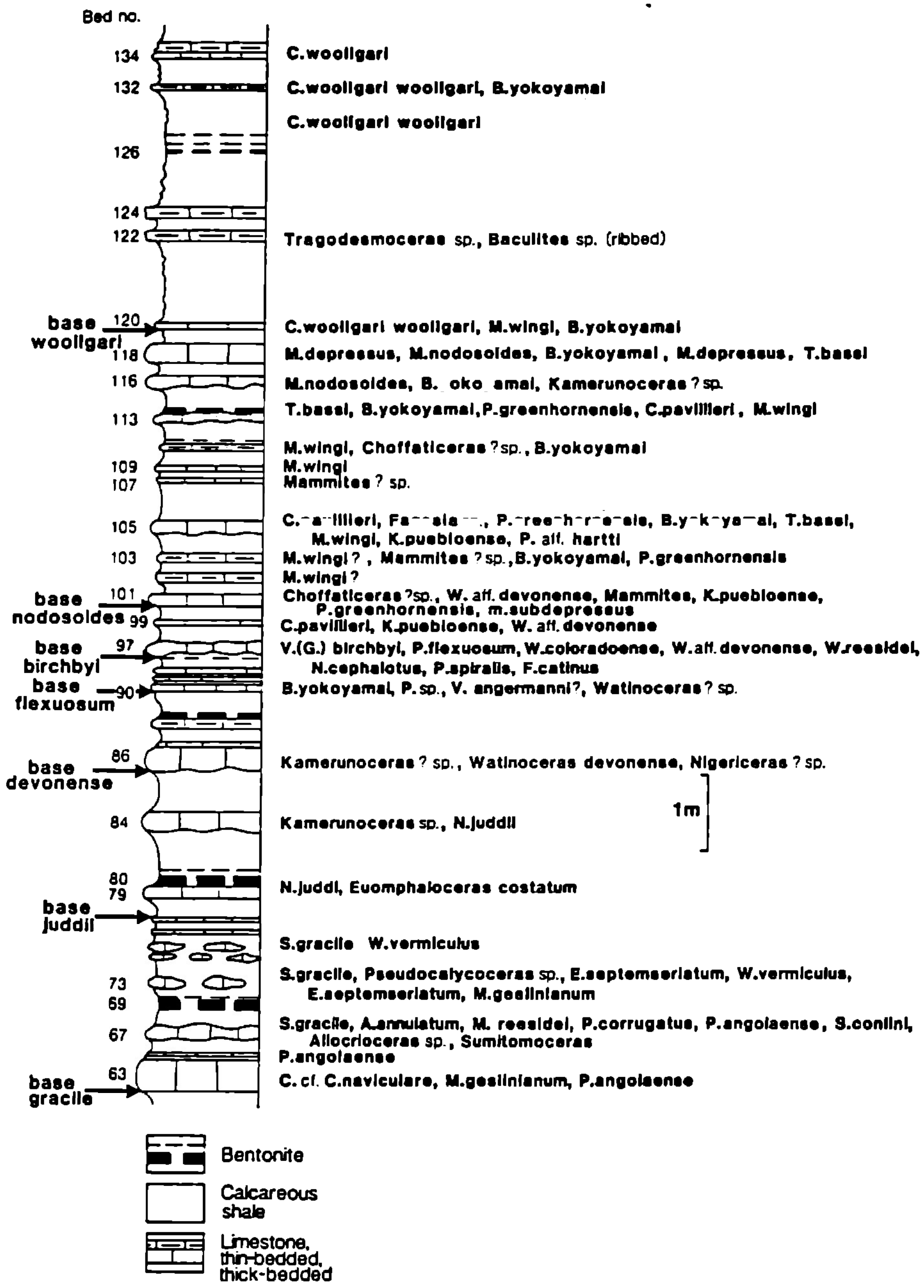


Fig. 8. The ammonite sequence in the Bridge Creek Member of the Greenhorn Limestone across the Cenomanian-Turonian boundary at Pueblo, showing some of the macrofossils collected and the positions of the bases of the ammonite zones recognized.

Bed 79 is 15 cm thick, quite hard, and massive. It's upper surface tends to weather into rounded forms, whilst it is easily recognized in the field because it is overlain by a prominent 15-cm-thick bentonite. Planktonic foraminifers are abundant in the bed, but megafossils are scare. Molluscan fossils include *Inoceramus pictus*, *Euomphaloceras* sp. nov., and fragments of *Neocardioceras juddii* (BARROIS & DE GUERNE, 1878). Bed 79 and the overlying bed of bentonite can be traced eastward to central Kansas, where they occur in the middle part of the Hartland Shale Member of the Greenhorn Limestone. In Kansas, bed 79 was referred to as the HL-3 marker bed by HATTIN (1975, p. 29, pl. 1).

There is no ammonite evidence for the *Nigericeras scotti* zone in the Pueblo section. COBBAN (1985, p. 137) suggested it was represented by bed 84, but recent work described below shows the *N. scotti*-bearing limestone bed of southeastern Colorado to be absent at Pueblo, where it is represented by a slightly more calcareous subunit in bed 83.

Bed 84 is a 23-cm-thick, hard, massive, burrow-mottled limestone that contains small pyritic spots and abundant planktonic foraminifers. Molluscan fossils are sparse and poorly preserved, and consists mainly of fragments of *Inoceramus;* a possible *Kamerunoceras* is also present.

The base of the *Watinoceras devonense* zone is drawn at the base of bed 86 (Fig. 8). This bed is clearly shown in a published photograph of part of the Bridge Creek Limestone Member (COBBAN & SCOTT, 1972, fig. 14). It is the second thickest limestone in the Bridge Creek Member. Like beds 79 and 84, bed 86 is hard and massive, and contains abundant foraminifers. Molluscan fossils are common, especially a rather weakly ornamented inoceramid that we are assigning to *Mytiloides* aff. *sackensis* (KELLER, 1982). The ammonite fauna is *Watinoceras devonense*, *W. depressum*, *W. coloradoense praecursor*, *Quitmaniceras reaseri*, *Quitmaniceras* sp., and *Hamites* sp.

The base of the *W. devonense* zone corresponds faunally to the base of the *Watinoceras* biozone of ELDER (1985), who draws the lower limit to the biozone in the lower part of the shale interval of bed 85. ELDER used the first positive appearance of *Mytiloides* n. sp. (= *M.* aff. *sackensis*) for this boundary. It should be noted that our records show *Mytiloides* first occurring in bed 84, and *Inoceramus* of the *pictus* group and *Mytiloides* aff. *sackensis* overlapping in bed 86. ELDER (1985) shows the upper limit of *I. pictus* in the lower third of bed 85 and the lower limit of *Mytiloides* extending down to the lower third of the same bed with certainty, and possibly to the base. Bed 85 is 63 cm thick and has not yielded any ammonites.

The base of the *Pseudaspidoceras flexuosum* zone is drawn at the base of bed 90 on the basis of the first occurrence of *Mytiloides columbianus* and the presence of *Vascoceras* cf. *proprium* (REYMENT, 1954). The *Vascoceras* is the *Vascoceras* sp. of COBBAN & SCOTT (1972, pl. 36, figs. 1, 2) that was considered as a somewhat crushed *Paravascoceras angermanni* (BOSE, 1918) by CHANCELLOR (1982, p. 102); KENNEDY, WRIGHT & HANCOCK (1987, p. 46) regarded this species as a synonym of *V. proprium*. *Mytiloides columbianus* first appears in the *Pseudaspidoceras flexuosum* zone in Trans-Pecos Texas, where *V. proprium* is common in the same zone.

Bed 90 is referred to as the "Pycnodonte bed." It is 13 cm thick, grey where fresh, and yellowish grey where weathered. Limonitic horizontal burrows are common, and planktonic foraminifers are abundant. Specimens of a small, smooth oyster that seems to be a *Pycnodonte* related to *P. newberryi* (STANTON, 1894) are scattered throughout the bed. The vesicular parts of the pycnodont shells are usually filled by limonite. Ammonites, other than the *Vascoceras* already noted, are *Baculites yokoyamai*, *Puebloites* sp. and fragments of some planispirally coiled ribbed form, probably *Watinoceras*.

The base of the *Vascoceras (Greenhornoceras) birchbyi* zone is drawn at the base of bed 97, which is referred to as the "Ammonite bed." An abundance of composite moulds in a good state of preservation characterizes this 15-cm-thick unit. The limestone is hard, dense and light medium grey with darker burrow mottling. Inoceramids and ammonites may have a grey-green coating of montmorillonitic clay (COBBAN & SCOTT, 1972, p. 23) that is highly diagnostic of the bed and has been recognized west of Pueblo as far as Huerfano Park near Walsenburg in south-central Colorado, and south into the Raton basin in northeastern New Mexico. In central Kansas, this bed of limestone forms the base of the Jetmore Chalk Member of the Greenhorn Limestone, where HATTIN (1975) designated it the JTl marker bed. Moulds of inoceramids are abundant and well-preserved; most can be assigned to *Mytiloides columbianus*; a few are referred to as *Mytiloides* aff. *opalensis* (BOSE, 1923). A diverse ammonite fauna is present. Species collected to date are *Watinoceras coloradoense* (HENDERSON, 1908), *W. reesidei* WARREN, 1930, *W.* aff. *devonense* WRIGHT & KENNEDY, 1981, *Pseudaspidoceras flexuosum* POWELL, 1963, *Vascoceras (Greenhornoceras) birchbyi*, *Fagesia catinus*, (MANTELL, 1822) *Neoptychites cephalotus* (COURTILLER, 1860) and *Puebloites spiralis* COBBAN & SCOTT.

The base of the *Mammites nodosoides* zone is drawn at the base of bed 101, which is referred to as the "Limonitic bed." This 15-cm-thick limestone is marked at outcrop by patches of limonite as much as 10 cm in diameter, formed by the weathering of iron sulphide. Fossils include abundant planktonic foraminifers, *Mytiloides columbianus*, *M. duplicostatus* (ANDERSON, 1903), *M.* aff. *opalensis*, *Watinoceras* cf. *W. devonense*, *Mammites nodosoides* (SCHLÜTER, 1871), *Kamerunoceras puebloense* (COBBAN & SCOTT, 1972), *Choffaticeras?* sp., *Puebloites greenhornensis* COBBAN & SCOTT, 1972, and rarely a small barnacle.

Bed 105 is a 15-cm-thick bed of massive to shaly limestone that is notable for its very well preserved inoceramids and the moderate abundance of fragments of the uncoiled ammonite *Puebloites*. Most of the inoceramids seem to be *Mytiloides columbianus*, and this occurrence may represent the top of its range. The varied ammonite fauna consists of *Morrowites wingi* (MORROW, 1935), *Kamerunoceras puebloense*, *Tragodesmoceras bassi* MORROW, 1935, *Fagesia* sp., *Choffaticeras pavillieri* (PERVINQUIERE, 1907), *Neoptychites cephalotus*, *Vascoceras* aff. *V. hartii* (HYATT, 1870), *Baculites yokoyamai* TOKUNAGA & SHIMIZU, 1926, and *Puebloites greenhornensis*.

Bed 113 is referred to as the "Shell bed." This 15-cm-thick bed of limestone is easily identified by the presence of abundant well-preserved *Mytiloides mytiloides* (MANTELL, 1822) and by a thin (2.5 cm) bed of bentonite immediately above it. In central Kansas this limestone bed is present in the upper part of the Jetmore Chalk Member of the Greenhorn Limestone, where it was designated the JT10 marker bed (HATTIN, 1975, p. 37, pl. 1). Bed 113 is burrow-mottled, hard, and very fossiliferous. Ammonites are fairly diverse and include *Tragodesmoceras bassi*, *Morrowites wingi*, *Choffaticeras pavillieri*, *Baculites yokoyamai* and *Puebloites greenhornensis*.

The base of the middle Turonian and of the *Collignoniceras woollgari* zone is drawn at the base of bed 120 (COBBAN, 1985, fig. 1), a white-weathering, 10-cm-thick limestone bed that contrasts to the grey- and brownish-grey-weathered beds of limestone above and below. In central Kansas, this bed may be the top of the Jetmore Chalk Member, where it is known as the JT13 marker bed (Hattin, 1975, p. 42). Bed 120 contains horizontal and vertical burrows and fragmentary molluscan fossils. Bivalves are mostly *Mytiloides mytiloides* and an occasional small, smooth oyster. Ammonites are *Tragodesmoceras bassi, Morrowites wingi, M. depressus* (Powell, 1963), *Collignoniceras woollgari* (Mantell, 1822) and *Baculites yokoyamai.*

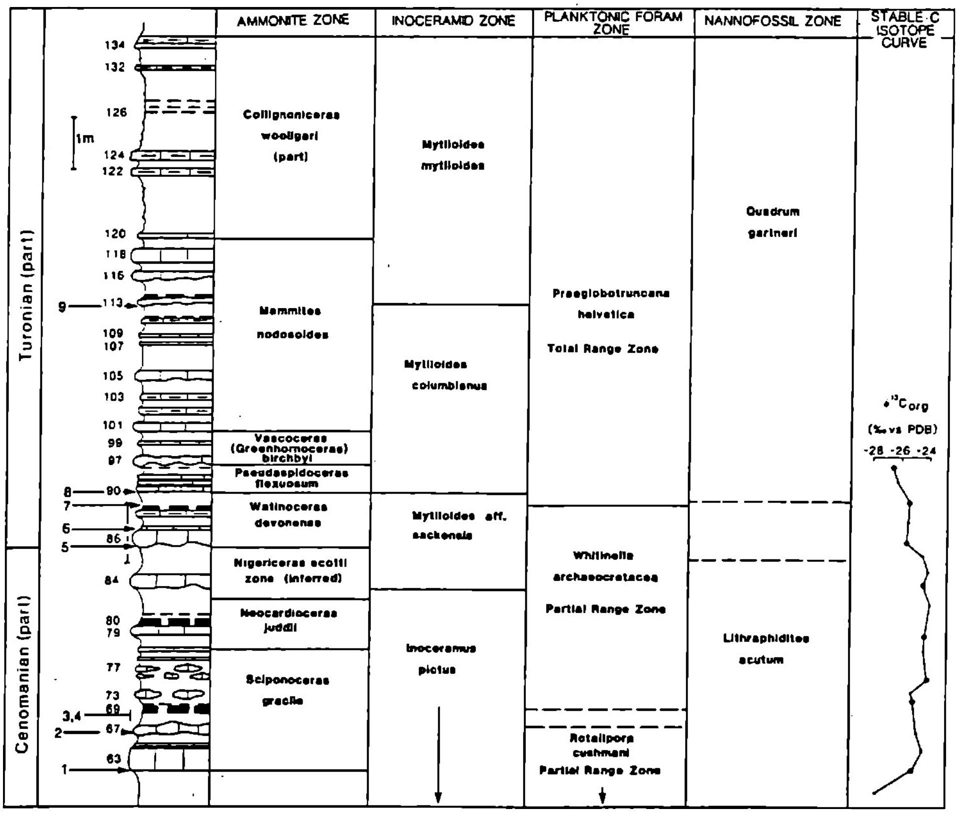


Fig. 9. Integrated ammonite, inoceramid, planktonic foraminifer and nannofossil zonation (after Watkins, 1985) of the Pueblo section, with the bases of zones indicated and the plot of the ^{13}C organic carbon excursion (stable C isotope curve). Positions of the base of the Turonian as discussed at the 1984 Copenhagen Symposium (Birkelund et. al., 1984, p. 12) are indicated as follows: 1 is the first appearance of *Metoicoceras geslinianum* (D'Orbigny, 1850), marking the base of its eponymous zone; 2 is the first occurrence of *Euomphaloceras septemseriatum* (Cragin, 1893); 3 is the last appearance of *Rotalipora cushmani* as well as of *Rotalipora*, corresponding to 4, the first appearance of *Whitinella archaeocretacea;* 5 is the interval in which *Quadrum gartneri* first appears according to Watkins (1985) (but see discussion in text); 6 is the first occurrence of *Watinoceras;* 7 is the first appearance of *Praeglobotruncana helvetica;* 8 is the base of the *Pseudaspidoceras flexuosum* zone; 9 is the first flood of *Mytiloides*, as represented by *M. mytiloides*. The stable carbon isotope curve is taken from Elder (1985). Bed numbers in the Bridge Creek Member from Cobban & Scott (1972).

3.3 Inoceramid zonation, with notes on certain inoceramids from the Bridge Creek Member

The inoceramid sequence across the Cenomanian-Turonian boundary involves a change from dominantly convex forms that have broad, ovate outlines (*Inoceramus*) to flatter forms that have more elongate outlines (*Mytiloides*). As we see it, the sequence through the Bridge Creek Member is *Inoceramus pictus* J. DE SOWERBY (1829) *Mytiloides* aff. *sackensis* (KELLER, 1982) *M. columbianus* (HEINZ, 1935), *M. mytiloides* (MANTELL, 1822), and *M. subhercynicus* (SEITZ, 1934). Each of these species ranges through one to several ammonite zones, and can be used to define a series of inoceramid zones (Fig. 9). Typical representatives are shown in Figs. 10 and 11; a full account of this succession and the taxonomy of these inoceramids will be given by ELDER (in prep.).

Inoceramus pictus zone – Dominant inoceramids include two forms. One has low convexity, closely spaced growth lines, and some rugae; this is *I. pictus* J. DE C. SOWERBY, 1829 (Fig. 10D, G). The other tends to be more convex and has more widely spaced growth lines and more rugae; some specimens can be referred to *I. capulus* SHUMARD, 1860 (neotype described and illustrated by MOREMAN, 1942), and other specimens are like those referred to as *I.* cf. *tenuistriatus* NAGAO & MATSUMOTO by HATTIN (1975, pl. 5, fig. S) (Fig. 10E). The zone of *I. pictus* in the Bridge Creek Member includes the ammonites zones of *Sciponoceras gracile, Neocardioceras juddii,* and *Nigericeras scotti.*

Mytiloides aff. *sackensis* zone – The dominant inoceramid is close to the form described by KELLER (1982, p. 67, pl. 2, figs. 4a, b) as *Inoceramus pictus sackensis* from the lower Turonian of Germany. KELLER's form, especially his paratype, has the elongate shape of *Mytiloides*, and we consider it a distinct species of that genus, although the species is transitional between *Inoceramus (pictus)* and *Mytiloides (columbianus)*. The holotype has closely spaced growth lines on the early part of the shell and then has weak ornament of growth lines and rugae on the later part. The paratype seems to have rugae on most of the shell. Specimens from the Bridge Creek Member are like these, although some individuals develop smooth or nearly smooth posterior margins (Fig. 10A-C). The species referred to herein as *M.* aff. *sackensis* is considered as a new species by ELDER (written commun., 1989), who plans to describe it. *Mytiloides* aff. *sackensis* is abundant in bed 86 (base of *Watinoceras devonense* zone in the Pueblo and Pritchett sections). The species is also present a little lower in bed 84.

Mytiloides columbianus zone – The dominant inoceramid was described from the lower Turonian of Colombia as *Orpheoceramus columbianus* HEINZ, 1935 (holotype, by monotype is *Inoceramus plicatus* D'ORBIGNY of HEINZ, 1928, pl. 4, fig. 4). The type is an elongate form that has a distinctive ornament of uniformly spaced rugae that bear mostly two growth lines. Specimens that seem assignable to *M. columbianus* are abundant in beds 90–105 at Pueblo in the ammonite zones of *Pseudaspidoceras flexuosum* and *Vascoceras birchbyi* and in the lower part of the zone of *Mammites nodosoides*. Variation is considerable; some specimens have rugae with 2 growth lines on part of the shell and 2 or 3 on other parts (Fig. 11B) or with several growth lines on most of the rugae (fig. 11A). The species has been recorded from the Western Interior as *Mytiloides* aff. *duplicostatus* (ANDERSON, 1958) (KAUFFMAN & POWELL, 1977) and *M. plicatus* (D'ORBIGNY, 1842) (COBBAN, 1985). Associated with *M. columbianus* are inoceramids of similar outlines that have rather evenly spaced concentric ornament on the juvenile part of the shell and rugae and growth lines on the adult part (figs. 11D, E). These specimens seem to be the form referred by KAUFFMAN & POWELL (1977, p. 79, pl. 6, figs. 3, 6) as *M. opalensis* (BÖSE). These specimens may be mere variants of *M. columbianus*.

Mytiloides mytiloides zone – Bed 113 of the Pueblo and Pritchett areas contains numerous well-preserved specimens of *M. mytiloides* (MANTELL, 1822) that may represent the base of the *M. mytiloides* zone. The species is characterized by its elongate form, low angle between the hinge line and axis of the shell, and narrowly curved growth lines and rugae (Figs. 11F, G). Some specimens (Fig. 11H) are transitional from *M. columbianus* and others (Fig. 11I) seem gradational to the type of inoceramid figured by SORNAY (1982, p. 139, pl. 7, figs. 1, 5) as *Inoceramus goppelnensis transiens* SEITZ, 1935, a form mainly found in the *Mammites nodosoides* zone of Europe. Bed 113 also lies in the *M. nodosoides* zone.

3.4 The planktonic foraminifer sequence

Distribution of foraminifers in the Cenomanian-Turonian boundary sequence at Rock Canyon is described by LECKIE (1985), and additional information is provided by EICHER & DINER (1985). These results are summarized in Fig. 9. The boundary between the *Rotalipora cushmani* and *Whiteinella archaeocretacea* zones is drawn within bed 68, in the *Sciponoceras gracile* zone.

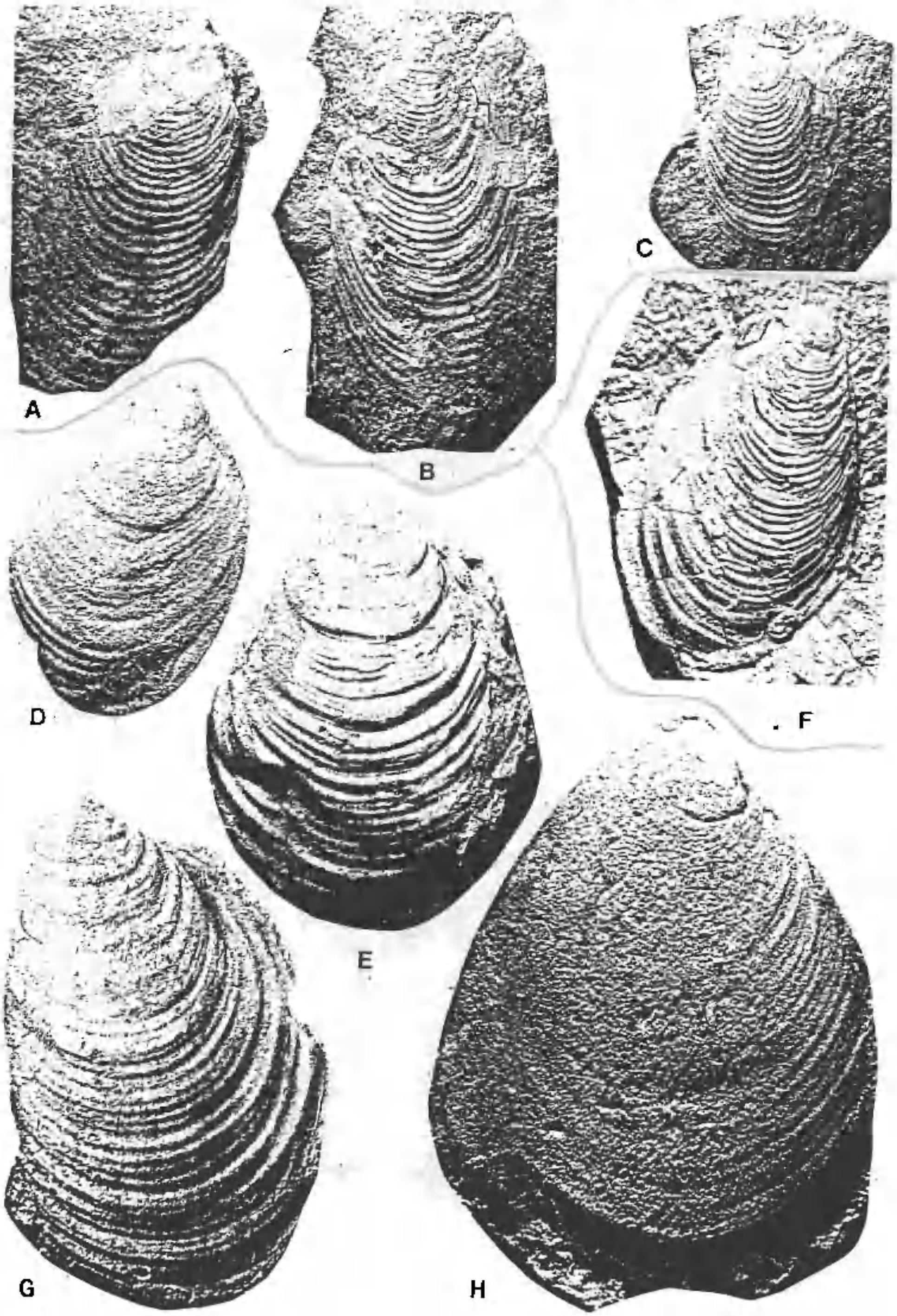
3.5 The nannofossil sequence

Nannofossils from the Rock Canyon sequence were studied by WATKINS (1985). According to this author, the base of the *Quadrum gartneri* zone lies somewhere between the middle of bed 85, from which we have no ammonites, and the middle of bed 89 (see Fig. 9), presumably within the *Watinoceras devonense* zone, although the sampling interval used by WATKINS was too wide to allow precise determination of the relative position of the ammonite and nannofossil zones in this 100-cm-thick interval. BRALOWER (1988) re-examined the sequence and provided a quite different nannofossil zonation, as well as recording the first appearance of *Quadrum gartneri* in the *Metoicoceras mosbyense* zone, below the base of the Bridge Creek Member, in the Hartland Shale Member of the Greenhorn Limestone. WATKINS' assignment to a younger position is more comparable to the stratigraphic position of *Q. gartneri* in Europe (Fig. 13).

3.6 The $^{13}C/^{12}C$ excursion

The Cenomanian-Turonian boundary anoxic event and corresponding positive (heavy) excursion in carbon stable isotope values was demonstrated by PRATT (1981, 1983, 1984, 1985) and

Fig. 10. Inoceramids from the Bridge Creek Member. A–C, *Mytiloides* aff. *sackensis* (KELLER, 1982), USNM 441469 to 441471 from USGS Mesozoic locality D3975, SW1/4 sec. 30, T. 20 S., R. 65 W., Pueblo County, Colorado, *Watinoceras devonense* zone, bed 86 of the Greenhorn Limestone. F, *Mytiloides sackensis*, the holotype, the original of KELLER, 1982, pl. 2, fig. 4, from Sack-Mülde, West Germany. D, E, G, H, *Inoceramus pictus* J. DE C. SOWERBY, 1829. USNM 441472 to 441475; E, specimen resembling *I.* cf. *tenuistriatus* of authors, USNM 441473. From USGS Mesozoic locality D6571, SW1/4NW1/4NE1/4 sec. 21, T. 18 S., R. 68 W., Fremont County, Colorado, *Sciponoceras gracile* zone.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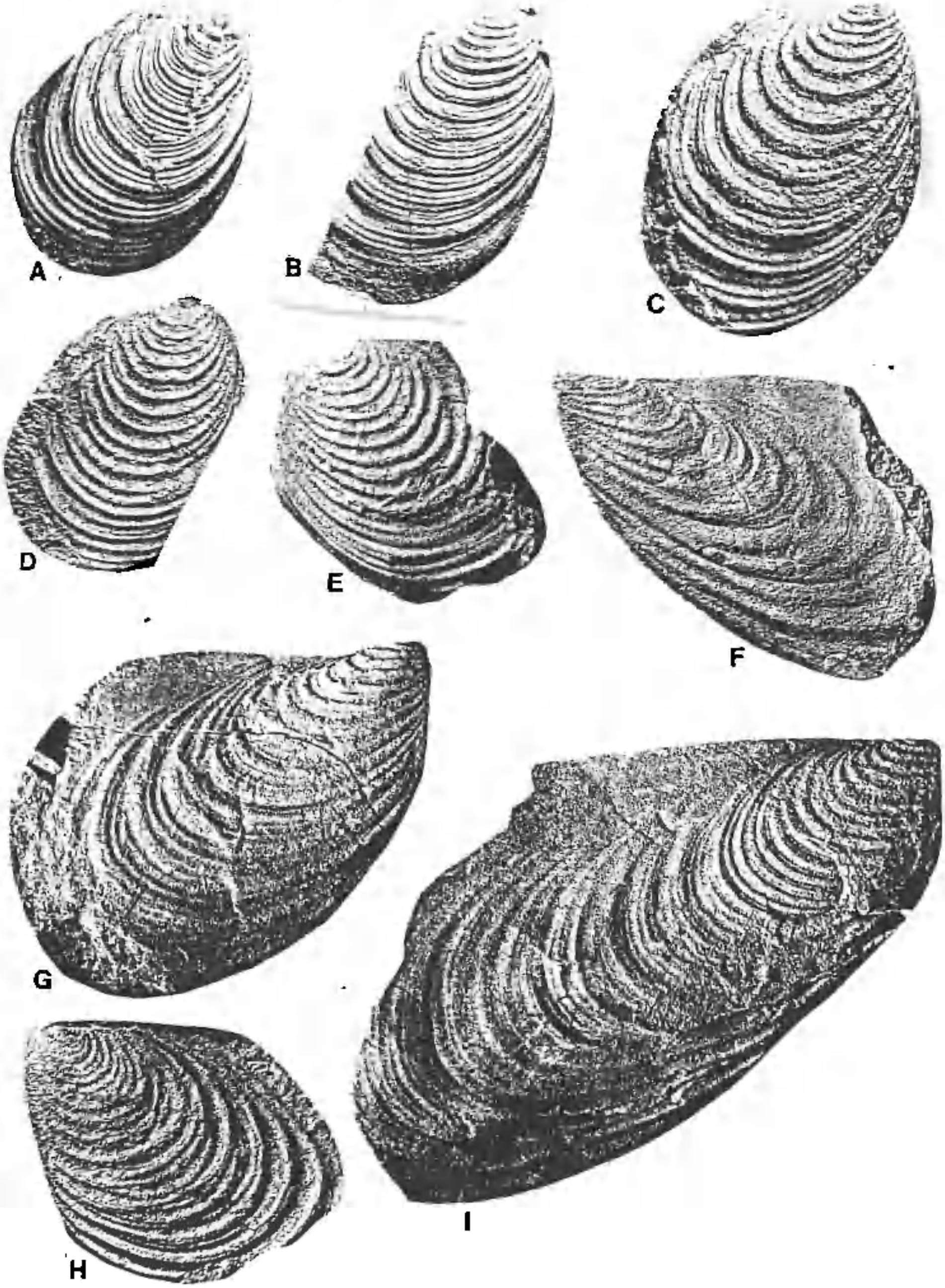
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discussed by PRATT, KAUFFMAN & ELDER (1983), PRATT & THRELKELD (1984), ELDER (1985, 1987) and HERBIN, MONTADERT, MULLER, GOMEZ, THUROW & WIEDMANN (1986), ARTHUR, DEAN & PRATT (1988) and others.

The Pueblo data derives from analyses of fresh core material; fig. 9 correlates these data with the outcrop sequence, bed numbers and zonal boundaries described in section 3.1, and is redrawn from ELDER (1985, fig. 1). Note that the excursion encompasses the *Sciponoceras gracile* to *Pseudaspidoceras flexuosum* zones.

4 The Cenomanian-Turonian boundary succession near Pritchett, Baca County, Colorado

The Bridge Creek Member of the Greenhorn Limestone is well exposed along a tributary to Freezeout Creek 13 km northwest of Pritchett near the southeast corner of Colorado and some 170 km southeast of Pueblo (Fig. 1). This section is important because it contains a bed of limestone that has *Nigericeras scotti* which is absent at Pueblo (Fig. 12). The outcrops are near those illustrated by McLAUGHLIN (1954, fig. 43). The sequence is much like that at Pueblo although somewhat thicker. However, due to the limited time spent near Pritchett, collections of fossils were made by us from only a few of the beds.

The basal bed, like that at Pueblo, is the thickest bed of limestone in the member. The bed is 28 cm thick and forms a conspicuous white ledge; it contains an occasional fragment of *Inoceramus pictus*. About 15 cm above this bed are white limestone concretions that contain abundant *Sciponoceras gracile* and a few *I. pictus*, *Metoicoceras geslinianum*, *Puebloites corrugatus*, and gastropods. A 15-cm-thick bed of bentonite 13 cm above the "*Sciponoceras* bed" is the same as bed 69 at Pueblo (Fig. 8). A thin bed of lenticular limestone 38 cm above this bentonite contains *I. pictus*, *Pseudocalycoceras angolaense* and *Euomphaloceras septemseriatum*. A bed of white chalky limestone 81 cm above the lenticular limestone contains *I. pictus*, *Phelopteria* sp., *Worthoceras* sp., and *Sciponoceras*? sp. This bed may still be in the zone of *Sciponoceras gracile*.

A 20-cm-thick bed of limestone overlain by a 7-cm-thick bed of bentonite represents beds 79 and 80 of the Pueblo section (Fig. 8). An occasional fragment of *Neocardioceras juddii* can be found in the limestone. A 7cm-thick bed of fairly soft, massive, foraminiferal limestone 48 cm above the bentonite bed contains *Nigericeras scotti*. This limestone bed is present at La Junta, midway between Pritchett and Pueblo, where it still contains *N. scotti*, but it is poorly developed or absent at Pueblo (Fig. 8). A prominent bed of limestone a little above the *N. scotti*-bearing bed in the Pritchett area is the same as bed 84 at Pueblo.

Fig. 11. Inoceramids from the Bridge Creek Member. A–C, *Mytiloides columbianus* (HEINZ, 1935). A, B, C, USNM 441476 to 441478, from USGS Mesozoic locality D6147, SW1/4NW1/4NW1/4 sec. 1, and NE1/4 NE1/4 sec. 2, T. 21 S, R. 66 W., Pueblo County, Colorado. *Vascoceras (Greenhornoceras) birchbyi* zone. D, E, *Mytiloides* sp. USNM 441479 to 441480, from USGS Mesozoic locality D6147 (see above) and D3977 in SW1/4 sec. 30, T. 20 S., R. 65 W., Pueblo County, Colorado. F–I, *Mytiloides mytiloides* (MANTELL, 1822). USNM 441481 to 441484, from USGS Mesozoic locality D4443, NE1/4SE1/4NW1/4 sec. 25, T. 20 S., R. 66 W., Pueblo County, Colorado, *Mammites nodosoides* zone.

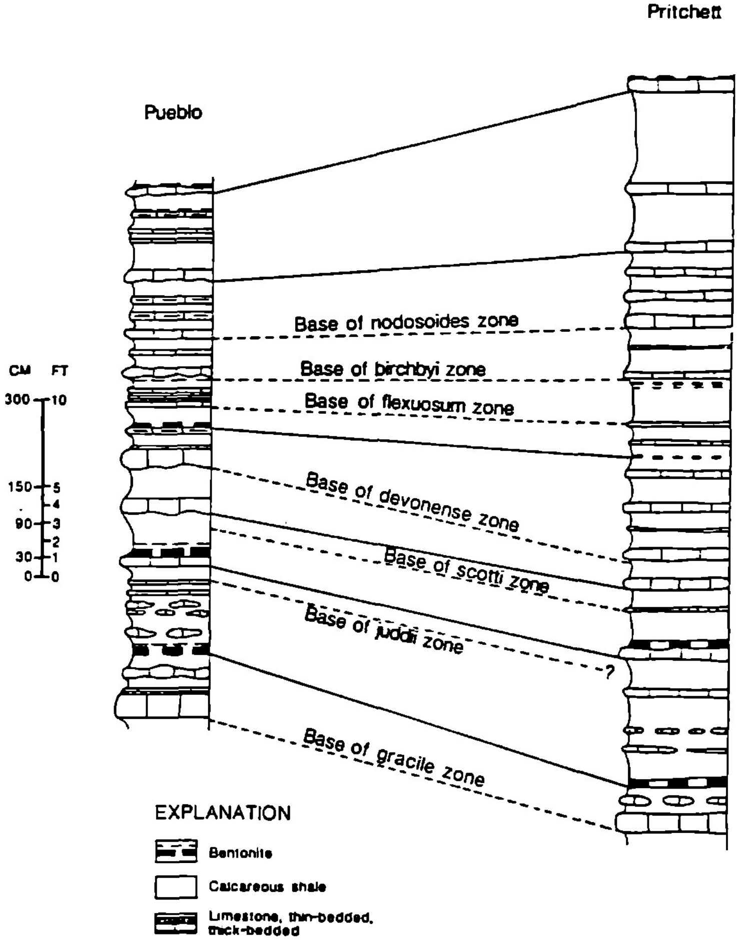

Fig. 12. Correlation of the Cenomanian-Turonian boundary within the Bridge Creek Member at Pueblo with that at Pritchett, Baca County, Colorado. Marker bed correlations are indicated by solid lines; the bases of ammonite zones by broken lines.

Bed 86 at Pueblo is represented by an 18-cm-thick bed of limestone in the Pritchett section (Fig. 12). At both localities the bed contains abundant crushed *Watinoceras devonense, W. depressum, W. coloradoense praecursor, Quitmaniceras reaseri, Quitmaniceras* sp., and *Hamites* sp.

An 8-cm-thick bed of limestone 107 cm above the *Watinoceras*-bearing bed at the Pritchett locality is probably bed 90 at Pueblo (Fig. 8). No fossils were collected, but the bed should be the base of the *Pseudaspidoceras flexuosum* zone.

A hard bed of limestone 71 cm higher in the section near Pritchett is bed 97 at Pueblo. Fossils collected include abundant *Mytiloides columbianus* and a few *Vascoceras birchbyi* and *Watinoceras coloradoense coloradoense.*

A bed of limestone 69 cm above the *V. birchbyi*-bearing bed is bed 101 at Pueblo. The only fossils noted were abundant *Mytiloides columbianus*. Ammonites at Pueblo indicate this bed to be the base of the *Mammites nodosoides* zone (Figs. 9, 12).

A bed of limestone 107 cm higher is bed 105 at Pueblo. Fossils collected at the Pritchett section include *Mytiloides columbianus*, *Morrowites wingi*, *Puebloites greenhornensis*, and *Baculites yokoyamai*.

Bed 113 at Pueblo, which is a limestone overlain by bentonite, is represented by a 15-cm-thick bed of limestone overlain by bentonite at the Pritchett locality, where it lies 2.3 m above the *Morrowites*-bearing bed. As at Pueblo, bed 113 contains abundant well-preserved *Mytiloides mytiloides*.

5 Position of the Cenomanian-Turonian boundary at Pueblo

Figure 9 plots the positions of the bases of ammonite, inoceramid, planktonic foraminifer and nannofossil zones (sensu WATKINS, 1985) at Pueblo, and superimposes the stable isotope curve.

Of various boundary levels discussed by BIRKELUND et al. (1984), all but one, the first appearance of *Mytiloides*, can be placed in sequence. The first possible boundary proposed is the base of a zone of *Metoicoceras geslinianum*. This first appears in bed 63, at the base of the *Sciponoceras gracile* zone (Fig. 9, 1). Second proposal: the first appearance of *Euomphaloceras septemseriatum*; at Pueblo this is in bed 67 (Fig. 9, 2). Third: extinction of *Rotalipora* or of *R. cushmani*. These occur within bed 68 at Pueblo (Fig. 9, 3). Fourth: first appearance of *Whitinella archaeocretacea*. This is within bed 68 at Pueblo (Fig. 9, 4). Fifth: first appearance of *Quadrum gartneri*. This is somewhere between the middle of bed 85 and the middle of bed 89 at Pueblo (Fig. 9, 5) according to WATKINS (1985), but in the Hartland Shale Member below the Bridge Creek Member according to BRALOWER (1988). Sixth: the base of the assemblage zone of *Watinoceras coloradoense*. At Pueblo this is the base of the *W. devonense* zone, which yields *W. coloradoense praecursor* in bed 86. Seventh: the first appearance of *Praeglobotruncana helvetica*. At Pueblo, EICHER & DINER (1985, p. 64) state that this first appears 5 m (16.5 feet) above the base of the Bridge Creek Limestone Member but do not state a particular bed. It must be within bed 89, and is so plotted in Fig. 9 (7). Eighth: the base of the *Pseudaspidoceras flexuosum* zone. This was believed to correspond to the base of the *Watinoceras coloradoense* zone (BIRKELUND et al., 1984, p. 12), but is here shown to be significantly higher in Fig. 9 (8). Ninth: the appearance of a flood of *Mytiloides* at the base of the assemblage zone of *Mammites nodosoides*. At Publeo, the base of this zone is at the base of bed 101, but there is no *Mytiloides* flood; instead, *M. mytiloides* is abundant in bed 113, high in the zone, and we presume this to be the flood referred to by BIRKELUND et al. (1984); see Fig. 9 (9).

As already noted, we have not detected the first appearance of *Mytiloides* at Pueblo, but observations by MATSUMOTO (in BIRKELUND et al., 1984) and KAUFFMAN & POWELL (1977) place this within the *Sciponoceras gracile* zone at other localities.

Whatever actual Cenomanian-Turonian boundary position is adopted by the Subcommission on Cretaceous Stratigraphy, the value of the present synthesis of the Pueblo section is the recognition of first/last appearance of all of the important boundary markers considered by

BIRKELUND et al. (1984), and the clarification of their relative positions, never previously demonstrated in a single section. It also reveals certain errors in the 1984 review. The base of the assemblage zone of *Watinoceras coloradoense* and that of *Pseudaspidoceras flexuosum* do not coincide; the former is well below the latter. *Quadrum gartneri* does not appear in the *Neocardioceras juddii* zone at Pueblo, but within the *Watinoceras devonense* zone, according to WATKINS (1985). In contrast, BRALOWER (1988, fig. 16), shows *Q. gartneri* first appearing in the *Metoicoceras mosbyense* zone, below the *Sciponoceras gracile* zone, in the Hartland Shale Member.

Our own preference, as ammonite workers, is to place the Cenomanian-Turonian boundary at the first appearance of *Watinoceras* at the base of the *W. devonense* zone, currently placed at the base of bed 86. This is close to the first appearance of *Praeglobotruncana helvetica*, if we correctly interpret EICHER & DINER (1985, p. 64), and can thus be recognized indirectly even when ammonites are absent.

Because all of these faunal zones can be recognized at Pueblo, we believe the Pueblo section merits serious consideration as a boundary stratotype, while the presence of bentonites that are amenable to direct radiometric dating at key levels (Fig. 8, 9) adds to the value of the section.

6 Comparison with the Cenomanian-Turonian boundary sequence in southern England

The most complete ammonite succession across the Cenomanian-Turonian boundary in Western Europe is that developed in Spain and Portugal, which was described by WIEDMANN (1960, 1964) and BERTHOU and his collaborators (see summary in BERTHOU, 1984). Unfortunately this sequence is in a Tethyan biofacies, dominated by vascoceratids which, in the case of the Spanish successions, are largely endemic. More useful biofacies are the successions in the Anglo-Paris basin that are considered here, in particular those of the Channel Coast. The lithological sequence concerned is of rhythmically bedded chalks and marls below – the Plenus Marls of English workers, and the Formation des Crupes of French workers. These rocks are remarkably similar to those of the Bridge Creek Member. The overlying chalks are nodular with extensive early diagnetic cementation and are known as the Melbourn Rock of English workers and the Formation du Grand Blanc Nez of French workers. The underlying Plenus Marls are divided into eight beds that can be traced throughout the whole of the Anglo-Paris basin. Ammonite occurrence is sporadic and in part controlled by pre-burial dissolution (JEFFERIES, 1961, 1963; WRIGHT & KENNEDY, 1981). Small ammonites are uncommon in the nodular facies. Figure 13 shows the sequence at Shakespeare Cliff, near Dover, Kent.

A better ammonite record can be recognized in the condensed and reworked calcarenitic facies between Lyme Regis and Branscome in Devon in southwest England; the succession at the Beer Stone adit west of Beer Roads is shown in Figure 14.

6.1 The Cenomanian-Turonian boundary ammonite sequence in southern England

This succession is described in detail by WRIGHT & KENNEDY (1981), and details are inserted on Figures 13 and 14.

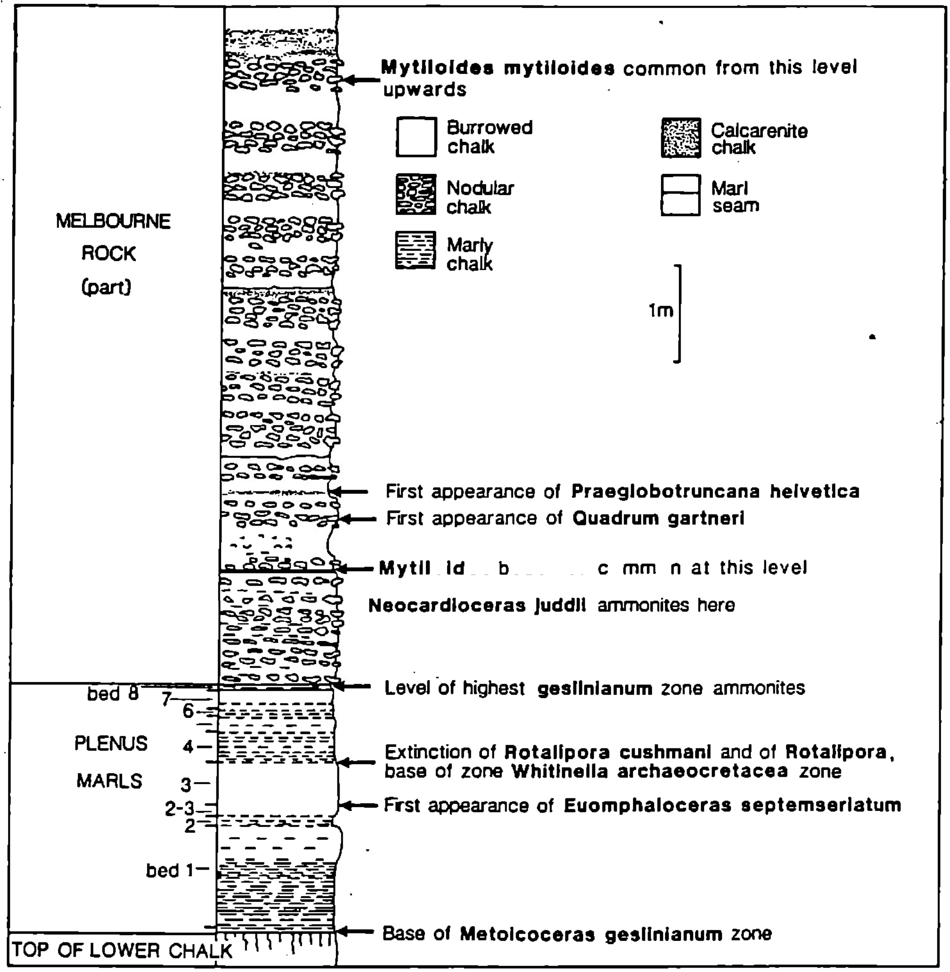

Fig. 13. Stratigraphic sequence at the base of Shakespeare Cliff, west of Dover, England, showing the nine possible marker events for the base of the Turonian discussed by Birkelund et al. (1984).

6.1.1 *Metoicoceras geslinianum* zone

The base of the zone is marked by the first appearance of *Metoicoceras geslinianum*. The fauna is: *Puzosia* sp., *Puzosia odensis* Kossmat, 1898, *P. (Anapuzosia) dibleyi* (Spath, 1922), *Calycoceras (Calycoceras) naviculare*, *Pseudocalycoceras angolaense*, *Sumitomoceras cautisalbae* (Wright & Kennedy, 1981), *Euomphaloceras septemseriatum* (Cragin, 1893), *Metoicoceras geslinianum*, *Vascoceras diartianum*, *Hamites* cf. *simplex* D'Orbigny, 1850, *Allocrioceras annulatum*, *Sciponoceras gracile*, *Scaphites (Scaphites) equalis* J. Sowerby, 1813.

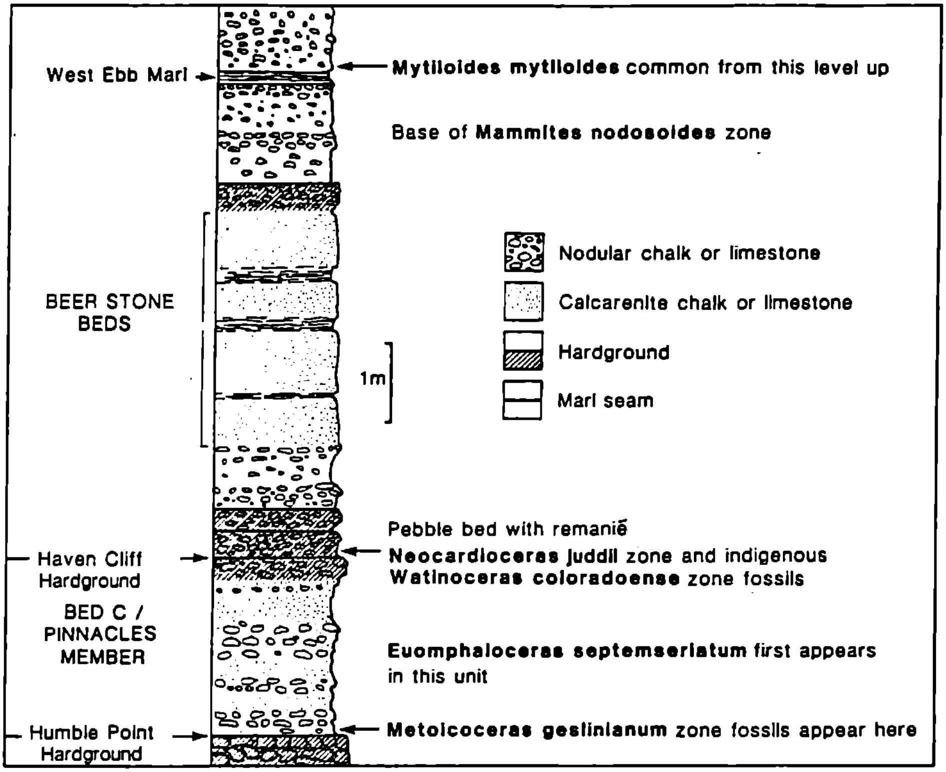

Fig. 14. Stratigraphic sequence at the Beer Stone adit southwest of Beer Roads, Devon, England.

6.1.2 Unnamed assemblage

At Shapwick Grange, Devon (WRIGHT & KENNEDY, 1981), the following fauna occurs above the *M. geslinianum* zone but below the succeeding *Neocardioceras juddii* zone: *Puzosia odiensis, Kamerunoceras* sp. nov., *Nigericeras* cf. *gignouxi* SCHNEEGANS, 1943, *Thomasites gongilensis tectiformis* (BARBER, 1957), *T. gongilensis lautus* (BARBER, 1957).

6.1.3 *Neocardioceras juddii* zone

The base of the zone is marked by the appearance of the index species. The fauna is: *Thomelites serotinus* WRIGHT & KENNEDY, 1981, *Neocardioceras juddii juddii, N. juddii barroisi* WRIGHT & KENNEDY, 1981, *N. tenue* WRIGHT & KENNEDY, 1981, *Thomasites gongilensis lautus, Allocrioceras annulatum, Sciponoceras bohemicum anterius* WRIGHT & KENNEDY, 1981. Also probably belonging to the *N. juddii* zone are *Spathites (Jeanrogericeras)* cf. *subconciliatus* (CHOFFAT, 1898) and *Thomasites* cf. *rollandi* (PERON, 1889).

6.1.4 *Watinoceras coloradoense* zone

The base of the zone is marked by the appearance of *Watinoceras* div. spec.: *Watinoceras amudariense* (ARKHANGUELSKY, 1916), *Watinoceras depressum* WRIGHT & KENNEDY, 1981, *Watinoceras devonense* WRIGHT & KENNEDY, 1981, *Watinoceras* cf. *jackeli* (SOLGER, 1904), *Mammites* aff. *nodosoides*.

The base of the Turonian in ammonite terms has been drawn at the base of the *Watinoceras coloradoense* zone.

6.1.5 *Mammites nodosoides* zone

The base of the zone is marked by the appearance of the index species: *Parapuzosia (Austiniceras) austeni* (SHARPE, 1855), *Lewesiceras peramplum* (MANTELL, 1822), *Mammites nodosoides*, *Morrowites wingi wingi*, *Metasigaloceras rusticum* (J. SOWERBY, 1817), *Pseudaspidoceras footeanum* (STOLICZKA, 1864), *Fagesia catinus* (MANTELL, 1822), *Fagesia pachydiscoides* SPATH, 1925.

6.1.6 *Collignoniceras woollgari* zone

The base of the zone is marked by the appearance of the index species.

6.2 The Cenomanian-Turonian boundary inoceramid sequence in southern England

Studies on inoceramids across this interval in England have suffered the same problems of nomenclature as have those in the Western Interior of the United States, and there is little published information, although sequences elsewhere in Europe are proposed by SEIBERTZ (1979), TRÖGER (1981), KELLER (1982) and HILBRECHT (1986) among others. Only KAUFFMAN (1978), JARVIS & WOODROOF (1984), JARVIS, CARSON, HART, LEARY & TOCHER (1988) and JARVIS, CARSON, COOPER, HART, LEARY, TOCHER, HORNE & ROSENFELD (1988) have published observations on the sequence, in large part based on the unpublished work of WOODROOF (1981).

As in the U.S. Western Interior the highest Cenomanian assemblage is characterized by *Inoceramus pictus*, which spans all of the upper middle and upper Cenomanian, extending to the top of the *Neocardioceras juddii* zone.
Mytiloides mytiloides appears in numbers in the *Mammites nodosoides* zone, but the intervening inoceramid assemblage or assemblages remain inadequately characterized. This in part reflects the attenuated nature of the sequence as well as lack of proper description of the species. *Mytiloides submytiloides*, *Mytiloides mytiloides*, *Mytiloides duplicostatus* (ANDERSON, 1903) and *Mytiloides opalensis* of KAUFFMAN (non BÖSE) (e.g. *Mytiloides columbianus*) have been recorded.

6.3 The boundary sequence at Dover, Kent

Figure 13 shows the sequence at the base of Shakespeare Cliff, west of Dover, and plots the levels of certain ammonites, inoceramids, planktonic foraminifers and nannofossils. The last was provided by Professor M. B. HART of Plymouth Polytechnic on the basis of his published and unpublished results (see also JARVIS, CARSON, COOPER, HART, LEARY, TOCHER, HORNE & ROSENFELD, 1988). Also indicated are the eight possible marker events for the base of the Turonian discussed by BIRKELUND et al. (1984) and recognizable in the Pueblo succession (Fig. 8).

The base of the *Metoicoceras geslinianum* zone is drawn at the base of bed 1 of the Plenus Marls on the basis of the presence of xenomorphic oysters that were attached to that species at this level at Steyning in Hampshire (JEFFERIES, 1963); no ammonites are known at Dover. The first appearance of *Euomphaloceras septemseriatum* is in bed 3 of the Plenus Marls based on records of ROBASZYNSKI et al. (1980) in the Boulonnais in Pas de Calais, France. The extinction of *Rotalipora cushmani* and of *Rotalipora* is at the top of bed 3 of the Plenus Marls at Dover and throughout the Anglo-Paris Basin (e.g. CARTER & HART, 1977). The base of the *Whitinella archaeocretacea* zone is at the base of bed 4 of the Plenus Marls.

The base of the *Neocardioceras juddii* zone cannot be defined at Dover, but *Sciponoceras boehmicum anterius* 80–100 cm above the base of the Melbourn Rock indicates the presence of the zone. There is no evidence for the *Watinoceras coloradoense* zone, but *Mytiloides* becomes common 1.15–1.2 m above the base of the Melbourn Rock. *Quadrum gartneri* first appears 1.5–1.55 m above the base of the Melbourn Rock, and *Praeglobotruncana helvetica* 1.9–2 m above the base of the Melbourn Rock. The base of the *Mammites nodosoides* zone has not been located *in situ*, but *Mytiloides mytiloides* is common 6.5 m above the base of the Melbourn Rock and upwards.

6.4 The boundary sequence near Beer Roads, Devon

Figure 14 shows the sequence at the Beer Stone adit southwest of Beer Roads, Devon; see JARVIS & WOODROOF (1984), WOODROOF (1981) and observations by KENNEDY. Microfaunal and microfloral data were provided by Professor HART; see also JARVIS, CARSON, HART, LEARY & TOCHER (1988). The sequence is highly condensed at the base, but the zonal boundaries plotted against the Dover section are shown, as well as a few additional points.

The base of the *Metoicoceras geslinianum* zone is drawn at the base of Bed C of the Cenomanian Limestone, the Pinnacles Member of JARVIS & WOODROOF (1984). This yields a complex fauna with remanié phosphates from lower horizons in the upper Cenomanian plus hardened and glauconitized moulds of *M. geslinianum* zone fossils. Although *Euomphaloceras septemseriatum* occurs in this unit, its precise level of appearance is not known.

The top surface of Bed C, the Haven Cliff Hardground, is overlain by a complex conglomerate, the *Neocardioceras* Pebble Bed, at the base of the Connet's Hole Member of the Seaton Chalk, the latter a local term proposed by JARVIS & WOODROOF (1984) for this part of the Middle Chalk division of traditional terminology. The *Neocardioceras juddii* zone is represented by remanié pebble fossils including the index species, *Inoceramus pictus* and abundant *Sciponoceras bohemicum anterius*. At the same level is an indigenous fauna of the lower Turonian *Watinoceras coloradoense* zone, plus indigenous *Mytiloides* and other inoceramids. The base of the *Mammites nodosoides* zone is just below the West Ebb Marl. *Mytiloides mytiloides* is common from 10–20 cm above the West Ebb Marl and upwards.

	AMMONITE ZONES PUEBLO	AMMONITE ZONES, S.ENGLAND	COMMON DATUM POINTS
TURONIAN (part)	**Collignoniceras woollgari**	**Collignoniceras woollgari**	← Base of **Collignoniceras woollgari** zone
	Mammites nodosoides	**Mammites nodosoides**	← Base of **Mytiloides mytiloides** zone ← Base of **Mammites nodosoides** zone
	Vascoceras (Greenhornoceras) birchbyi	**Watinoceras coloradoense**	
	Pseudaspidoceras flexuosum		
	Watinoceras devonense		← Base of **Praeglobotruncana helvetica** zone ← First appearance of **Watinoceras spp.**
CENOMANIAN (part)	**Nigericeras scotti (inferred)**	**Neocardioceras juddii**	
	Neocardioceras juddii		← Base of **Neocardioceras juddii** zone
	Sciponoceras gracile	**Metoicoceras geslinianum**	← Extinction of **R.cushmani** and of **Rotalipora** : base of **W.archaeocretacea** zone ← First appearance of **Euomphaloceras septemseriatum** ← First appearance of **Metoicoceras geslinianum**

Fig. 15. Correlation of the ammonite zones at Pueblo, Colorado, and southern England.

7 Correlation of the Cenomanian-Turonian boundary sequence between Pueblo and southern England

Figure 15 correlates the zonal schemes and marker events between Pueblo and southern England. The base of the *Metoicoceras geslinianum* and *Sciponoceras gracile* zones are correlated on the basis of the first appearance of the index species, as are the bases of the *Neocardioceras juddii* zones in both regions. The bases of the *Watinoceras coloradoense* and *Watinoceras devonense* zones are correlated on the basis of the common occurrence of *W. devonense* and other *Watinoceras* species. The bases of the *Mammites nodosoides* zones in both regions are correlated on the first appearance of the index species. The relative position of the first appearance of *Euomphaloceras septemseriatum*, the extinction of *Rotalipora cushmani* and of *Rotalipora*, the appearance of *Whitinella archaeocretacea* and the base of the *Praeglobotruncana helvetica* zones are constant when plotted against the integrated macrofossil zonation, which indicates the essential synchronism of these events and datum. The first appearance of *Quadrum gartneri* lies within the *Watinoceras devonense* zone at Pueblo according to WATKINS (1985) and above the first occurrence of *Watinoceras coloradoense* zone fossils in southern England according to JARVIS et al. (1988). In both areas this is below the first appearance of *Praeglobotruncana helvetica*. BRALOWER (1988, figs. 2b, 8) shows a much lower first occurrence of *Q. gartneri* at Pueblo (Fig. 2b), but does not record it from Shakespeare Cliff, Dover (Fig. 8).

Whatever the finally agreed position of the Cenomanian-Turonian boundary, the present review demonstrates the relative positions of the most widely proposed levels in Europe and the United States. The Pueblo section has the fullest representation of these levels yet described and merits serious consideration as a boundary stratotype.

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References

ARTHUR, M. A., W. E. DEAN & L. M. PRATT (1988): Geochemical and climatic effects of increased marine organic carbon burial at the Cenomanian/Turonian boundary. – Nature 335: 714–717, London.

BERTHOU, P.-Y. (1984): Albian-Turonian stage boundaries and subdivisions in the western Portuguese Basin, with special emphasis on the Cenomanian-Turonian boundary in the ammonite facies and rudist facies. – Bull. geol. Soc. Denmark 33: 41–55, Copenhagen.

BIRKELUND, T., J. M. HANCOCK, M. B. HART, P. F. RAWSON, J. REMANE, F. ROBASZYNSKI, F. SCHMID & F. SURLYK (1984): Cretaceous stage boundaries – Proposals. – Bull. geol. Soc. Denmark 33: 3–20, Copenhagen.

BRALOWER, T. J. (1988): Calcareous nannofossil biostratigraphy and assemblages of the Cenomanian-Turonian boundary interval: implications for the origin and timing of oceanic anoxia. – Paleoceanography 3: 275–316, Washington, D.C.

CARTER, D. J. & M. B. HART (1977): Aspects of mid-Cretaceous stratigraphical micropalaeontology. – Bull. Br. Mus. nat. Hist. (Geol.) 29: 1–135, London.

CHANCELLOR, G. R. (1982): Cenomanian-Turonian ammonites from Coahuila, Mexico. – Bull. geol. Instns., Univ. Uppsala, N.S. 9: 77–129, Uppsala.

COBBAN, W. A. (1984): Mid-Cretaceous ammonite zones, Western Interior, United States. – Bull. geol. Soc. Denmark 33: 71–89, Copenhagen.

– (1985): Ammonite record from Bridge Creek Member of Greenhorn Limestone at Pueblo Reservoir State Recreation Area, Colorado. – Soc. Econ. Paleontologists and Mineralogists, Guidebook 4: 135–138, Tulsa.

COBBAN, W. A., S. C. HOOK & W. J. KENNEDY (1989): Upper Cretaceous rocks and ammonite faunas of southwestern New Mexico. – N. Mex. Bur. Mines & Min. Res. Mem. 45: 1–137.

COBBAN, W. A. & G. R. SCOTT (1972): Stratigraphy and ammonite fauna of the Graneros Shale and Greenhorn Limestone near Pueblo, Colorado. – U.S. geol. Surv. Prof. Pap. 645: 1–108.

COURTILLER, [A] (1860): Description (et figures) de trois nouvelles espèces d'ammonites du terrain crétacé des environs de Saumur (étage Turonien) et des ammonites *Carolinus* et *Fleuriausianus* à l'état adulte. – Mém. Soc. d'Agric., Sci., et Arts d'Angers 3: 246–252.

EICHER, D. L. & R. DINER (1985): Foraminifera as indicators of water mass in the Cretaceous Greenhorn Sea, Western Interior.·Soc. Econ Paleontologists and and Mineralogists, Gurdehook 4: 60–71; Tulsa.

EINSELE, G, (1982): General remarks about the nature, occurrence, and recognition of cyclic sequences (periodites). – In: EINSELE, G. & A. SEILACHER (Eds.): Cyclic and Event Stratification: 3–7. Springer Verlag, Berlin etc.

ELDER, W. P. (1985): Biotic patterns across the Cenomanian-Turonian extinction boundary near Pueblo, Colorado. – Soc. Econ. Paleontologists and Mineralogists, Guidebook 4: 157–169, Tulsa.

– (1987): The paleoecology of the Cenomanian-Turonian (Cretaceous) stage boundary extinctions at Black Mesa, Arizona. – Palaios, 2: 24–40, Tulsa.

– (1988): Geometry of Upper Cretaceous bentonite beds: implications about volcanic source areas and paleowind patterns, western interior, United States. – Geology 16: 835–838, Boulder.

– (1989): Molluscan extinction patterns across the Cenomanian-Turonian Stage boundary in the Western Interior of the United States: Paleobiology, 15, no. 3: 299–320.

FISCHER, A. G., T. HERBERT & I. PREMOLI SILVA (1985): Carbonate bedding cycles in Cretaceous pelagic and hemipelagic sediments. – Soc. Econ. Paleontologists and Mineralogists, Guidebook 4: 1–10, Tulsa.

GILBERT, G. K. (1895): Sedimentary measurement of Cretaceous time. – J. Geol. 3: 121–127, Chicago.

GRACIANSKY, P. C. DE, J. P. DEROO, J. P. HERBIN, L. MONTADERT, C. MULLER, A. SCHAAF & J. SIGAL (1984): Ocean-wide stagnations episode in the Late Cretaceous. – Nature 308: 346–349, London.

HANCOOCK, J. M. (1984): Some possible boundary stratotypes for the base of the Cenomanian and Turonian Stages. – Bull. geol. Soc. Denmark 33: 123–128, Copenhagen.

HART, M. B. & K. C. BALL (1986): Late Cretaceous anoxic events, sea-level changes and the evolution of the planktonic formanifera. – Geol. Soc. Spec. Publ. 21: 67–78, Oxford.

HATTIN, D. E. (1971): Widespread, synchronously deposited, burrow-mottled limestone beds in Greenhorn Limestone (Upper Cretaceous) of Kansas and southeastern Colorado. – Bull. Am. Assoc. Petrol. Geol. 55: 412–431, Chicago.

– (1975): Stratigraphy and depositional environment of Greenhorn Limestone (Upper Cretaceous) of Kansas. – Bull. Kans. Univ. geol. Surv., 209: 128 p., Topeka.

– (1979): Regional stratigraphy of limestone marker beds in Bridge Creek Limestone Member, Greenhorn Limestone (Upper Cretaceous), Western Interior United States. – Bull. Am. Assoc. Petrol. Geol. 63: 464, Chicago.

– (1985): Distribution and significance of widespread, time parallel pelagic limestone beds in Greenhorn Limestone (Upper Cretaceous) of the central Great Plains and southern Rocky Mountains. – Soc. Econ. Paleontologists and Mineralogists, Guidebook 4: 28–37, Tulsa.

HEINZ, R. (1928): Über die Oberkreide-Inoceramen Süd-Amerikas. – Mitt. miner.-geol. St. Inst. Hamb. 10: 41–97, Hamburg.

– (1935): Unterkeide-Inoceramen von der Kapverden-Insel Maio: – N. Jahrb. Min., Geol. u. Paläontol. Beil.-Bd 73: 302–311.

HERBIN, J. P., L. MONTADERT, C. MULLER, R. GOMEZ, J. THUROW & J. WIEDMANN (1986): Organic-rich sedimentation at the Cenomanian-Turonian boundary in oceanic and coastal basins in the North Atlantic and Tethys. – Geol. Soc. Spec. Publ. 21: 389–422, Oxford.

HILBRECHT, H. (1986): On the correlation of the Upper Cenomanian and Lower Turonian of England and Germany (Boreal and N. Tethys). – Newsl. Stratigr. 15: 115–138, Berlin, Stuttgart.

JARVIS, I., G. A. CARSON, M. K. E. COOPER, M. B. HART, P. N. LEARY, B. A. TOCHER, D. HORNE & A. ROSENFELD (1988): Microfossils and the Cenomanian-Turonian (Late Cretaceous) Oceanic Anoxic Event. – Cret. Res. 9: 3–103, London etc.

Jarvis, J., C. Carson, M. Hart, P. Leary, B. Tocher (1988): The Cenomanian-Turonian (Late Cretaceous) anoxic event in S.W. England: evidence from Hooken Cliffs, near Beer, S. E. Devon. – Newsl. Stratigr. 18: 147–164, Berlin, Stuttgart.

Jarvis, J. & P. B. Woodroof (1984): Stratigraphy of the Cenomanian and basal Turonian (Upper Cretaceous) between Branscombe and Seaton, SE Devon, England. – Proc. Geol. Ass. 95: 193–215, London.

Jefferies, R. P. S. (1961): The palaeoecology of the *Actinocamax plenus* Subzone (lowest Turonian) in the Anglo-Paris Basin. – Palaeontology 4: 609–647, London.

– (1963): The stratigraphy of the *Actinocamax plenus* Subzone (Turonian) in the Anglo-Paris Basin. – Proc. Geol. Ass. 74: 7–33, London.

Kauffman, E. G. (1978): British Middle Cretaceous inoceramid biostratigraphy. – Ann. Mus. Hist. nat. Nice 4: 1–12, Nice.

– (1984): The fabric of Cretaceous marine extinctions. – In: Berggren, W. A. & J. Van Couvering (Eds.): Catastrophes and earth history – the new uniformitarianism: 151–246. Princeton University Press, Princeton, New Jersey.

Kauffman, E. G. & J. D. Powell (1977): Paleontology. – In: Kauffman, E. G., D. E. Hattin & J. D. Powell: Stratigraphic, paleontologic, and paleoenvironmental analysis of the Upper Cretaceous rocks of Cimarron County, northwestern Oklahoma. – Mem. geol. Soc. Amer. 149: 47–114, New York.

Keller, S. (1982): Die Oberkreide der Sack-Mulde bei Alfeld (Cenoman – Unter-Coniac). Lithologie, Biostratigraphie und Inoceramen. – Geol. Jb. A64: 3–171, Hannover.

Kennedy, W. J., C. W. Wright & J. M. Hancock (1987): Basal Turonian ammonites from west Texas. – Paleontology 30: 27–74.

Leckie, R. M. (1985): Foraminifera of the Cenomanian-Turonian boundary interval, Greenhorn Formation, Rock Canyon anticline, Pueblo, Colorado. – Soc. Econ. Paleontologists and Mineralogists, Guidebook 4: 139–150.

McLaughling, T. G. (1954): Geology and ground-water resources of Baca County, Colorado. – U.S. geol. Surv. Water-Supply Paper 156: 1–232, Washington, D.C.

Moreman, W. L. (1942): Paleontology of the Eagle Ford group of north and central Texas. – J. Paleont. 16: 192–220, Chicago.

Pratt, L. M. (1981): A paleo-oceanographic interpretation of the sedimentary structures, clay minerals, and organic matter in a core of the Middle Cretaceous Greenhorn Formation near Pueblo, Colorado. – Ph.D. Thesis, Princeton University, 176 p.

– (1983): Isotopic studies on organic matter and carbonate in mid-Cretaceous strata near Pueblo, Colorado. – Penrose Conference on Cretaceous paleoclimates, Florissant, Colorado, Excursion Guidebook: 77–98, Boulder.

– (1984): Influence of paleoenvironmental factors on preservation of organic matter in Middle Cretaceous Greenhorn Formation, Pueblo, Colorado. – Bull. Am. Assoc. Petrol. Geol. 68: 1146–1159, Chicago.

– (1985): Isotopic studies of organic matter and carbonate in rocks of the Greenhorn marine cycle. – Soc. Econ. Paleontologists and Mineralogists, Guidebook 4: 38–48, Tulsa.

Pratt, L. M., E. G. Kauffman & W. P. Elder (1983): Paleontological and geochemical resolution of the Cenomanian-Turonian (Cretaceous) extinction event in the Western Interior of North America. – Geol. Soc. Amer. Abstr. Prog. 15: 664.

Pratt, L. M. & C. N. Threlkeld (1984): Stratigraphic significance of $^{13}C/^{12}C$ ratios in mid-Cretaceous rocks of the Western Interior. – Mem. Canad. Soc. Petrol. geol. 9: 305–312, Calgary.

Raup, D. M. & J. J. Sepkoski (1982): Mass extinctions in the marine fossil record. – Science 215: 1501–1503.

Reeside, J. B., jr. (1923): A new fauna from the Colorado group of southern Montana. – U.S. Geol. Surv. Prof. Pap. 132–B: 25–33.

Robaszynski, F., F. Amédro, J. C. Foucher, D. Gaspard, F. Magniez, H. Manivit & J. Sornay (1980): Synthèse biostratigraphique de l'Aptien au Santonien du Boulonnais à partir de sept groupes paléontologiques: Foraminifères, nannoplancton, dinoflagellés et macrofaunes. Zonations micropaléontologiques integrées dans le cadre du Crétacé boréal – nord-européen. – Rev. Micropal. 22: 195–321, Paris.

Schlanger, S. O., M. A. Arthur, H. C. Jenkyns & P. A. Scholle (1987): The Cenomanian-Turonian oceanic anoxic event, I. Stratigraphy and distribution of organic carbon-rich beds and the marine ^{13}C excursion. – Geol. Soc. Spec. Publ. 26: 371–399, Oxford.

Schlanger, S. O. & H. C. Jenkyns (1976): Cretaceous oceanic anoxic events: causes and consequences. – Geol. Mijib. 55: 179–184, Den Haag.

SCHLÜTER, C. (1871–72, 1876): Cephalopoden der oberen deutschen Kreide. – Palaeont. 1871–72, 21, p. 1–120, 1876; 24, p. 121–264.
SCOTT, G. R. (1964): Geology of the Northwest and Northeast Pueblo quadrangles, Colorado. – U.S. Geol. Surv. Misc. geol. Inv. Map I–408: Washington, D.C.
– (1970): Geologic map of the Southwest and Southeast Pueblo quadrangles, Colorado. – U.S. Geol. Surv. Misc. geol. Inv. Map I–597: Washington, D.C.
SEIBERTZ, E. (1979): Biostratigraphie im Turon des SE-Münsterlandes und Anpassung an die internationale Gliederung aufgrund von Vergleichen mit anderen Oberkreide-Gebieten. – Newsl. Stratigr. 8: 111–123, Berlin, Stuttgart.
SORNAY, J. (1982): Inocérames du Saumurois. – Bull. Centres Rech. Expl.-Prod. Elf-Aquitaine 6: 138–140, Pau.
STANTON, T. W. (1894): The Colorado Formation and its invertebrate fauna. – Bull. U.S. geol. Surv. 106: 288 pp., Washington, D.C.
TRÖGER, K. A. (1981): Zu Problemen der Biostratigraphie der Inoceramen und der Untergliederung des Cenomans und Turons in Mittel- und Osteuropa. – Newsl. Stratigr. 9: 139–156, Berlin, Stuttgart.
WATKINS, D. K. (1985): Biostratigraphy and paleoecology of calcareous nannofossils in the Greenhorn Marine Cycle. – Soc. Econ. Paleontologists and Mineralogists Guidebook 4: 151–156, Tulsa.
WIEDMANN, J. (1960): Le Crétacé Supérieur de l'Espagne et du Portugal et ses céphalopodes. – C.R. congrès des Sociétés Savantes-Dijon, 1959: Colloque sur le Crétacé Supérieur français: 709–764, Paris.
– (1964): Le Crétacé Supérieur de l'Espagne et du Portugal et ses céphalopodes. – Estudios geol. Invest. geol. Lucas Mallada 20: 107–148, Madrid.
WOODROOF, P. B. (1981): Faunal and stratigraphic studies in the Turonian of the Anglo-Paris Basin. – Unpublished D. Phil. Thesis, Oxford University: 354 p.
WRIGHT, C. W. & W. J. KENNEDY (1981): The Ammonoidea of the Plenus Marls and the Middle Chalk. – Monogr. Palaeont. Soc. 134: 148 pp., London.

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