Acta Geologica Polonica, Vol. 50 (2000), No. 3, pp. 295-334

Pueblo, Colorado, USA, candidate Global Boundary Stratotype Section and Point for the base of the Turonian Stage of the Cretaceous, and for the base of the Middle Turonian Substage, with a revision of the Inoceramidae (Bivalvia)

W.J. KENNEDY[1], I. WALASZCZYK[2] & W.A. COBBAN[3]

[1]*Geological Collections, Oxford University Museum of Natural History, Parks Road, Oxford OX1 3PW, United Kingdom.*
E-mail: Jim.Kennedy@earth.ox.ac.uk.
[2]*Institute of Geology of the University of Warsaw, Al. Żwirki i Wigury 93, 02-089 Warszawa, Poland. E-mail: walas@geo.uw.edu.pl.*
[3]*70 Estes Street, Lakewood, Colorado 80226, USA*

ABSTRACT:

KENNEDY, W.J., WALASZCZYK, I. & COBBAN, W.A. 2000. Pueblo, Colorado, USA, candidate Global Boundary Stratotype Section and Point for the base of the Turonian Stage of the Cretaceous, and for the base of the Middle Turonian Substage, with a revision of the Inoceramidae (Bivalvia). *Acta Geologica Polonica*, **50** (3), 295-334. Warszawa.

An updated account of the candidate Global Boundary Stratotype Section and Point for the base of the Turonian Stage and the base of the Middle Turonian Substage in the Bridge Creek Member of the Greenhorn Limestone exposed in the Rock Creek Anticline west of Pueblo, Colorado is provided. Key ammonite distributions are revised and marker species illustrated. A taxonomic revision of the uppermost Cenomanian to lower Middle Turonian bivalve family Inoceramidae provides, for the first time, an adequately documented detailed zonation for the interval in the form of five successive partial range zones based on species of the genus *Mytiloides*. These are successive zones of *M. hattini* ELDER (uppermost Cenomanian), *M. puebloensis* n.sp., *M. kossmati* (HEINZ), *M. mytiloides* (MANTELL) (all Lower Turonian) and *M. subhercynicus* (SEITZ) (lower Middle Turonian). The base of the Turonian, defined by the first appearance of the ammonite *Watinoceras devonense* WRIGHT & KENNEDY at the base of bed 86 of the Bridge Creek Member corresponds to the first occurrence of *Mytiloides puebloensis*, and the base of the *puebloensis* Zone. The base of the Middle Turonian, defined by the first occurrence of the ammonite *Collignoniceras woollgari* (MANTELL) in bed 120 of the Bridge Creek Member is just below the first occurrence of *M. subhercynicus* in bed 121, and the base of the *subhercynicus* Zone.

Key words: Cretaceous, Turonian, GSSP, Ammonites, Inoceramids, Stratigraphy, Stable isotopes, Foraminifera.

INTRODUCTION

The purpose of the present document is to provide an updated account of the candidate Global Boundary Stratotype Section and Point (GSSP) for the base of the Turonian Stage of the Upper Cretaceous, and a GSSP for the base of the Middle Turonian Substage, together with a full taxonomic account of the Inoceramidae of the sequence. It arises from the decisions of the Turonian Working Group of the Subcommission on Cretaceous Stratigraphy at its meetings during the Second International Symposium on Cretaceous Stage

Boundaries held in Brussels from September 8-16 1995. A report of the conclusions of the Turonian Working Party was provided by Bengtson (compiler) (1996).

As Bengtson noted, there has long been an informal but well-established usage that the Turonian Stage is best subdivided into three substages, and this was adopted by the Working Party without dissent. At the Brussels meeting, the following proposals were made (Bengtson, 1996):

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

At the Brussels meeting, 28 out of 39 members of the Working Group were present. The result of the subsequent postal ballot on the above proposal was 34 votes in favour (including ballots not returned), 3 votes against the proposal, and 2 abstentions. Two of the negative voters argued that the boundary stratotypes should be selected in Europe where the historical stage stratotypes are, and that the Rock Canyon Anticline section belongs to another palaeobiogeographic region, which may lead to diachronism of boundary stratotypes and stage stratotypes. The third negative voter considered the proposed Rock Canyon Anticline section to be still too poorly known, in particular with respect to microfossil stratigraphy.

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

Following the Brussels meeting a ballot of the 39 members of the Working Group was 33 in favour of the above proposal, 4 against, and 2 abstentions. The grounds for opposition to this second proposal were the same as those for the stage boundary proposal.

It is not the purpose of this contribution to reopen discussions on these boundaries or repeat all of the arguments summarised by Bengtson (1996). Rather, we set out below the required information on the two GSSP's in accordance with the formal requirements set out by Remane & *al.* (1996), together with the first full taxonomic account of the inoceramid bivalves, a key group in the zonation and intercontinental correlation of the boundary intervals.

HISTORICAL BACKGROUND

The definition of the boundary between Cenomanian and Turonian Stages should, as far as possible follow d'Orbigny's views. Wright & Kennedy (1981, p. 126) reviewed this historical evidence, in the context of an ammonite zonal scheme as follows:

LOWER TURONIAN	*Mammites nodosoides* Zone
	Watinoceras coloradoense Zone
UPPER CENOMANIAN	*Neocardioceras juddii* Zone
(part)	*Metoicoceras geslinianum* Zone

They concluded that although d'Orbigny did not define the Cenomanian-Turonian boundary in unmistakable terms, and although there are conflicting data in the *Prodrome* (d'Orbigny 1850) and *Cours Elementaire* (d'Orbigny 1852) (conflicts stressed by Hancock 1984, p. 124), there is an argument that the *Metoicoceras geslinianum* Zone as used by Wright & Kennedy is Cenomanian and the *Mammites nodosoides* Zone as used by Wright & Kennedy is Turonian (other, earlier definitions have regarded the *nodosoides* Zone as including horizons as low as *geslinianum* Zone).

The interval spanning *geslinianum* to *nodosoides* Zones of Wright & Kennedy encompasses most of the proposed markers noted by Birkelund & *al.* (1984) in their summary following the 1983 Copenhagen Meeting, which were:

(a) Base of the *Metoicoceras geslinianum* ammonite Zone, or slightly later appearance of the ammonite *Euomphaloceras septemseriatum*.

(b) Base of the *Pseudaspidoceras flexuosum* ammonite Zone (or better the appearance of some vascoceratid ammonite, possibly *Vascoceras proprium*).

(c) "The appearance of the [ammonite] Assemblage Zone of *Watinoceras coloradoense* is the definition that has been most used by ammonite workers in Europe during the last few years. This level is close to proposal (b) above. However, the nominate subspecies is absent in Europe, and the base of the zone is drawn at a lower level than the base of the zone of the same name in the USA. This lower level probably corresponds to the base of the *P. flexuosum* Zone" (Birkelund & *al*. 1984, p. 12).

(d) Definition on the basis of the *Mytiloides* inoceramid bivalve lineage.

(e) The appearance of a flood of *Mytiloides* at the base of the assemblage zone of *Mammites nodosoides*.

(f) Appearance of the coccolith *Quadrum gartneri* in the ammonite zone of *Neocardioceras juddii*.

(g) The extinction of the planktic foraminiferan genus *Rotalipora* in the *Metoicoceras geslinianum* Zone.

(h) The appearance of the planktic foraminifer *Whiteinella archaeocretacea*.

(i) The appearance of the distinctive Turonian planktic foraminifer *Praeglobotruncana helvetica.*

The only mention of anoxia at this level is the observation that "the distinctive anoxic event of Schlanger & Jenkyns (1976) has recently been shown by Hart & Bigg (1981) to fall within the *W. archaeocretacea* Zone".

The conclusion of Birkelund & *al*. was as follows:

Boundary level: The boundary at the base of the *Pseudaspidoceras flexuosum* Zone gained some support. In the present volume it is recommended in papers by Cobban and by Kennedy. However, *P. flexuosum* has a restricted geographical distribution.

Important support for that boundary is the widespread appearance of early *Mytiloides* as represented by *M. opalensis sensu* Kauffman at the same level, an event which can be traced in both Tethyan and Boreal regions (recommended by Hancock, this volume).

The appearance of *Quadrum gartneri* immediately below, in the *Neocardioceras juddii* Zone and the extinction of *Rotalipora* in the *Metoicoceras geslinianum* Zone further below are world-wide markers."

The Copenhagen Meeting stimulated work on the

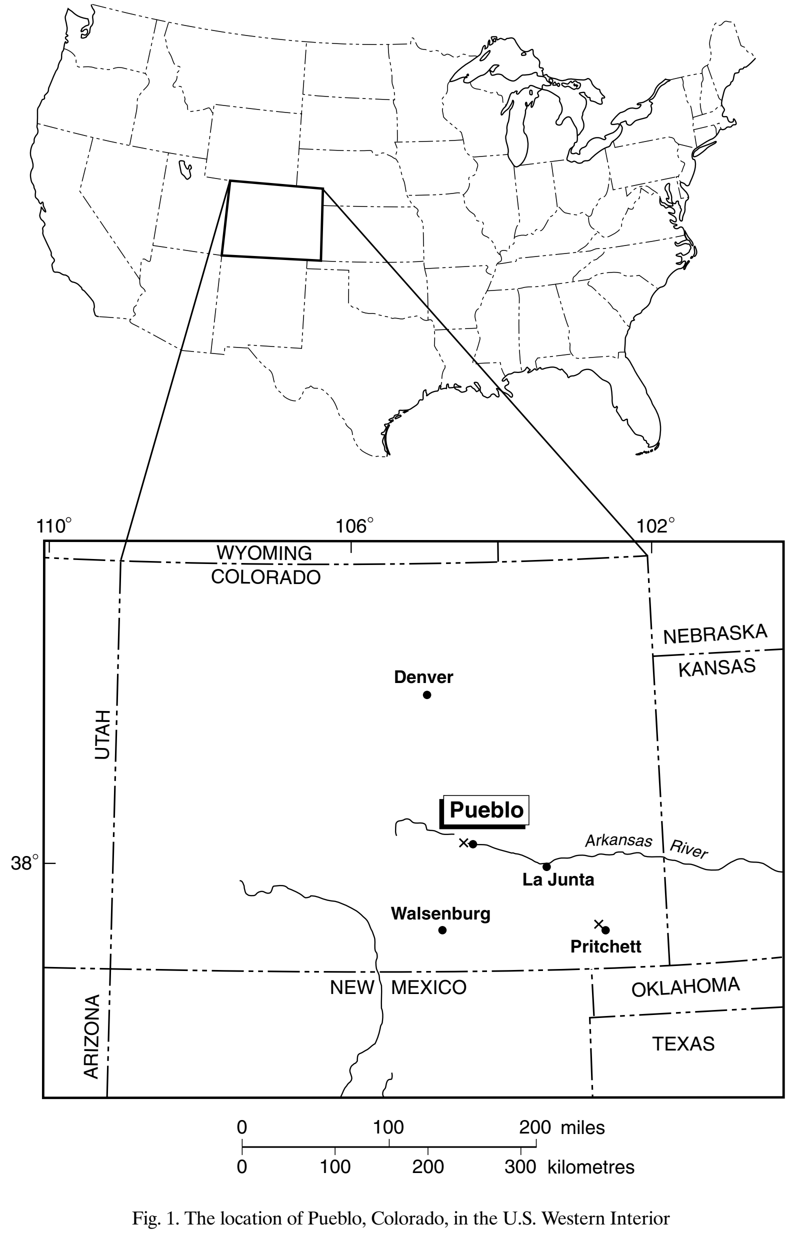


Fig. 1. The location of Pueblo, Colorado, in the U.S. Western Interior

Cenomanian-Turonian boundary, such that it is now recognised as an interval in which a major oceanic anoxic event occurred, and during which a phase of mass extinction is claimed. Work on ammonite faunas in the U.S. Western Interior has produced great refinement of the ammonite zonation across the boundary interval, while biostratigraphic, isotopic, geochemical and radiometric analysis on the section at Pueblo in Colorado (Text-fig. 1) and its correlatives has led to its proposal as a candidate stratotype for the Cenomanian-Turonian boundary.

ROBASZYNSKI (*in* ROBASZYNSKI & GALE 1993, p. 608) has pleaded for stability of zonal nomenclature across the boundary, pointing out that “changes in names of zonal schemes destabilise the accepted biostratigraphic scheme”, in particular with reference to the *Pseudaspidoceras flexuosum* Zone. But stage boundaries should be defined on the range of fossil taxa, as reviewed below. Furthermore, such zonal stability, although desirable can be retrogressive – as would be retention of the *Mammites nodosoides* Zone in the sense of DE GROSSOUVRE, within which several discrete ammonite zones are now recognised.

An ideal section for the Cenomanian-Turonian boundary would encompass all of the biostratigraphic marker levels outlined above, in an expanded succession well-documented with respect to geochemical and isotopic data, and also dated numerically. The section should be permanent, and easily accessible.

The section at Pueblo (Text-figs 1-2; Tables 1-2) fulfils many of these criteria. Known to STANTON (1894), it was mapped by SCOTT (1964, 1970) and ammonite faunas documented by COBBAN & SCOTT (1972), COBBAN (1985), ELDER (1985), KENNEDY & COBBAN (1991) and KENNEDY & *al.* (1999). Inoceramid bivalves are documented by KENNEDY & COBBAN (1991) and ELDER

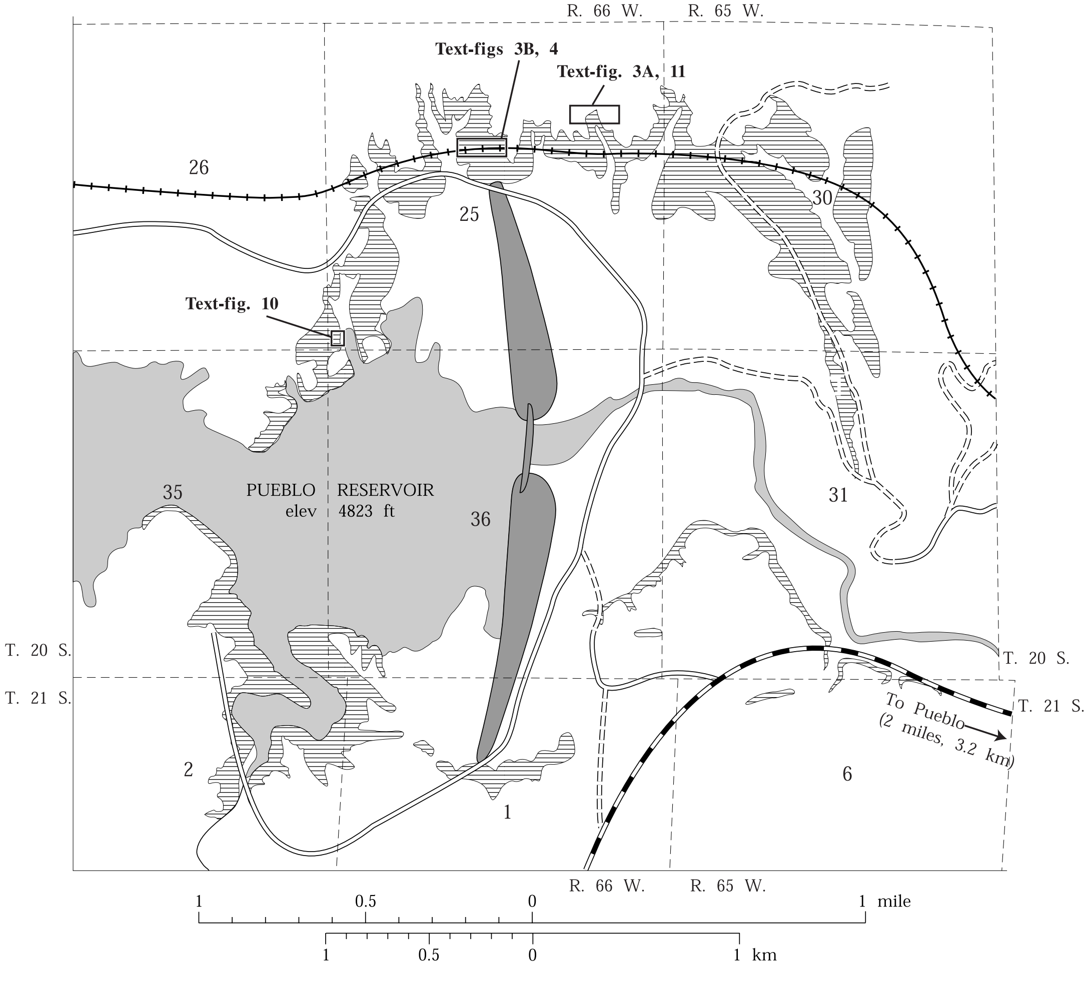


Fig. 2. Geological sketch map of the area around the Pueblo Reservoir, including the proposed global Stratotype Standard Section on the north side of the reservoir, and the Points for the base of the Turonian Stage (Text-figs 3, 4, 11), and the Middle Turonian Substage (Text-fig. 10) (based on SCOTT 1964); numbered localities correspond to sections illustrated in Text-figs 3, 4, 10, 11; horizontal pattern shows outcrop of Greenhorn Limestone

Fig. 3A. Natural exposures of the lower part of the Bridge Creek Member of the Greenhorn Limestone north of the railroad on the north side of the reservoir; see Text-fig. 2 for location. The proposed GSSP for the base of the Turonian Stage is at the base of bed 86 of the Bridge Creek Member of the Greenhorn Limestone; 3B. Cuts of the Denver and Rio Grande Western Railroad at the north boundary of the Pueblo Reservoir State Recreation Area; see Text-fig. 2 for location; this outcrop is a kilometer long, and provides the best and freshest exposures of the proposed GSSP for the base of the Turonian Stage, which is drawn at the base of Bed 86 of the Bridge Creek Member of the Greenhorn Limestone

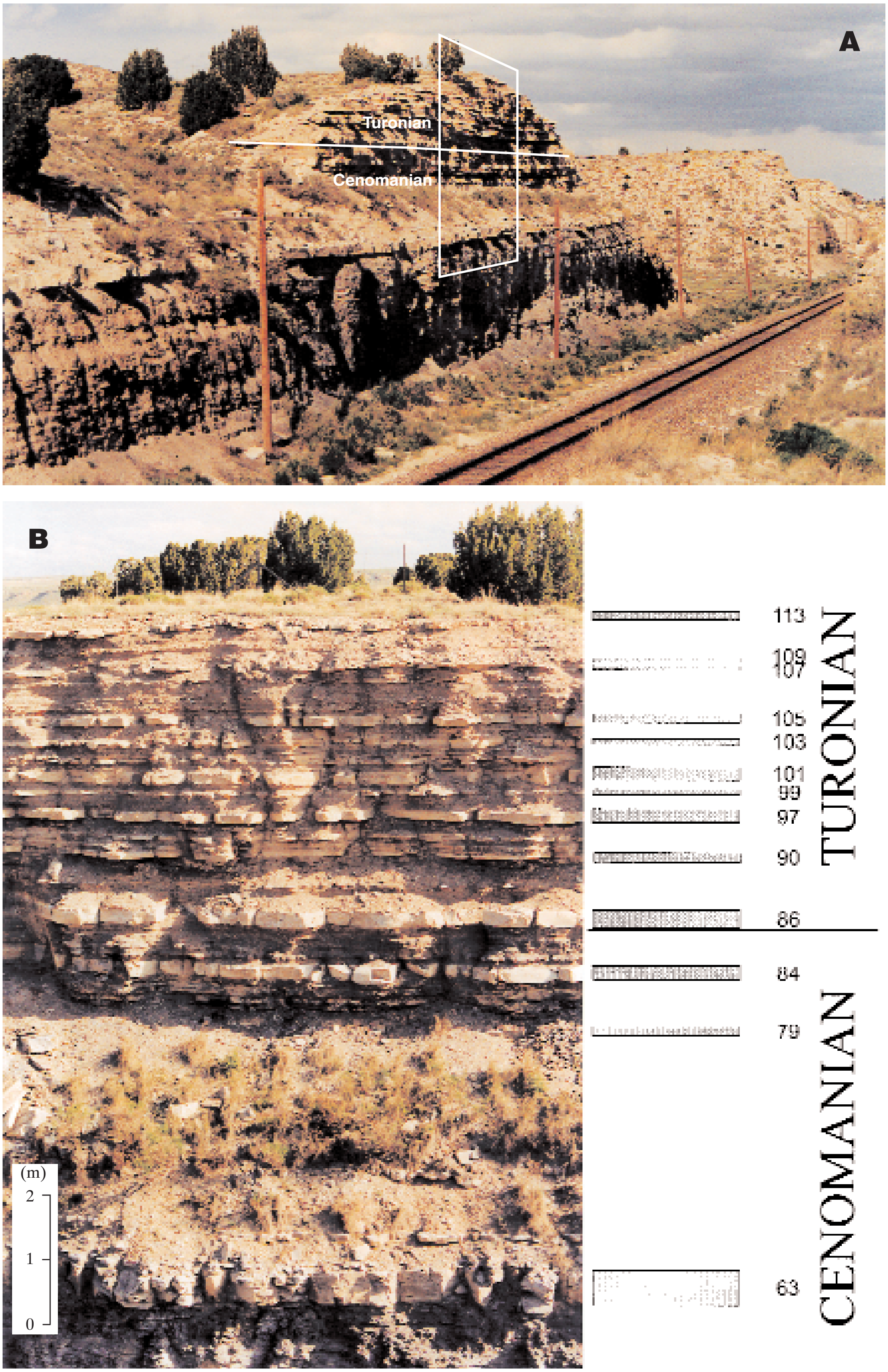


Fig. 4A. Cut on the north side of the Denver and Rio Grande Western Railroad. The proposed GSSP for the base of the Turonian Stage is drawn at the base of bed 86 of the Bridge Creek Member of the Greenhorn Limestone; 4B. Detail of A, showing the proposed GSSP for the base of the Turonian Stage, at the base of bed 86 of the Bridge Creek Member of the Greenhorn Limestone; scale is 1 m long. See Text-fig. 2 for location

Tab. 1. Principal reference section of Bridge Creek Member of the Greenhorn Limestone measured on Rock Canyon anticline in the NW$^{1}/_{4}$NE$^{1}/_{4}$ sec. 31, T. 20 S., R. 65 W., and in the SW$^{1}/_{4}$ and NW$^{1}/_{4}$NW$^{1}/_{4}$ sec. 30. T. 20 S., R. 65 W. Pueblo County, Colorado: from Cobban & Scott, 1973 with inoceramid names updated

		Ft	in	(cm)
	Bridge Creek Member of the Greenhorn Limestone			
150	Calcarenite, shaly to platy; contains some fragments of *Mytiloides* and *Collignoniceras woollgari*		4	(10.2)
149	Shale, calcareous, soft		5	(12.7)
148	Bentonite		$^{1}/_{2}$	(1.3)
147	Shale, calcareous, soft		3	(7.6)
146	Shale, calcareous; contains numerous hard thin partings of calcarenite. Contains some fragments of *Mytiloides*	1	3	(38)
145	Shale, calcareous, soft; contains a few thin partings of calcarenite		5$^{1}/_{2}$	(14)
144	Bentonite		$^{1}/_{2}$	(1.3)
143	Shale, calcareous, hard		4	(10.2)
142	Bentonite, orange-brown, limonitic		2	(5.1)
141	Shale, calcareous, hard and soft		3	(7.6)
140	Bentonite, yellowish-orange; contains selenite crystals		1$^{1}/_{2}$	(3.8)
139	Shale, calcareous, hard, platy		5	(12.7)
138	Shale, calcareous, soft		11	(28)
137	Limestone, shaly; contains fragments of *Ostrea* and *Mytiloides*		2	(5.1)
136	Shale, calcareous, soft		4	(10.2)
135	Limestone, light-gray, shaly USGS D3985 and D3986: *Mytiloides subhercynicus* (Seitz), *Collignoniceras woollgari* (Mantell)		5	(12.7)
134	Shale, gray, calcareous		6	(15.2)
133	Limestone, gray, shaly; top has worm burrows. Contains *Mytiloides subhercynicus* (Seitz)		5	(12.7)
132	Shale, gray, calcareous; contains three hard beds	3	7	(109.2)
131	Shale; medium gray where fresh, orange brown where weathered, soft, calcareous; contains very thin partings of harder shale and calcarenite USGS D3983 at top: *Baculites* cf. *B. yokoyamai* Tokunaga & Shimizu, *Collignoniceras woollgari* (Mantell)	5	0	(152.4)

130	Bentonite, orange-brown		2	(5.1)
129	Shale, calcareous, soft	1	5	(43.2)
128	Bentonite		$\frac{1}{2}$	(1.3)
127	Shale, calcareous, soft		$7\frac{1}{2}$	(19.1)
126	Shale, calcareous; contains thin hard partings of calcarenite and hard shale	2	11	(88.9)
125	Bentonite		$\frac{1}{2}$	(1.3)
124	Shale, calcareous, soft		$3\frac{1}{2}$	(8.9)
123	Calcarenite, shaly; contains fragments of *Inoceramus*		7	(17.8)
122	Limestone, light-gray, massive, chalky		$3\frac{1}{2}$	(8.9)
121	Shale, calcareous, soft	1	2	(35.6)
120	Limestone, gray, hard, irregularly bedded. Forms top of bluff locally USGS D3982: *Mytiloides mytiloides* (Mantell), *Morrowites wingi* (Morrow)		5	(12.7)
	BASE OF MIDDLE TURONIAN			
119	Shale, gray, calcareous		8	(20.3)
118	Limestone, gray, hard, irregularly bedded. Commonly forms top of bluff USGS D3981: *Mytiloides mytiloides* (Mantell), *Baculites* cf. *B. yokoyamai* Tokunaga & Shimizu, *Morrowites wingi* Morrow		8	(20.3)
117	Shale, gray, calcareous		9	(22.9)
116	Limestone, gray, hard, irregularly bedded. Contains *Mytiloides mytiloides* (Mantell)		7	(17.8)
115	Shale, gray, calcareous		10	(25.4)
114	Bentonite, yellowish-orange		3	(7.6)
113	Limestone, gray, hard, irregularly bedded. Contains well-preserved fossils USGS D3980: *Mytiloides mytiloides* (Mantell), *M. ganuzaensis* (López), *M. goppelnensis* (Badillet & Sornay), *Baculites* cf. *B. yokoyamai* Tokunaga & Shimizu		4	(10.2)
112	Shale, gray, calcareous		9	(22.9)
111	Bentonite		1	(2.5)

110	Shale, gray, calcareous	1	1	(33)
109	Limestone, gray, shaly. Contains *Mytiloides* sp.		3	(7.6)
108	Shale, gray, calcareous		5	(12.7)
107	Limestone, gray, shaly. *M. mytiloides* (Mantell), *M. goppelnensis* (Badillet & Sornay),		$2\frac{1}{2}$	(6.4)
106	Shale, gray, calcareous	1	7	(48.3)
105	Limestone, gray, hard, massive to shaly. Fragments of *Puebloites* rather common USGS D3979: *Mytiloides kossmati* (Heinz), *M. labiatus* (Schlotheim), *Puebloites greenhornensis* Cobban & Scott, *Tragodesmoceras bassi* Morrow sp., *Kamerunoceras puebloense*, *Morrowites wingi* (Morrow), *Choffaticeras pavillieri* (Pervinquière)		6	(15.2)
104	Shale, gray, calcareous		9	(22.9)
103	Limestone, gray, shaly, platy; contains baculites		6	(15.2)
102	Shale, gray, calcareous; middle is harder and in part a shaly limestone that contains abundant pelagic Foraminifera and some flattened baculites USGS D6134: *Baculites* cf. *B. yokoyami* Tokunaga of Shimizu	1	5	(43.2)
101	Limestone, gray, hard, somewhat shaly; contains pyrite in places USGS D3978: *Mytiloides kossmati* (Heinz), *Watinoceras coloradoense* Henderson?, *Mammites* sp., *Choffaticeras* sp., *M. labiatus* (Schlotheim)		6	(15.2)
100	Shale, gray, calcareous		8	(20.3)
99	Limestone, gray, shaly		2	(5.1)
98	Shale, gray, calcareous		10	(25.4)
97	Limestone, gray, hard, irregularly bedded; contains horizontal burrows and here and there grayish-green patches and films of montmorillonitic clay that contains small amounts of quartz and pyrite USGS D3977: *Mytiloides kossmati* (Heinz), *M. puebloensis, M. goppelnensis, M. labiatus*, *Ostrea* sp., *Puebloites spiralis* Cobban & Scott, *Watinoceras coloradoense* (Henderson), *W. reesidei* Warren?, *Vascoceras (Greenhornoceras) birchbyi* Cobban & Scott, *Fagesia* sp.		6	(15.2)
96	Shale, gray, calcareous		9	(22.9)
95	Limestone, gray, shaly		3	(7.6)
94	Shale, gray, calcareous		2	(5.1)
93	Limestone, gray, shaly		2	(5.1)

92	Shale, gray, calcareous		2	(5.1)
91	Bentonite		$\frac{1}{2}$	(1.3)
90	Limestone, gray, hard, massive; weathers yellowish gray; contains numerous horizontal burrows filled with limonitic marl that give rock a mottled appearance USGS D3976: *Mytiloides puebloensis, M. kossmati, M. hattini*, *Ostrea* sp., *Baculites* cf. *B. yokoyamai* Tokunaga & Shimizu, *Puebloites* sp.		5	(12.7)
89	Shale, gray, calcareous		10	(25.4)
88	Bentonite		$\frac{1}{2}$	(1.3)
87	Shale, gray, calcareous	1	8	(50.8)
86	Limestone, gray, hard; largely massive but upper few inches shaly; contains abundant pelagic Foraminifera and some mollusks USGS D3975: *Mytiloides hattini* Elder*, M. puebloensis*, *Puebloites*? sp., *Kanabiceras* sp., *Anisoceras* sp.		11	(27.9)
	BASE TURONIAN			
85	Shale, gray, calcareous	2	1	(63.5)
84	Limestone, gray, hard, massive; contains small pyritic spots and abundant pelagic Foraminifera, *Inoceramus pictus*		9	(22.9)
83	Shale, gray, calcareous	1	8	(50.8)
82	Bentonite, rusty		1	(2.5)
81	Shale, gray, calcareous		3	(7.6)
80	Bentonite, orange-gray		6	(15.2)
79	Limestone, gray, hard, massive. Contains a few *Inoceramus pictus*		6	(15.2)
78	Shale, gray, calcareous	2	0	(61)
77	Limestone, gray, nodular, hard, extremely irregular in thickness (3-6 in.); weathers light tan. Fossils sparse USGS D3974: *Sciponoceras* sp., *Euomphaloceras septemseriatum* (Cragin), *Worthoceras verniculus* (Shumard)		6	(15.2)
76	Shale, gray, calcareous		3	(7.6)
75	Limestone, gray, nodular, concretionary (commonly lensing out); may be as thick as 2 in (5.8 cm)		1	(2.5)

74	Shale, gray, calcareous		7	(17.8)
73	Limestone, gray, nodular, rather soft and unbedded; contains burrows as much as 1 in. in diameter. Thickness ranges from 3 to 6 in USGS Mesozoic locality D4444: Echinoid, *Inoceramus pictus* Sowerby, *Sciponoceras gracile* (Shumard), *Camptonectes* sp., *Pseudocalycoceras* sp., *Euomphaloceras septemseriatum* (Cragin)		5	(12.7)
72	Shale, gray, calcareous		4	(10.2)
71	Bentonite		1	(2.5)
70	Shale, gray, calcareous		2	(5.1)
69	Bentonite, yellowish-orange, limonitic		7	(17.8)
68	Shale, gray, calcareous		9	(22.9)
67	Limestone, gray, hard, nodular, concretionary USGS D3973 and D6472: *Holaster feralis* Cooke, *Inoceramus pictus, Camptonectes* sp., Gastropods (sparse), *Metaptychoceras reesidei* Cobban & Scott, *Sciponoceras gracile* (Shumard), *Allocrioceras annulatum* (Shumard), *Puebloites corrugatus* (Stanton), *Pseudocalycoceras angolaense* (Douvillé), *Euomphaloceras septemseriatum* (Cragin), *Metoicoceras geslinianum* (d'Orbigny)		6	(15.2)
66	Shale, gray, calcareous		6	(15.2)
65	Limestone, gray		2	(5.1)
64	Shale, gray, calcareous		3	(7.6)
63	Limestone, gray, hard, massive; weathers light gray and forms conspicuous ledge USGS D3972 and D6473: *Inoceramus pictus* Sowerby, *Calycoceras* cf. *C. naviculare* (Mantell), *Metoicoceras* sp.	1	6	(45.7)
	Total Bridge Creek Member (rounded)	57	0	17.4 meters

(1991), and are comprehensively reviewed below; planktic foraminifera by Eicher & Diner (1985), dinoflagellates by Dodsworth (2000), calcareous nannofossils by Watkins (1985) and Bralower (1988), stable isotopes by Pratt (1981, 1983, 1984, 1985, Pratt & *al*. 1993, Pratt & Threlkeld 1984), Iridium anomalies by Orth & *al*. (1988), and numerical dating of correlative sections by Obradovich (1993). Elder (1985, 1987), Harries & Kauffman (1990), and Harries (1993) discuss extinctions across the interval, and there is much valuable and additional information in Pratt & *al.* (1985).

The succession at Pueblo shows no obvious signs of condensation or non-sequence across the boundary interval and consists of diagenetically modified limestone-marl Milankovitch cycles, individual limestone and marl beds of which can be correlated across tens of thousands of square kilometres in the U.S. Western Interior (e.g. Hattin 1971).

FORMATION	MEMBER	THICKNESS AND LITHOLOGY
CARLILE SHALE	JUANA LOPEZ	0 - 0.6 m (2 ft) fetid calcarenite (dark shale)
	CODELL SST	91.5 m (30 ft) cliff forming sandstone
	BLUE HILL SHALE	30.8 m (101 ft) dark grey, hard to soft blocky shale; sandy in upper half, with two layers of large septarian concretions
GREENHORN LIMESTONE	FAIRPORT CHALKY SHALE	30.2 m (99 ft) grey to yellowish-brown soft bentonitic platy calcareous shale
	BRIDGE CREEK LIMESTONE	15.8 m (52 ft) hard, grey, shaly weathering limestones, interbedded with soft calcareous shale and bentonite
	HARTLAND SHALE	18 m (59 ft) dark grey calcareous shale with thin layers of calcarenite and bentonite
	LINCOLN LIMESTONE	11.6 m (38 ft) grey limestone-shale alternations with bentonite beds
GRANEROS SHALE		31.4 m (103 ft) dark-grey fissile soft to medium-hard non-calcareous shale with numerous bentonite beds

Tab. 2. The Graneros Shale to Carlile Shale west of Pueblo, Colorado (*modified after* Scott 1964)

The section at the Rock Canyon anticline lies west of Pueblo, where the Arkansas River cuts through the Cretaceous section (Text-figs 1, 2). As Kennedy & Cobban (1991, p. 10) note, the construction of a dam on the Arkansas River and subsequent development of a State Park (the Pueblo Reservoir Recreation Area) provide easy vehicular access, and although fossil collecting without permit is not possible from natural outcrops in the State Park, relocation of the adjacent Denver and Rio Grande Western Railroad has exposed several kilometres of fresh cuts through the Bridge Creek Member of the Greenhorn Limestone.

Kennedy & Cobban (1991) drew the following conclusion on the Pueblo section: “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 & *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 recognised indirectly even when ammonites are absent".

"Because all of these faunal zones can be recognised 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 adds to the value of the section".

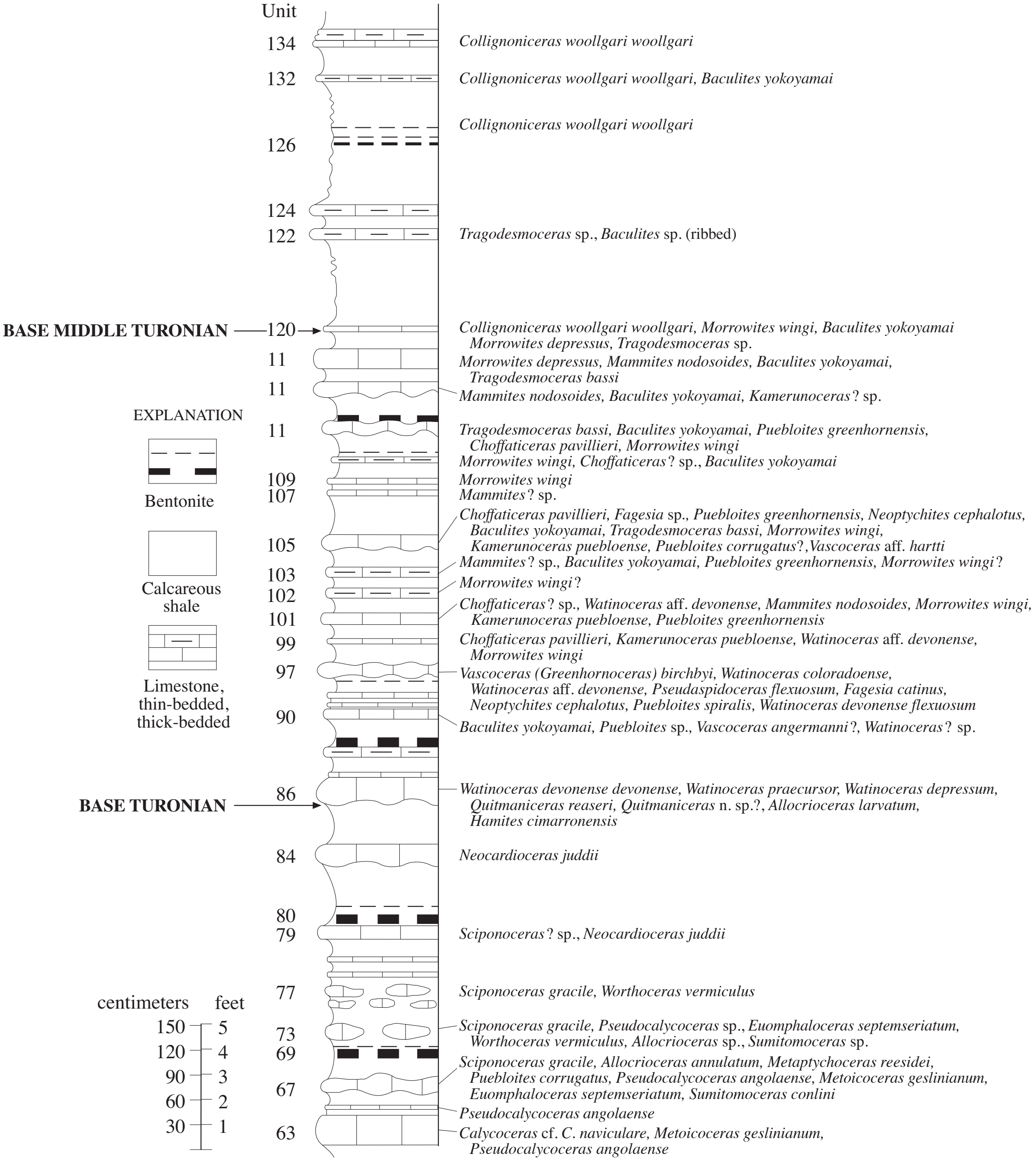


Fig. 5. Lithological succession in the Bridge Creek Member of the Greenhorn Limestone on the north side of Pueblo Reservoir State Recreation Area, in sec. 25, T. 20S., R. 66W., with principal ammonite occurrences marked. The proposed GSSP for the base of the Turonian Stage is drawn at the base of bed 86; the proposed GSSP for the base of the Middle Turonian Substage is drawn at the base of bed 120 (*modified after* KENNEDY & COBBAN 1991)

THE PROPOSED CANDIDATE GLOBAL STRATOTYPE SECTION AND POINT FOR THE BASE OF THE TURONIAN STAGE.

Location: The recommended GSSP is located north and northeast of Pueblo Reservoir, west of Pueblo, Colorado, where the Arkansas River cuts through the Rock Canyon anticline (Text-figs 1-2). The area is semi-arid, with little vegetation cover, and there are semi-continuous exposures throughout most of the outcrop indicated in Text-fig. 2. These outcrops form an arcuate belt several kilometers long mostly in secs. 25, 35, and 36 of T. 20S., R. 66W., and secs. 30 and 31, T. 20S., R. 65W., Northwest Pueblo $7^1/_2$ minute quadrangle, scale 1:24,000, and lie within Townships 20 and 21 South, Ranges 65 and 66 west, latitude 38° North, longitude 104° 30' West.

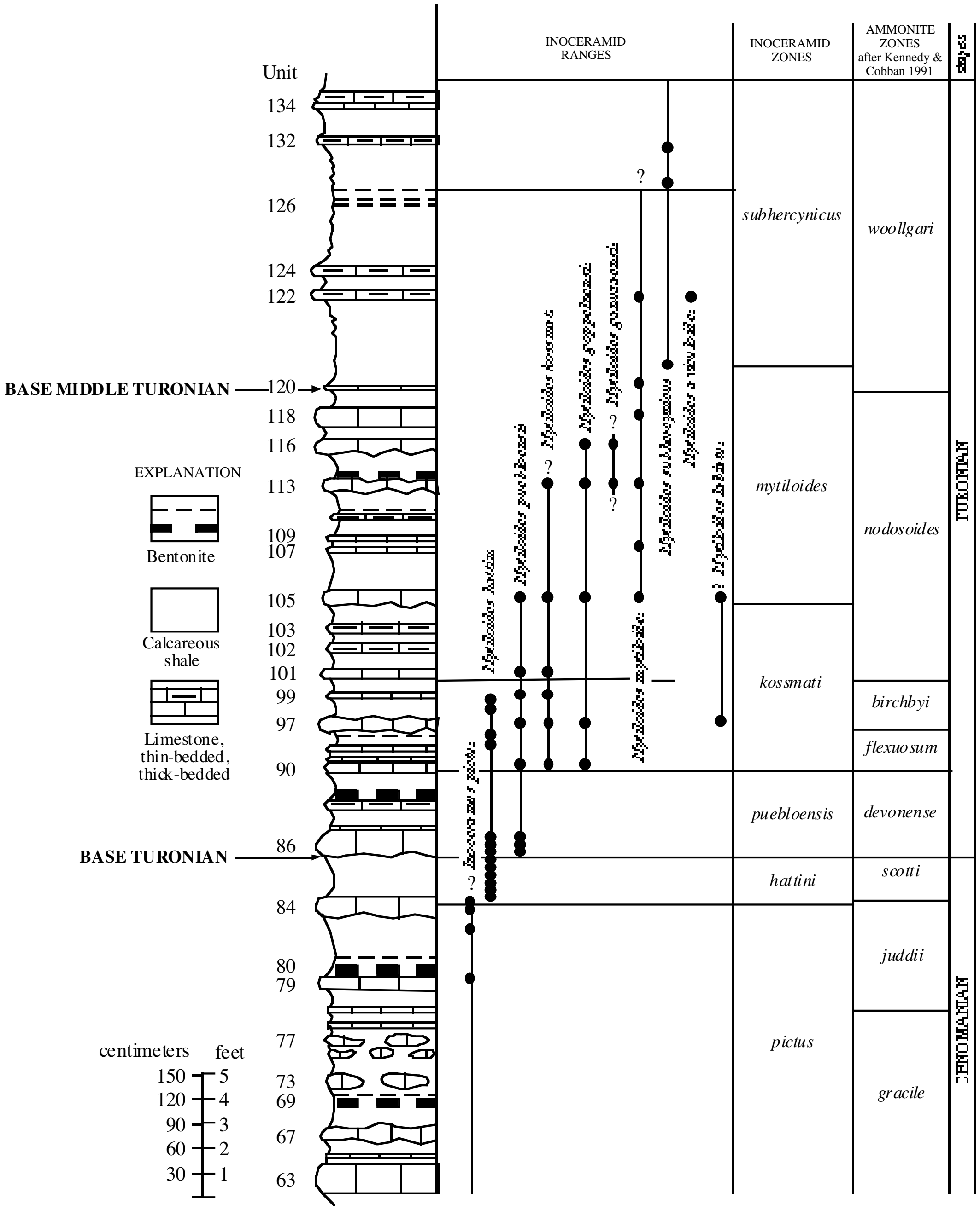


Fig. 6. Lithological succession in the Bridge Creek Member of the Greenhorn Limestone on the north side of the Pueblo Reservoir State Recreation Area, in sec. 25, T. 20S., R. 65W., with ranges of key inoceramid bivalves and proposed inoceramid zonation by Walaszczyk; ammonite zones after Kennedy & Cobban 1991

Access: Following the damming of the Arkansas River, the resultant reservoir has become the focus of the Pueblo State Recreation Area. Vehicular access is now possible by tarmac road, by taking State Highway 96 west from the center of Pueblo. Within the State Recreation Area, permission must be obtained prior to sampling by contacting the Rangers at the Park headquarters. All reasonable requests for collecting are likely to be granted. Roads within the State Recreation Area are all tarmac. Text-fig. 3A shows natural outcrops within the State Recreation Area; Text-figs 3B, 4 show outcrops along the several kilometers of cut of the railroad immediately north of the State Recreation Area. It is these cuts that currently provide the freshest outcrops of the GSSP, which can be traced for several kilometers, both within and outside the State Recreation Area.

Description of the CANDIDATE GSSP: Table 1 is a detailed lithological log of the interval that encompasses the proposed base of the Turonian Stage, and the base of the Middle Turonian substage, which is within the Bridge

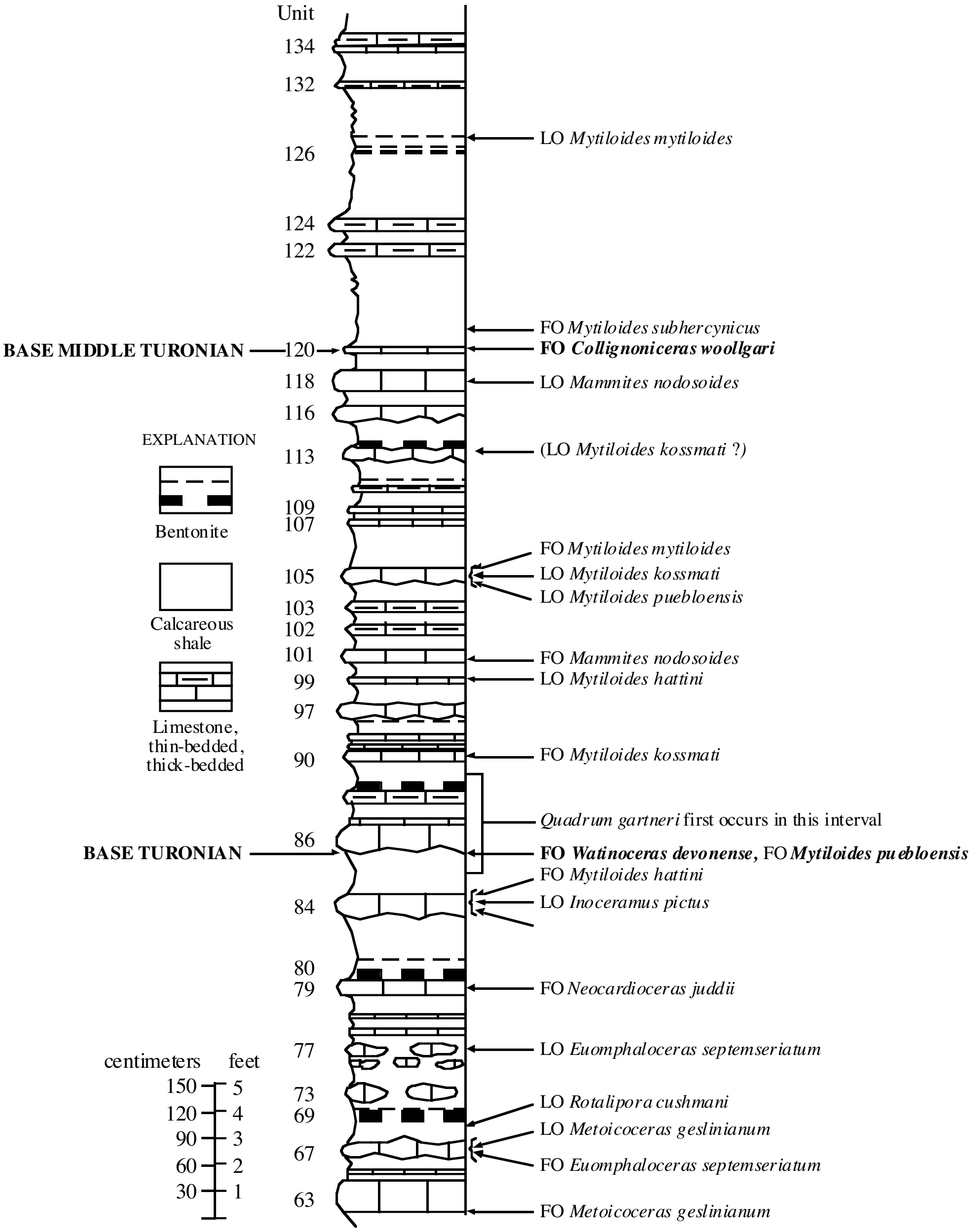


Fig. 7. The primary and secondary markers for the base of the Turonian Stage, and the Upper Turonian Substage, plotted on the outcrop section of the proposed Global Standard Stratotype – section on the north side of Pueblo Reservoir, Colorado; LO = last occurrence; FO = first occurrence

Creek Member of the Greenhorn Limestone (Text-fig. 5). Table 2 puts this unit in its regional lithostratigraphic context.

Text-fig. 5 provides a summary lithostratigraphic section, with the base of the Turonian Stage and Middle Turonian substage indicated, as well as key bed-by-bed ammonite records.

Text-fig. 6 gives our revised data on the distribution of the inoceramid bivalves, key secondary markers in the boundary intervals.

As can be seen from Text-figs 3-5, the basic succession within the Bridge Creek Member is of alternations of limestone and shale; the alternations are in part primary in origin, accentuated by diagenetic redistribution of carbonate. Much of the sequence is bioturbated, with laminated and sublaminated units. Petrographically, the limestones are fossiliferous biomicrites.

The alternations in the Bridge Creek are climatically driven (Milankovitch) cycles, and individual beds are of wide geographical extent. As noted above, HATTIN (1971) was the first to demonstrate their wide distribution, and this was extended by ELDER (1985, 1987), ELDER & KIRKLAND (1985) and others. Individual marker beds can be traced for hundreds of kilometers away from Pueblo, into Kansas, New Mexico, Utah, and Arizona. The Bridge Creek Member is also characterised by the presence of bentonites, and several of these have been traced for equally long distances (ELDER 1988). Detailed descriptions of the lithostratigraphy of the Pueblo sequence are to be found in SCOTT (1964), COBBAN & SCOTT (1972), and in the many papers edited by PRATT & *al.* (1985).

THE BOUNDARY LEVEL: PRIMARY AND SECONDARY BIOSTRATIGRAPHIC MARKERS

The boundary level is taken at the base of bed 86 of the above section (Text-fig 7). This bed is indicated in Text-figs 3 and 4. It is most easily recognised in the field by working up from the lowest, and very prominent limestone of the Bridge Creek Member: Bed 63, and there is a prominent yellow-weathering bentonite (bed 88) 50.4 cm above the top of bed 86. The base of bed 86 corresponds to the first occurrence of the ammonite *Watinoceras devonense* WRIGHT & KENNEDY, 1981 in the section; the characteristic ammonite fauna of bed 86 is shown in Plates 1, 2 and in Pl. 3, Figs 1-7.

Apart from its occurrence at Pueblo, *Watinoceras devonense* also occurs elsewhere in bed 86 in Colorado, and in southern England. There are also a series of secondary biostratigraphic markers for the basal boundary level in the Pueblo section; these are indicated in Text-fig. 7, and, from lowest to highest, are:

1. The first occurrence of the ammonite *Metoicoceras geslinianum* (D'ORBIGNY) at the base of bed 63, and last occurrence in bed 67 (geographic range: Wyoming, Montana, Utah, Colorado, Kansas, Arizona, New Mexico, and Texas in the United States; Mexico, southern England, France, Spain, Germany, Czech Republic, Iran (?), Angola, Nigeria, and, possibly, Morocco).
2. The first occurrence of the ammonite *Euomphaloceras septemseriatum* (CRAGIN) in bed 67 and last occurrence in bed 77 (geographic range; Wyoming, Montana, Utah, Colorado, Kansas, Oklahoma, Arizona, New Mexico, and Texas in the United States; Mexico, southern England, France, Germany, Nigeria, Angola, Japan).
3. The last occurrence of the planktic foraminifer *Rotalipora cushmani* (MORROW) as well as other *Rotalipora* morphotypes in bed 68.
4. The first occurrence of the ammonite *Neocardioceras juddii* (BARROIS & GUERNE) (Pl. 3, Figs 8, 10, 11) in bed 79, and its last occurrence in bed 84 (geographic range: Montana, Colorado, Utah, New Mexico, Arizona, southern England, France, Germany, Czech Republic).
5. The last occurrence of the bivalve *Inoceramus pictus* J. DE C. SOWERBY in bed 84 (geographic range: Wyoming, Montana, Utah, Colorado, Kansas, Oklahoma, Arizona, New Mexico, and Texas in the United States, England, France, Germany, Poland, Czech Republic, Russia, Kazakhstan, Madagascar).
6. The first occurrence of the bivalve *Mytiloides hattini* ELDER (Pl. 4, Figs 7-14; Pl. 5, Figs 1-11) in the topmost part of Bed 84, and last occurrence in the lower part of Bed 99 (geographic range: Colorado, Kansas, Utah, and Arizona in the United States; southern England, France, Spain, Portugal, Germany, Kazakhstan, Russia).
7. The primary marker: the first occurrence of the ammonite *Watinoceras devonense* WRIGHT & KENNEDY, 1981, in bed 86.
8. The first occurrence of the bivalve *Mytiloides puebloensis* WALASZCZYK & COBBAN (Pl. 6, Figs 1-11; Pl. 7, Figs 2, 3, 5-8, 12, 14; Pl. 8, Figs 1-11, 13; Pl. 10, Figs 1, 4, 6-8) in bed 86, and last occurrence in bed 105 (geographic distribution: Colorado, Kansas, New Mexico in the United States; Portugal).
9. The first occurrence of the nannofossil *Quadrum gartneri* PRINS & PERCH-NIELSEN between the middle of bed 85 and the middle of bed 89.
10. The first occurrence of the planktic foraminifer *Helvetoglobotruncana helvetica* (BOLLI) in bed 89.

11. The first occurrence of the bivalve *Mytiloides kossmati* (HEINZ) in bed 90, and last occurrence in bed 105 (geographic distribution: Colorado, Utah, in the United States: Germany, Russia, Kazakhstan, Madagascar and Japan).
12. The first occurrence of the ammonite *Mammites nodosoides* (SCHLÜTER) in bed 101, and its last occurrence in bed 118 (geographic distribution: Montana, Wyoming, Utah, Colorado, South Dakota, Arizona, Kansas, New Mexico, Texas, in the United States; Mexico, England, France, Spain, Germany, the Czech Republic, Romania, Kazakhstan, Iran(?), Lebanon, Israel, Algeria, Tunisia, Morocco(?), Angola, Nigeria, Madagascar, Colombia, Venezuela, Peru, Brazil).
13. The first occurrence of the bivalve *Mytiloides mytiloides* (MANTELL) (Pl. 12, Figs 4, 5, 7-12) in bed 105 (geographic distribution: Montana, Wyoming, South Dakota, Kansas, Oklahoma, Colorado, Utah, Arizona, and New Mexico in the United States; Europe, Western Asia, Madagascar, Japan).
14. DODSWORTH (2000) has recently documented the dinoflagellate cyst biostratigraphy across the Cenomanian-Turonian boundary in the Pueblo section, and noted the disappearance of consistent/common *Litosphaeridium siphoniphorum* (COOKSON & EISENACK) DAVEY & WILLIAMS in bed 73, and the first occurrence of *Heterosphaeridium difficile* (MANUM & COOKSON) IOANNIDES in bed 95.

STABLE ISOTOPE STRATIGRAPHY OF THE BOUNDARY INTERVAL

It is now well-established that the Cenomanian-Turonian boundary interval was characterized by abnormally high rates of burial of organic carbon in the marine realm, leading to a positive (heavy) carbon isotope excursion in the marine carbonate record that defines what has become known as an Oceanic Anoxic Event (OAE II) (SCHLANGER & JENKYNS 1976; JENKYNS 1980; SCHLANGER & *al.* 1987; SCHOLLE & ARTHUR 1980).

This anoxic event and corresponding positive (heavy) carbon stable isotope excursion was demonstrated in the Pueblo sequence by analysis of a core drilled within the Pueblo Recreation area in the NW$^1/_4$ NW$^1/_4$ NE$^1/_4$ Sec. 31, T. 20S., R. 65W. (Text-fig. 2), and comprehensively documented by PRATT (1981, 1983, 1984, 1985) and discussed by PRATT & *al*. (1983), PRATT & THRELKELD (1984), ELDER (1985, 1987), ARTHUR & *al.* (1988), GALE & *al*. (1993), ACCARIE & *al*. (1996) and others.

The δ^{13}Corg (PDB) curve from the core is plotted against the outcrop log of the Cenomanian-Turonian boundary interval in Text-fig. 8. It will be seen that the base of bed 86 falls immediately below the third positive peak in the curve.

It is now known that expanded Cenomanian-Turonian boundary sections in pelagic facies in other parts of the Western Interior (e.g. PRATT 1985; PRATT & *al*.1993), in southern England (GALE & *al.* 1993), northern Spain (PAUL & *al*. 1994), northern Tunisia (ACCARIE & *al*. 1996), and Japan (HAGESAWA 1995) preserve a similarly ornate excursion, and that peaks and troughs in the curve can be correlated between sections. As discussed further below, the succession of many of the biostratigraphic markers around the boundary interval occur in the same sequence in southern England and the Pueblo section, and in the same position relative to the detail of the isotope curve.

RADIOISOTOPIC DATING OF THE BOUNDARY INTERVAL

No less than four prominent bentonites occur in the boundary interval (Text-figs 5, 8), as well as a number of minor bentonitic levels. Integration of biostratigraphy, lithostratigraphy and chemostratigraphy show these bentonites to be widely recognisable throughout the U.S. Western Interior. We have failed to obtain satisfactory dates from the Pueblo section where the bentonites are thin and weathered, but correlative bentonites in Arizona and Nebraska have provided ^{40}Ar/^{39}Ar ages that can be tied to the coeval bentonites in the Pueblo section; identifying numbers in parentheses correspond to those in OBRADOVICH (1993). From oldest to youngest:

(22) Marker bed BM5, 0.9 m bentonite, 5.7 m above base of Mancos Shale (lower calcareous shale member), Lohali Point, Black Mesa, NE Arizona (KIRKLAND 1991, 1996), corresponding to bed 64 Pueblo. 93.90 ± 0.72 Ma.

(21) Marker bed BM6, 22.5 cm bentonite 6.8 m above base of Mancos Shale (lower calcareous shale member), Lohali Point, Black Mesa, NE Arizona (KIRKLAND 1991, 1996), corresponding to bed 69 at Pueblo. 93.49 ± 0.89 Ma.

(20) Bentonite in upper third of *Neocardioceras juddii* Zone in sec. 33, T. 31N., R. 20W., Rocky Point Quadrangle, San Juan County, New Mexico, correlated with bed 80 at Pueblo. 93.78 ± 0.49 Ma; 93.59 ± 0.58 Ma.

(20) Bentonite in Greenhorn Limestone Member, corresponding to HL3 marker bed of HATTIN (1975) and Bed 80 at Pueblo; Alexandria Quadrangle, Little Blue River, in NE$^1/_4$ Sec. 5, T. 2N., R.1N, Thayer County, Nebraska. 93.30 ± 0.4 Ma.

(19) Marker bed BM15, 0.6 m bentonite, 6.4 m above base of Mancos Shale (lower calcareous shale member), Lohali

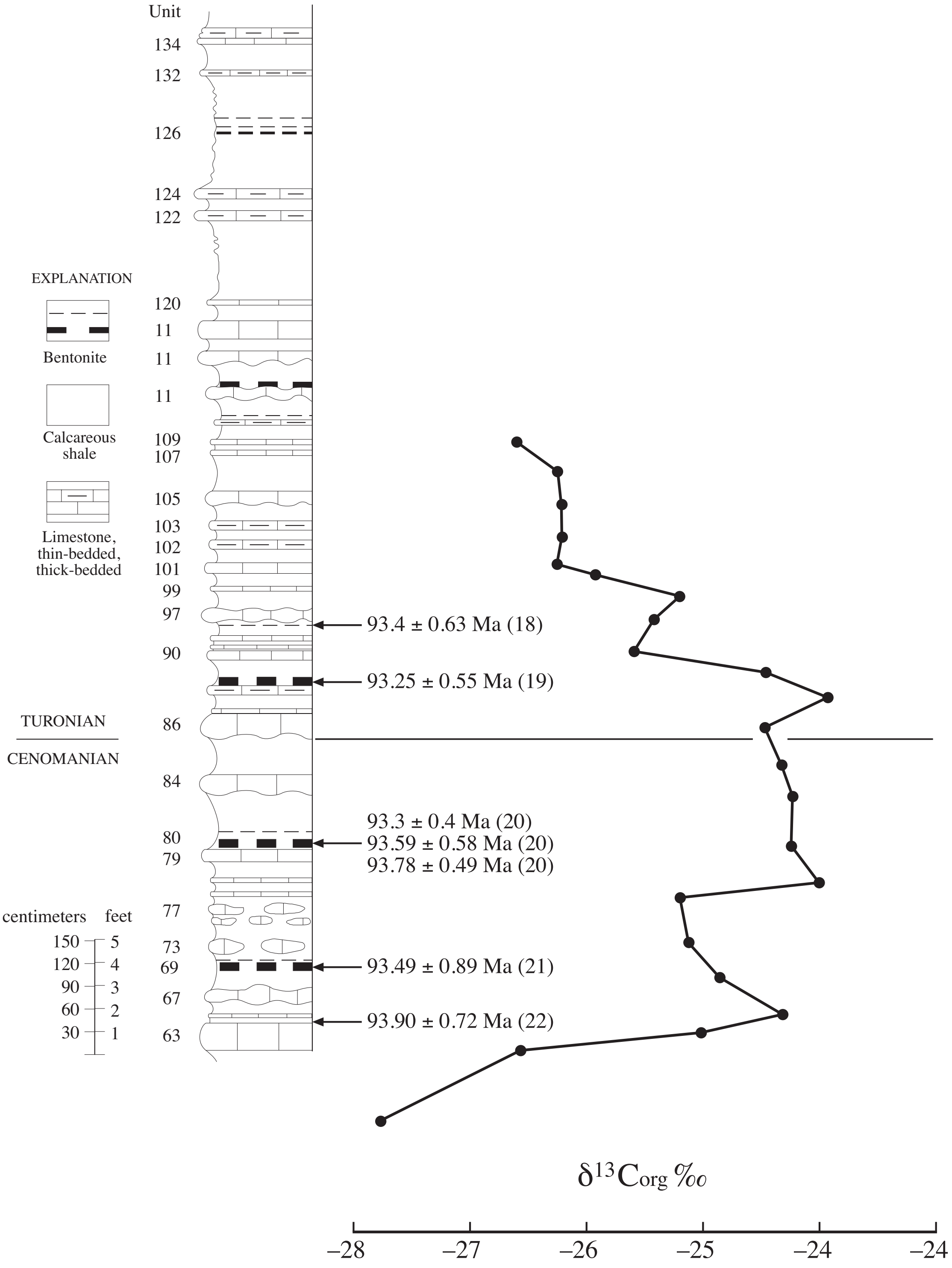


Fig. 8. The δ¹³Corg positive (heavy) excursion as determined in the nearby Pueblo Core plotted against the outcrop section of the Bridge Creek Member of the Greenhorn Limestone on the north side of the Pueblo Reservoir. Isotopic data from PRATT & THRELKELD (1984) and PRATT & *al.* (1993); Also plotted are ^{40}Ar/^{39}Ar ages for correlative bentonites elsewhere in the U.S. Western Interior, from OBRADOVICH (1993); (20) etc. correspond to bentonite samples listed in OBRADOVICH (1993), Table 1

Point, Black Mesa, NE Arizona (KIRKLAND 1991, 1996), corresponding to bed 88 at Pueblo. 93.25 ± 0.5 Ma.

(18) Marker bed BM17, 0.16 m bentonite, 25 m above base of Mancos Shale (lower calcareous shale member), Lohali Point, Black Mesa, NE Arizona (KIRKLAND 1991, 1996), corresponding to bed 96 at Pueblo. 93.40 ± 0.63 Ma.

These radiometric dates are plotted onto Text-fig. 8.

On the basis of these data, OBRADOVICH (1993) dated the Cenomanian-Turonian boundary at 93.3 ± 0.2 Ma; note that dates around the boundary level are not without problems, as discussed by OBRADOVICH. KOWALLIS & *al.* (1995) dated the boundary at 93.1 ± 0.3 Ma.

DISCUSSION: CORRELATION OF BIOSTRATIGRAPHIC MARKERS AND THE $\delta^{13}C$ EXCURSION AROUND THE CENOMANIAN-TURONIAN BOUNDARY

The work of GALE & *al.* (1993) provided a valuable test of the relationship between chemostratigraphy and biostratigraphy across the Cenomanian-Turonian boundary; these authors compared the $\delta^{13}C$ curves at Pueblo, and at Eastbourne in Sussex, England, more than 8000 km to the east. Text-fig. 9 (modified after GALE & *al.* 1993) compares the isotope curves, and the position of 8 floral/faunal markers between the sections. As the authors noted:

"we show the detailed stratigraphy of the Pueblo outcrop set against carbon-isotope data on organic matter obtained from nearby core samples. The resemblance in fine details between this profile and that of Eastbourne is striking".

"Detailed biostratigraphical correlation between Eastbourne and Pueblo can be obtained using the appearances and disappearances of calcareous nannofossils, planktonic foraminiferans, ammonites, and inoceramid bivalves. In ascending order these faunal/floral markers are as follows.

(1) Appearance of the ammonite *Metoicoceras geslinianum* (D'ORBIGNY): in the top of Bed 1 of the Plenus Marl at Eastbourne; Bed 63 at Pueblo (COBBAN 1985).

(2) Disappearance of the planktonic foraminiferan *Rotalipora cushmani* (MORROW): at the top of Bed 3 of the Plenus Marl at Eastbourne (LEARY & PERYT 1991); Bed 68 at Pueblo (LECKIE 1985 [it is now known to extend into Bed 4 of the Plenus Marl at Eastbourne (PAUL & *al.* 1999)].

(3) Disappearance of the calcareous nannofossil *Axopodorhabdus albianus* (BLACK): in Bed 6 of Plenus Marl at Eastbourne (K. COOPER *in* GALE & *al.* 1993); between Beds 72 and 76 at Pueblo (BRALOWER 1988).

(4) Appearance of the ammonite *Neocardioceras juddii* (BARROIS & GUÈRNE): 2 m above base of Melbourn Rock beds at Eastbourne; middle of Bed 78 at Pueblo (ELDER, 1985).

(5) Base of the *Watinoceras devonense* Zone, marked by the disappearance of ammonites of the *N. juddii* Zone at Eastbourne where *Thomelites serotinus* WRIGHT & KENNEDY and *Sciponoceras bohemicum anterius* WRIGHT & KENNEDY disappear 10 cm above Meads Marl 4; at Pueblo the zonal index species *N. juddii* disappears in Bed 84 (KENNEDY & COBBAN 1991), and the base of the *devonense* Zone is at the base of Bed 86. These mark the base of the Turonian stage.

(6) Appearance of bivalve "*Mytiloides* gr. *columbianus* (HEINZ)" [= *Mytiloides kossmati* (HEINZ) herein] "level of Holywell Marl 1 at Eastbourne; base of Bed 90 at Pueblo (KENNEDY & COBBAN 1991).

(7) Appearance of the ammonite *Fagesia catinus* (MANTELL): 0.3 m. above Holywell Marl 2 at Eastbourne; Bed 97 at Pueblo (COBBAN 1985).

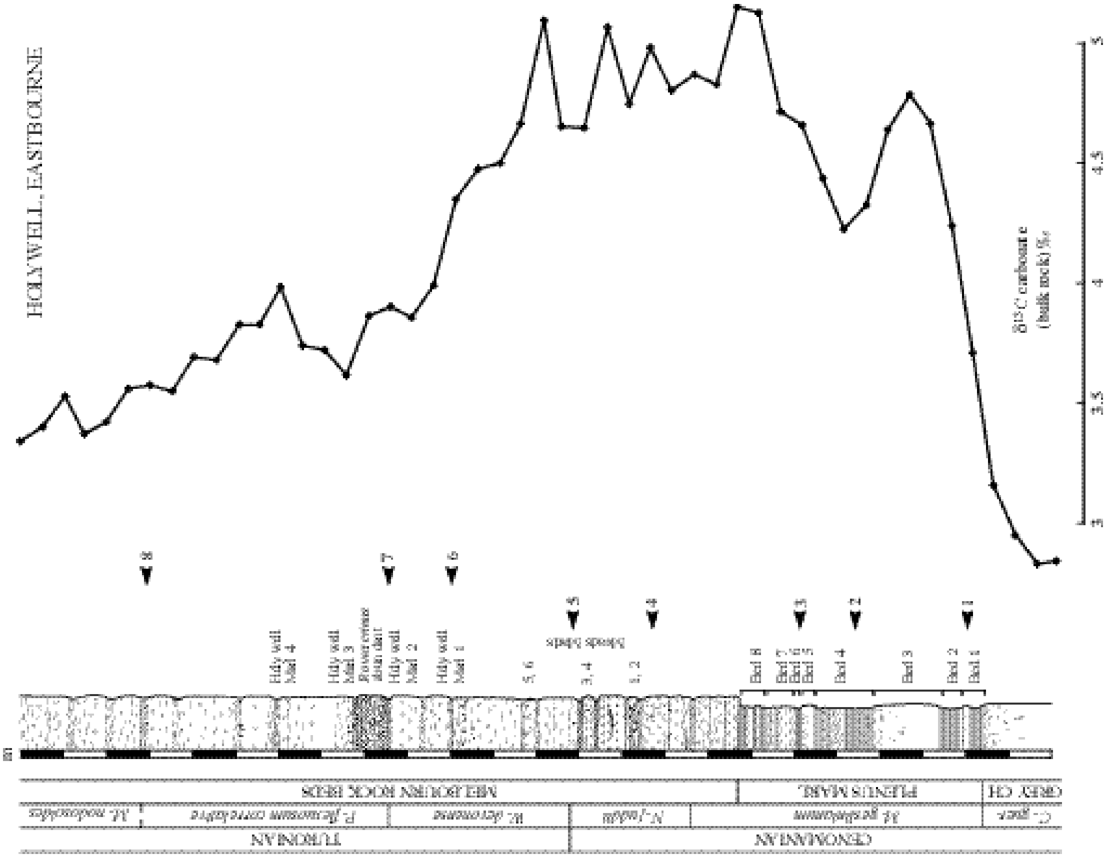
(8) Appearance of ammonite *Mammites nodosoides* (SCHLÜTER): 3-4 m above Holywell Marl 4 at Eastbourne; Bed 101 at Pueblo (COBBAN 1985).

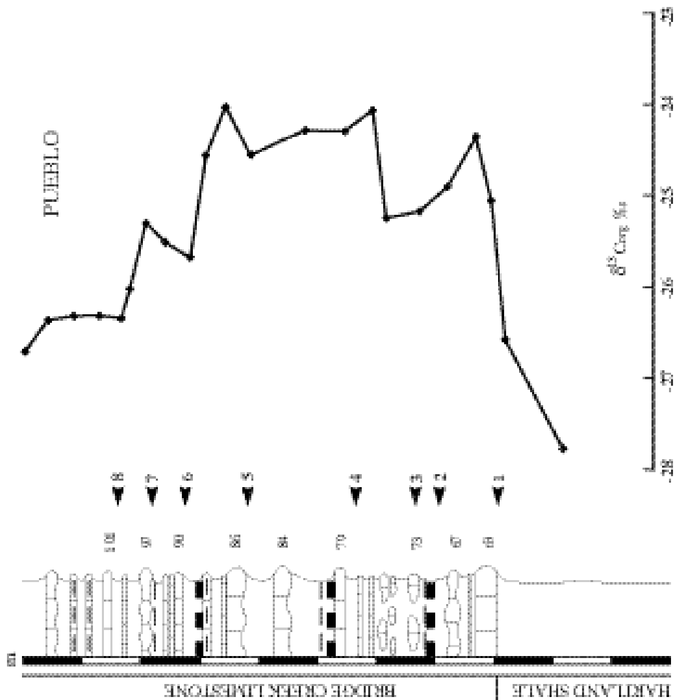
It is important to note that not all taxa common to the two regions have identical ranges. For example, the planktonic foraminiferan *Rotalipora greenhornensis* (MORROW) disappears at the same level as *R. cushmani* at Pueblo, in Bed 68 (LECKIE 1985), but in Europe consistently vanishes at a lower level than the latter species (e.g. JARVIS & *al.* 1988)".

"The fact that biostratigraphical markers among diverse fossil groups occur in the same order at both Pueblo and Eastbourne is persuasive of their likely synchroneity on the scale of tens of thousands of years, although there could conceivably be a systematic displacement between the European and North American sections. More telling is the fact that the 3 peaks of $\delta^{13}C$ on the isotopic curves are in the same positions relative to the 8 faunal and floral events in both sections" (Text-fig. 9 herein).

"The first peak falls between data 1 and 2, the second between 3 and 4, and the highest between 5 and 6. There is also a small subsidiary peak in both sections between data 7 and 8".

"Another area of interest in this context is Tarfaya, Morocco, where the Cenomanian-Turonian boundary interval is particularly thick and organic-carbon-rich (KUHNT & *al.* 1990). Carbon-isotope data from organic matter in core material from this region show a complex peak, similar to those of Eastbourne and Pueblo but with even more detail: the extinction level of *R. cushmani* again occurs below the highest peak in the middle of the excursion. A carbon-isotope profile derived from organic matter of the Livello Bonarelli, Italian Apennines, similarly shows a three-pointed peak across the Cenomanian-


HOLYWELL, EASTBOURNE
δ13C carbonate (bulk rock) ‰
3
3.5
4
4.5
5
CENOMANIAN
TURONIAN
C. guer.
M. geslinianum
N. juddii
W. devonense
F. flexuosum coveralas
M. nodosoides
GREY CH
PLENUS MARL
MELBOURN ROCK BEDS
Bed 1
Bed 2
Bed 3
Bed 4
Bed 5
Bed 6
Bed 7
Bed 8
1, 2
3, 4
5, 6
Meads Marls
Holywell Marl 1
Holywell Marl 2
Holywell Marl 3
Holywell Marl 4
1
2
3
4
5
6
7
8


PUEBLO
δ13C org ‰
-28
-27
-26
-25
-24
-23
CENOMANIAN
TURONIAN
M. mosbyense
S. gracile
N. j.
W. dev.
P. f.
V. b.
M. nodo-
HARTLAND SHALE
BRIDGE CREEK LIMESTONE
63
67
73
79
84
86
90
97
102
1
2
3
4
5
6
7
8

Turonian boundary but the carbonate-free nature of the facies precludes generation of useful stratigraphic data (Arthur & *al*. 1988)".

We conclude that the remarkable correspondence of biostratigraphic and chemostratigraphic events between the Pueblo and Eastbourne U.K. sections confirms the validity of the details of the δ^{13}C isotope excursion as proxies for the base of the Turonian stage in expanded pelagic sequences, and note that Hagesawa (1995) has recently made a precise integrated isotope correlation between the Pueblo section and the Oyubari section, Hokkaido, Japan.

Fig. 9. Outcrops logs and δ^{13}C profiles of expanded Cenomanian-Turonian boundary sections at Eastbourne, Sussex, England, and Pueblo, Colorado compared; note the closely similar detailed structure of the two δ^{13}C curves, with 3 peaks, of which the higher two fall on a plateau; the arrows 1-8 indicate the levels of eight faunal/floral markers that span the boundary interval; they fall into the same sequence in both sections, and lie in the same positions in relation to the detailed structure of the two δ^{13}C curves; in ascending order these markers are: (1) Appearance of the ammonite *Metoicoceras geslinianum* (d'Orbigny, 1850): in the top of Bed 1 of the Plenus Marl at Eastbourne; Bed 63 at Pueblo (Cobban 1985); (2) Disappearance of the planktic foraminiferan *Rotalipora cushmani* (Morrow, 1934): at the top of Bed 3 of Plenus Marl at Eastbourne (Leary & Peryt 1991); Bed 68 at Pueblo (Leckie 1985); (3) Disappearance of the calcareous nannofossil *Axopodorhabdus albianus* (BLACK 1967): in Bed 6 of Plenus Marl at Eastbourne (K. Cooper *in* Gale & *al*. 1993); between Beds 72 and 76 at Pueblo (Bralower 1988); (4) Appearance of the ammonite *Neocardioceras juddii* (Barrois & Guerne, 1878): 2 m above base of Melbourn Rock beds at Eastbourne; middle of Bed 78 at Pueblo (Elder 1985); (5) Base of the *Watinoceras devonense* Zone, marked by the disappearance of ammonites of the *N. juddii* Zone at Eastbourne, where *Thomelites serotinus* Wright & Kennedy, 1981, and *Sciponoceras bohemicum anterius* Wright & Kennedy, 1981. disappear 10 cm above Meads Marl 4; at Pueblo the zonal index species *N. juddii* disappears in Bed 84 (Kennedy & Cobban 1991), and the base of the *devonense* Zone is at the base of Bed 86. These mark the base of the Turonian stage; (6) Appearance of bivalve *Mytiloides kossmati* (Heinz 1930): level of Holywell Marl 1 at Eastbourne; base of Bed 90 at Pueblo (Kennedy & Cobban 1991); (7) Appearance of the ammonite *Fagesia catinus* (Mantell 1822) 0.3 m above Holywell Marl 2 at Eastbourne; Bed 97 at Pueblo (Cobban 1985); (8) Appearance of ammonite *Mammites nodosoides* (Schlüter, 1871): 3-4 m above Holywell Marl 4 at Eastbourne; Bed 101 at Pueblo (Cobban 1985); It is important to note that not all taxa common to the two regions have identical ranges; for example, the planktic foraminiferan *Rotalipora greenhornensis* (Morrow, 1934) disappears at the same level as *R. cushmani* at Pueblo, in Bed 68 (Leckie 1985), but in Europe consistently vanishes at a lower level than the latter species (e.g. Jarvis & *al*. 1988) (*modified after* Gale & *al*. 1993); scale in meters is given to the left of the two columns; with respect to the Eastbourne log, *C. guer.* = *Calycoceras guerangeri* Zone; with respect to the Pueblo log, *N.j.* = *Neocardioceras juddii* Zone; *W. dev.* = *Watinoceras devonense* Zone; *P.f.* = *Pseudaspidoceras flexuosum* Zone; *V.b.* = *Vascoceras birchbyi* Zone; *M. nodo*. = *Mammites nodosoides* Zone

OBJECTIONS TO THE PUEBLO SECTION AS GSSP FOR THE BASE OF THE TURONIAN STAGE

As noted above, three members of the Turonian Working Party of the Cretaceous Subcommission made written objections to the designation of the base Turonian GSSP at Pueblo (Bengston 1996, p.78, under Acknowledgements). These objections were as follows:

1. Two of the negative voters argued that "the boundary stratotypes should be in Europe, where the historical stage stratotypes are". Response: this is not a requirement of the Commission. The detailed correlation between Pueblo in Colorado and Eastbourne in Sussex, England demonstrates the high degree of correlation possible between the proposed GSSP and the Anglo-Paris Basin, in which Eastbourne, Le Mans, type section of the Cenomanian Stage, and the area between Saumur and Montrichard in Touraine, the type section of the Turonian Stage, all lie.
2. "The proposed Rock Canyon Anticline section in Colorado belongs to another palaeobiogeographic region, which may lead to diachronism in boundary stratotypes and stage stratotypes". Response: the type areas of the Cenomanian and Turonian stages lie in the southern part of what European workers term the Boreal Realm. Pueblo, Colorado, lies within what Kauffman (1984 and many subsequent publications) termed the Southern Interior Subprovince. Whatever the differences between the faunal composition of these biotic regions may or may not be, the primary biostratigraphic marker for the base of the Turonian Stage and all 13 of the secondary markers listed above occur not only in the Pueblo section, but also in the Anglo-Paris Basin within the Boreal Realm that also includes the type areas of the Cenomanian and Turonian stages. Indeed, if one considers the Département of Sarthe (in which Le Mans lies), and the sections between Saumur and Montrichard in Touraine, the following secondary markers occur: (1) *Metoicoceras geslinianum* (d'Orbigny); (2) *Euomphaloceras septemseriatum* (Cragin); (3) *Neocardioceras juddii* (Barrois & Guerne); (4) *Inoceramus pictus* J. de C. Sowerby; (6) *Quadrum gartneri* Prins & Perch-Nielsen; (7) *Whiteinella archaeocretacea* Pessagno; (8) *Rotalipora cushmani* (Morrow); (9) *Helvetoglobotruncana helvetica* (Bolli); (10) *Mytiloides kossmati* (Heinz); (12) *Mytiloides mytiloides* (Mantell); (13) *Mammites nodosoides* (Schlotheim).

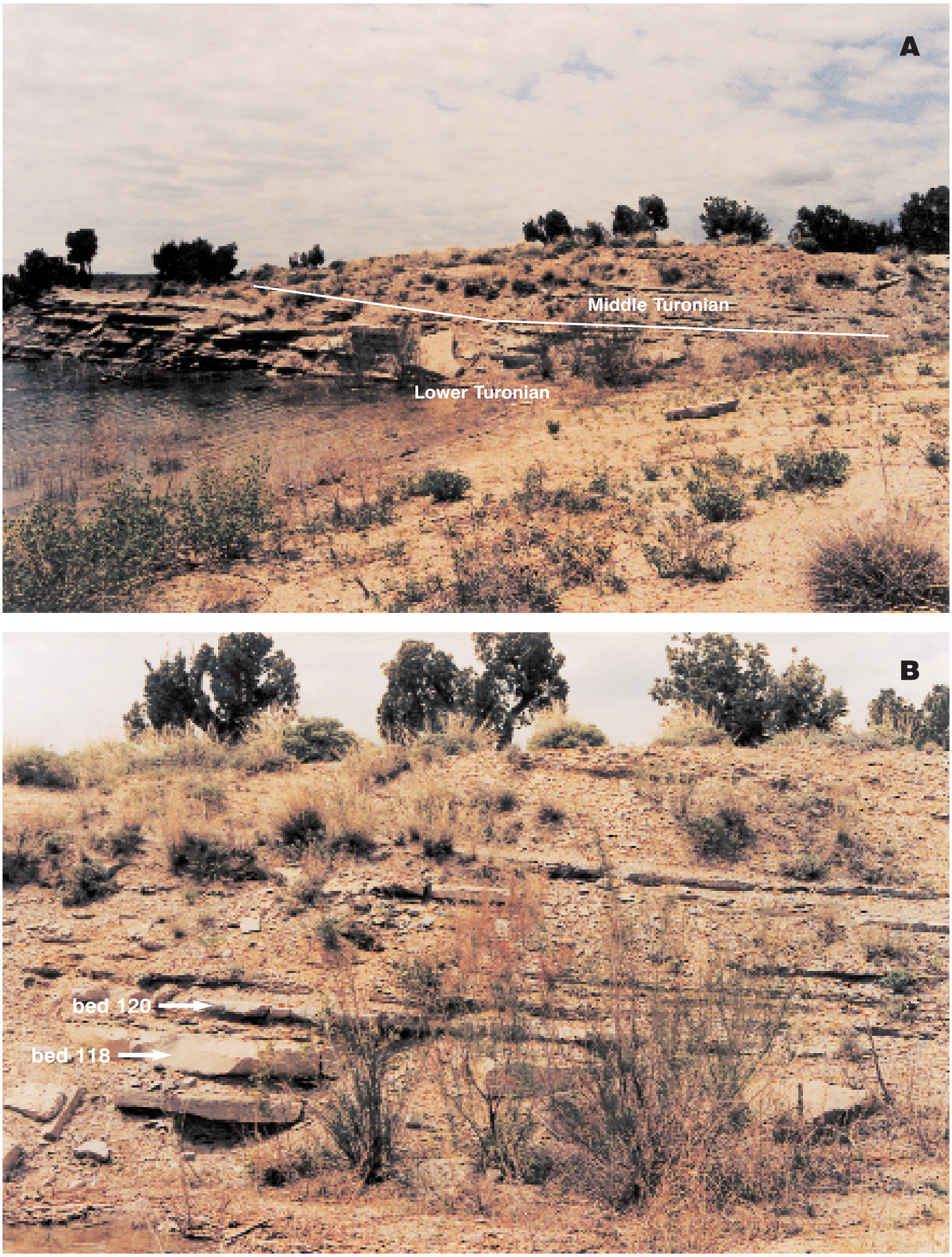


Fig. 10A. Natural outcrop of the proposed Global Standard Stratotype – section and Point for the base of the Middle Turonian substage on the north side of the Pueblo Reservoir, where it is drawn at the base of bed 120 of the Bridge Creek Member of the Greenhorn Limestone in the section shown in Text-fig. 5; see Text-fig. 2 for location of this section; Fig. 10B. Detail of Figure A; the proposed Global Standard Stratotype – section and Point for the base of the Middle Turonian substage is drawn at the base of bed 120

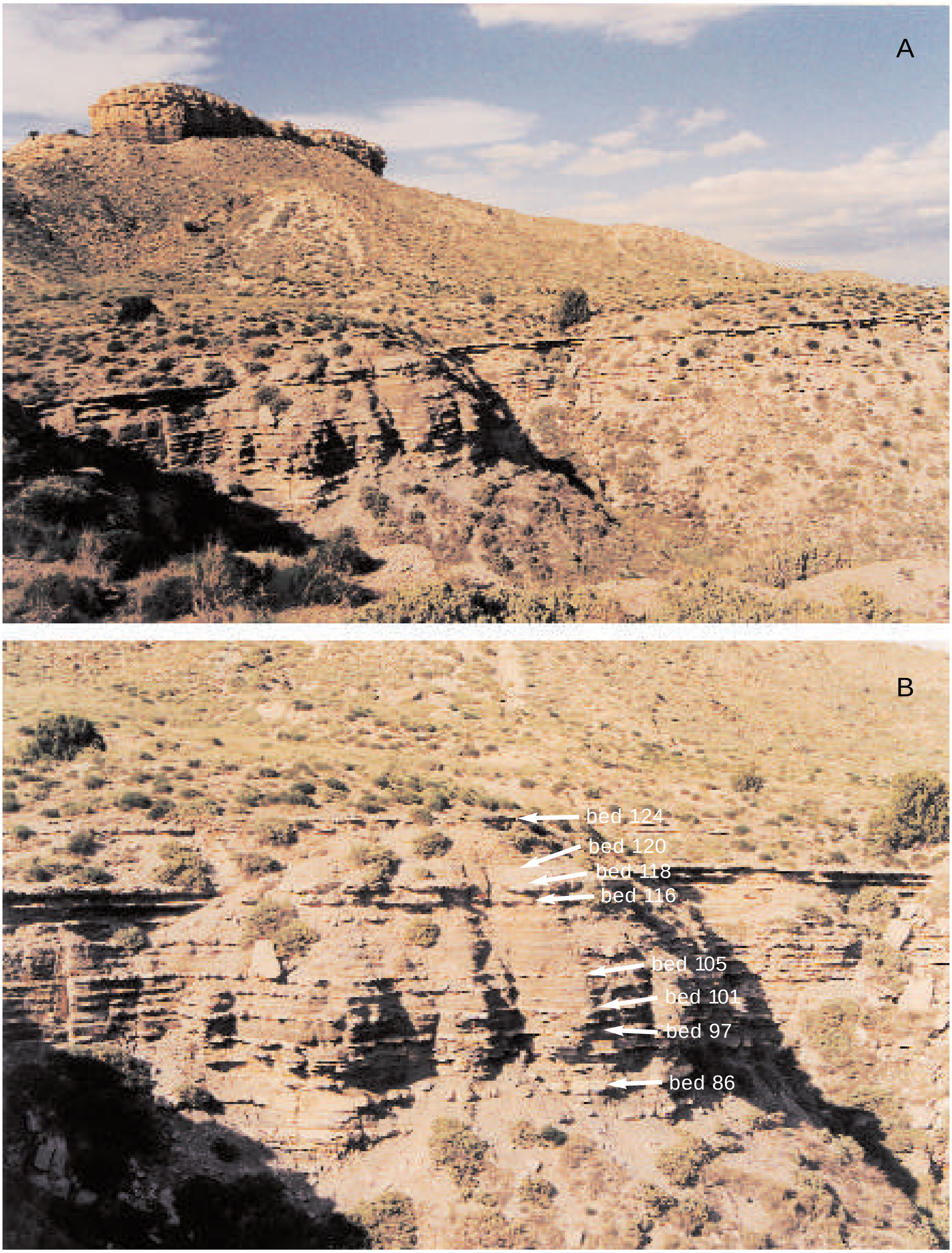


Fig. 11A. Natural exposures of the Bridge Creek Member of the Greenhorn Limestone north of the railroad on the north side of the reservoir; see Text-fig. 2 for location; Fig. 11B. Detail of Figure A. the proposed Global Standard Stratotype – section and Point for the base of the Turonian is drawn at the base of bed 86 and that for the base of the Middle Turonian substage is drawn at the base of bed 120

The primary biostratigraphic marker, *Watinoceras devonense* WRIGHT & KENNEDY has not been recorded in Sarthe; the facies at the critical level lacks originally aragonitic fossils in most sections, although KENNEDY & *al*. (1984) described *Watinoceras* from the region.

We conclude that there is such a high level of co-occurrence of marker taxa between the two areas as to render these objections invalid, and that the likelihood of diachronism is refuted by the correspondence between biostratigraphic markers and the details of the $\delta^{13}C$ curve. We note, however the well-established variance in some microfossil ranges, such as the disappearance of *Rotalipora greenhornensis* (MORROW) at the same level as *R. cushmani* (MORROW) at Pueblo, whereas *R. greenhornensis* disappears at a consistently lower level in Europe (JARVIS & *al*. 1988).

3. One negative voter wrote that "the proposed Rock Canyon Anticline section is still too poorly known, in particular with respect to microfossil stratigraphy". Response: the proposed GSSP is among the best documented Cenomanian-Turonian boundary sections in the world in terms of lithostratigraphy, macrofossil biostratigraphy and chemostratigraphy. Knowledge of micro- and nannofossil distributions can undoubtedly be refined, but this does not in our view disqualify it as a GSSP, given that the distribution of planktic foraminifers, dinoflagellates and coccolithophores has been published.

RECOMMENDED GLOBAL STRATOTYPE SECTION AND POINT FOR THE BASE OF THE MIDDLE TURONIAN SUBSTAGE

Location and Access: The recommended GSSP is located on the north side of the Pueblo Reservoir, west of Pueblo, and is simply a continuation of the section described above; the same terms of access apply.

Description of the GSSP: The GSSP is within bed 120 of the Pueblo section given in the lithological log (Table 1, Text-figs 5, 7), and also shown in Text-fig. 10; it corresponds to the first occurrence of the distinctive ammonite *Collignoniceras woollgari* (MANTELL), examples of which are shown in Pl. 3, Figs 12-14. Bed 120 is a 12.5 cm (5 inch) hard, grey, irregularly bedded limestone, the top surface a plaster of the bivalve *Mytiloides*. It is best recognized in the field by reference to the two prominent limestones (beds 118 and 113) below; the higher is a conspicuous ledge former, the lower is overlain by a bed of bentonite. Both of the marker limestones below bed 120 are also characterised by the abundance of *Mytiloides mytiloides* (MANTELL) (Pl. 12, Figs 4, 5, 7-12), which also occurs in bed 120. The section shown in Text-fig. 10 lies just south of the parking lot on the north side of Pueblo Reservoir, as indicated on Text-fig. 2.

The boundary level primary and secondary markers: As noted above, the primary biostratigraphic marker is the ammonite *Collignoniceras woollgari* (MANTELL) (Pl. 3, Figs 12-14: geographical range: Montana, Wyoming, North and South Dakota, Utah, Colorado, Kansas, Arizona, New Mexico, Texas, California and Oregon in the United States; northern Mexico, England, France, Spain, Germany, Czech Republic, Bulgaria, Kazakhstan, Japan, northern Australia). Secondary biostratigraphic markers are shown in Text-fig. 7:

1. The first occurrence of the bivalve *Mytiloides mytiloides* (MANTELL) (Pl. 12, Figs 4, 5, 7-12) in bed 105, and its last(?) occurrence in bed 130 (geographic distribution Montana, Wyoming, South Dakota, Nebraska, Kansas, Colorado, Utah, Arizona, Oklahoma, New Mexico in the United States; Europe, Western Asia, Madagascar, Japan).
2. The last occurrence of the ammonite *Mammites nodosoides* in bed 118 (geographic distribution: Montana, Utah, Colorado, South Dakota, Kansas, New Mexico, Texas in the United States; northern Mexico, England, France, Spain, Germany, the Czech Republic, Romania, Kazakhstan, Iran, Lebanon, Israel, Tunisia, Algeria, Morocco(?), Angola, Nigeria, Madagascar, Colombia, Venezuela, Peru, Brazil.
3. The first occurrence of the bivalve *Mytiloides subhercynicus* (SEITZ) (Pl. 15, Figs 1-7) in bed 121 (geographic distribution Colorado, Kansas, New Mexico in the United States; Europe: Germany, Spain, France, Poland, Russia).

The GSSP for the base of the Middle Turonian Substage lies within the *Helvetoglobotruncana helvetica* planktic foram Total Range Zone, and the *Quadrum gartneri* nannofossil Zone, as it does in the type area of the Turonian Stage (ROBASZYNSKI & *al*. 1982, fig. 14).

CONCLUSIONS

The candidate Global Boundary Stratotype Sections and Points for the base of the Turonian Stage and the base of the Middle Turonian Substage near Pueblo, Colorado can be seen to fulfill the following requirements set out by REMANE & *al*. (1996):

- Exposures extend over an adequate thickness, and the boundaries are well defined by both primary and secondary (auxiliary) biostratigraphic markers.
- The Pueblo section can be traced laterally over several kilometers distance.
- The pelagic, climatically driven, rhythmically bedded Milankovitch sequence shows no evidence for gaps or for condensation in the proximity of the proposed boundaries.
- The rate of sedimentation is sufficiently high that the successive biostratigraphic and isotopic events used as secondary markers are clearly separated.

- There is no synsedimentary or tectonic disturbance in the boundary intervals.
- Neither metamorphic nor strong diagenetic alternation of the boundary sequences has occurred.
- There is a well-preserved abundant and diverse fossil record across the boundary intervals, with key markers for Turonian intercontinental biostratigraphic correlation: ammonites, inoceramid bivalves, planktic forams, and nannofossils are well-represented.
- There are no prominent facies changes across the boundary levels other than the hemipelagic limestone/marl alternations typical of rhythmically bedded Milankovitch sequences.
- The offshore pelagic Milankovitch facies is ideal for long-distance lithostratigraphic correlation, and this is enhanced by the presence of bentonite horizons.
- The presence of bentonites straddling the boundary levels provides a theoretical basis for direct quantitative calibration of the boundaries. This has not been achieved at Pueblo owing to the thinness of the bentonite beds, but isochronous bentonites elsewhere in the U.S. Western Interior allow indirect dating of the base of the Turonian Stage.
- We have no information on the magnetostratigraphy of the sequence, although it is well-known that the Turonian Stage falls within the Cretaceous Quiet Interval.
- The δ^{13}C excursion across the Cenomanian-Turonian boundary interval has been recognized on a near world-wide basis in both continental and oceanic contexts. The δ^{13}Corg (PDB) profile from a core drilled close to the GSSP for the base of the Turonian stage can be directly correlated with the outcrop log. It is an ornate curve, with three well-defined peaks, and troughs between that can be precisely located with respect to no less than 13 secondary biostratigraphic markers. The δ^{13}C (PDB) curve for an expanded Cenomanian-Turonian boundary interval in pelagic chalk facies at Eastbourne, Sussex, England, more than 8000 km east of the proposed GSSP has a similarly ornate profile, and 8 of the secondary biostratigraphic marker events occur in both sections in the same relative order, and in the same relative position to the peaks and troughs in the δ^{13}C (PDB) curves, indicating that biostratigraphic and isotopic markers were synchronous in the two widely separated locations.
- The GSSP's are easily accessible by metalled road.
- They lie within a State Park where they are protected, with small access charge.

If the GSSP's are adopted, the Commission should seek the collaboration of the United States Geological Survey and the Colorado Division of Parks and Outdoor Recreation with a view to establishing permanent markers at appropriate points on the boundary sections.

MEASUREMENTS OF SPECIMENS

Measurements for selected inoceramid specimens described below are given in Table 3. Explanations of symbols used see Text-fig. 12.

REPOSITORIES OF SPECIMENS

All specimens described here are housed in the U.S. National Museum of Natural History in Washington D.C., and have been assigned USNM numbers.

DETAILS OF LOCALITIES MENTIONED IN THE TEXT

The fossils described in this report came from a number of localities, mostly in southeastern Colorado. The US Geological Survey (USGS) Mesozoic locality numbers, collector(s), year of collection, and localities are as follows:

D3975. G.R. Scott and W.A. Cobban, 1961. West of Pueblo in the SW$^1/_4$ sec. 30, T. 20 S, R. 65 W, Pueblo County, Colorado, Bridge Creek Limestone Member, bed 86.

D10176. W.A. Cobban, 1977. Center of sec. 25, T. 20 S, R. 66 W, Pueblo County, Colorado, bed 86.

D12460. W.A. Cobban, 1984. NE$^1/_4$ sec. 25, T. 20 S, R. 66 W, Pueblo County, Colorado, bed 86.

D12715. W.A. Cobban, 1986; W.A. Cobban and W.J. Kennedy, 1987. Northwest of Pritchett in the SE$^1/_4$ sec. 1, T. 30 S, R. 50 W, Baca County, Colorado.

D13246 W.P. Elder and J.I. Kirkland, 1985. South of Deora in the SE$^1/_4$ sec. 14, T. 29 S, R. 49 W, Baca County, Colorado.

D 3976 G.R. Scott and W.A. Cobban, 1961. SE $^1/_4$ SE $^1/_4$ SW $^1/_4$ sec. 30, T. 20 S., R 65 W., Pueblo County, Colorado, Bridge Creek Limestone Member, bed 90.

D 6147 W.H. Birchby. Boggs Creek in the NW $^1/_4$ NW $^1/_4$ sec. 1, and NW $^1/_4$ – NE $^1/_4$ sec. 2, T. 21 S., R. 66 W., Pueblo County, Colorado, Bridge Creek Limestone Member, bed 101.

D 3977 G.R. Scott and W.A. Cobban, 1961. SE $^1/_4$ SE $^1/_4$ SW $^1/_4$ sec. 30, T. 20 S., R 65 W., Pueblo County, Colorado, Bridge Creek Limestone Member, bed 97.

D 3980 G.R. Scott and W.A. Cobban, 1961. SE $^1/_4$ SE $^1/_4$ SW $^1/_4$ sec. 30, T. 20 S., R 65 W., Pueblo County, Colorado, Bridge Creek Limestone Member, bed 113.

D 4305 G.R. Scott. SW $^1/_4$ NE $^1/_4$ sec. 25, T. 20 S., R 66 W., Pueblo County, Colorado, Bridge Creek Limestone Member, bed 105.

D 12461 W.A. Cobban, 1984. SW $^1/_4$ NE $^1/_4$ sec. 25, T. 20 S., R. 66 W., Pueblo County, Colorado. Bed 90 of Greenhorn Limestone section.

D 11758 R.E. Burkholder & W.A. Cobban, 1982. W $^1/_2$ SW $^1/_4$

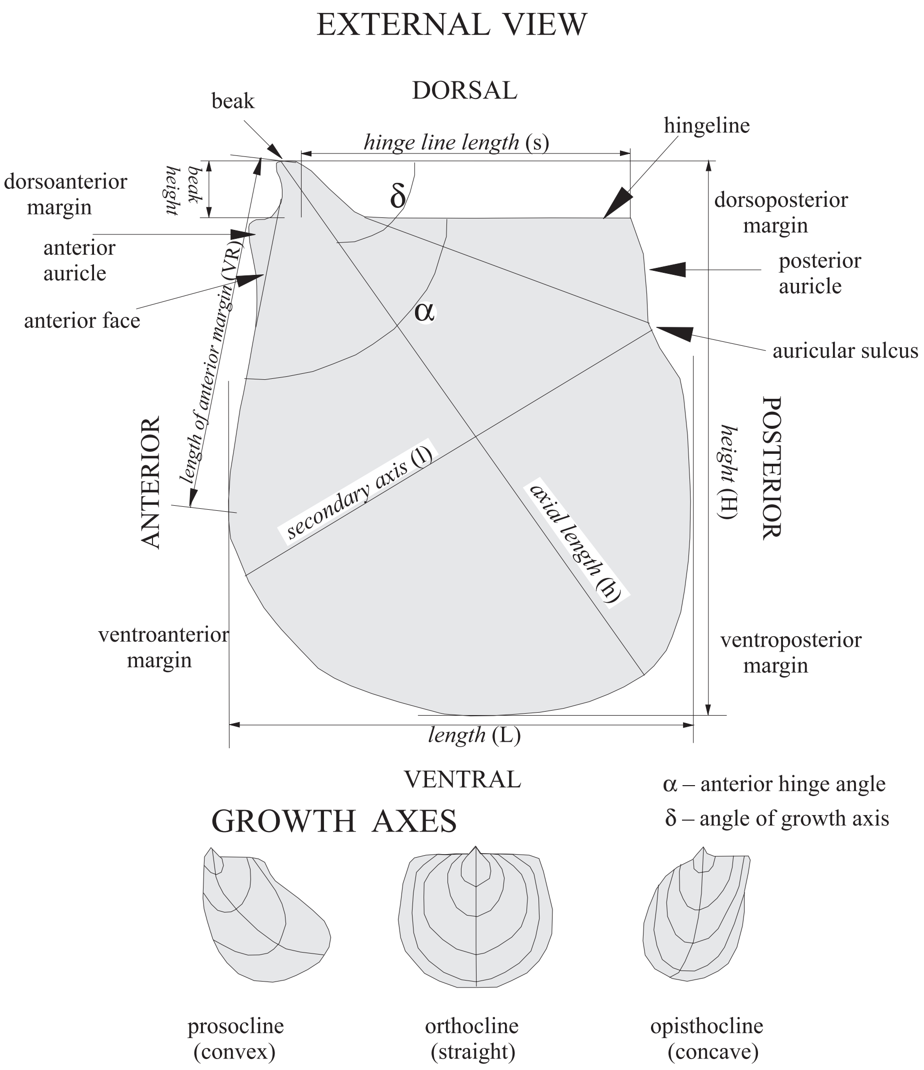


Fig. 12. Terminology and measurements of the external morfologic features of inoceramid shell as applied in this paper (after HARRIES & *al.* 1996, modified).

Tab. 3. Measurements (in mm) for selected inoceramid specimens described in this paper

Mytiloides mytiloides										
specimen	**illustration**	**h**	**l**	**H**	**L**	**s**	**α**	**δ**	**valve**	**hmax**
USNM 507408	unillustrated	57.0	35.0	—	—	—	—	—	LV	107
USNM 507409	unillustrated	63.0	34.0	—	—	—	—	41	LV	79
USNM 507414	pl. 13, fig. 7	80.0	47.0	—	—	—	—	35	LV	100
USNM 507426	unillustrated	49.0	21.0	33.0	40.0	16.0	84	40	RV	—
USNM 507428	pl. 12, fig. 11	52.0	27.5	37.4	41.5	15.5	95	40	RV	—
USNM 507439	pl. 12, fig. 4	84.0	34.0	44.0	76.0	29.0	75	30	RV	95
USNM 507443	pl. 12, fig. 12	50.0	31.0	38.0	40.0	13.0	—	40	RV	80
USNM 507471	pl. 12, fig. 9	70.0	31.5	54.0	57.0	19.0	90	38	RV	—

Mytiloides puebloensis										
specimen	**illustration**	**h**	**l**	**H**	**L**	**s**	**α**	**δ**	**valve**	**hmax**
USNM 507292	unillustrated	48.0	38.0	44.5	38.0	17.0	113	58	RV	65.0
USNM 507330	pl. 7, fig. 12	56.3	42.5	52.5	45.6	17.2	—	58	LV	69.0
USNM 507331	pl. 7, fig. 14	58.0	40.8	50.0	46.0	18.0	—	52	RV	69.0
USNM 507332	unillustrated	40.0	29.2	33.5	35.6	19.5	—	53	LV	47.0
USNM 507337	pl. 10, fig. 8	34.5	25.0	31.0	28.5	12.5	—	57	RV	48.0
USNM 507340	pl. 10, fig. 6	36.3	30.5	31.2	—	—	—	55	RV	46.5
USNM 507372	pl. 7, fig. 7	57.5	38.0	49.8	49.5	18.2	118	53	RV	74.0
USNM 507378	pl. 7, fig. 5	51.0	38.0	45.5	43.6	16.0	118	53	RV	63.0
USNM 507458	pl. 8, fig. 2	40.0	30.8	—	—	—	—	—	—	50.0
USNM 507459	pl. 8, fig. 3	39.7	29.8	35.0	34.0	18.5	—	50	RV	58.0
USNM 507460	pl. 8, fig. 5	37.0	29.3	32.0	33.8	18.0	—	48	RV	52.0
USNM 507461	pl. 8, fig. 4	34.0	26.7	28.6	29.0	17.0	—	47	LV	54.0
USNM 507462	pl. 8, fig. 8	31.4	28.0	30.7	31.0	18.0	—	53	RV	53.8
USNM 507463	pl. 8, fig. 6	32.0	27.0	30.5	29.0	14.0	—	52	LV	35.0
USNM 507465	pl. 8, fig. 7	37.0	27.3	32.0	30.5	18.0	—	47	LV	50.0
USNM 507466	pl. 8, fig. 9	45.0	33.0	—	—	—	—	—	LV	66.0
USNM 507468	pl. 7, fig. 2	33.0	27.0	30.0	29.0	15.0	116	55	RV	62.0
transitional morphotypes between *M. puebloensis* and *M. kossmati*										
specimen	**illustration**	**h**	**l**	**H**	**L**	**s**	**α**	**δ**	**valve**	**hmax**
USNM 507377	pl. 7, fig. 1	42.0	31.6	35.2	34.8	18.0	113	55	RV	45.0
Mytiloides goppelnensis										
specimen	**illustration**	**h**	**l**	**H**	**L**	**s**	**α**	**δ**	**valve**	**hmax**
USNM 507343	pl. 10, fig. 2	41.0	31.5	37.4	33.8	13.0	—	56	RV	50.4
USNM 507344	pl. 10, fig. 10	38.0	29.5	33.2	33.0	17.5	—	55	RV	49.0
USNM 507346	pl. 7, fig. 10	45.3	33.0	39.6	37.0	18.7	—	53	LV	52.7
USNM 507347	unillustrated	41.5	30.0	35.0	33.0	17.3	—	51	RV	51.0
USNM 507369	pl. 9, fig. 1	39.0	31.3	34.8	32.2	15.7	—	58	RV	62.1
USNM 507413	pl. 11, fig. 10	43.6	28.3	36.0	36.0	13.8	115	46	RV	65.6
USNM 507420	pl. 10, fig. 5	71.6	42.5	52.2	62.0	24.7	103	44	RV	77.0
USNM 507421	pl. 11, fig. 7	60.0	40.5	51.4	50.6	22.4	—	43	LV	95.0
USNM 507422	pl. 10, fig. 12	53.0	35.0	—	—	—	—	—	RV	81.0
USNM 507424	pl. 11, fig. 5	51.0	31.4	42.5	44.0	19.0	113	48	RV	80.0
USNM 507425	pl. 11, fig. 2	64.0	36.6	50.7	50.9	22.0	110	45	LV	67.0
USNM 507430	pl. 13, fig. 6	43.5	30.5	34.0	38.0	17.0	110	45	RV	80.0
USNM 507431	unillustrated	48.0	34.0	38.0	42.0	15.0	108	44	LV	75.0
USNM 507432	pl. 12, fig. 6	41.0	16.5	26.0	38.0	12.0	—	31	LV	—
Mytiloides ganuzaensis										
specimen	**illustration**	**h**	**l**	**H**	**L**	**s**	**α**	**δ**	**valve**	**hmax**
USNM 507415	pl. 13, fig. 3	55.0	40.5	46.5	49.0	18.0	113	44	RV	57.0
USNM 507416	pl. 13, fig. 5	70.0	46.0	54.0	63.0	20.5	108	42	RV	105.0
USNM 507417	pl. 13, fig. 1	62.5	46.0	50.5	55.5	23.0	120	45	LV	78.0
USNM 507423	pl. 11, fig. 8	69.0	51.0	59.5	58.0	19.5	115	50	RV	77.0
USNM 507427	pl. 11, fig. 9	44.5	32.4	38.0	38.0	17.0	105	48	RV	46.5
USNM 507429	pl. 11, fig. 1	67.0	45.5	52.5	61.0	17.0	125	45	RV	67.0
USNM 507474	pl. 13, fig. 2	71.0	52.0	56.5	64.4	27.5	108	45	RV	81.0

sec. 25, T. 20 S., R. 66 W., Pueblo County, Colorado. Bed 90 of Greenhorn Limestone section.

D 11328 S.C. Hook & W.A. Cobban, 1980. East side of Gold Hill, Gomez Peak quadrangle, Jeff Davis County, Texas. Boquillas Limestone.

D 11183 S.C. Hook, E.A. Merewether & W.A. Cobban, 1980. Calvert Canyon in Eagle Mountains SW quadrangle, Huspeth County, Texas. Ojinaga Formation.

D 10899 S.C. Hook & W.A. Cobban, 1979. About 1.7 km southwest of railroad cut at Chispa Summit, Jeff Davis County, Texas. Chispa Summit Formation, 50 m above base.

D 10763 S.C. Hook & W.A. Cobban, 1979. Southwest of Love triangulation station in Eagle Mountains, SW quadrangle, Texas. Ojinaga Formation.

D 13621 T.S. Dyman, G.L. Pollock & W.A. Cobban, 1995. Highway 14 cut in SE $^1/_4$ NW $^1/_4$ sec. 36, T. 36 S., R. 10 W., Iron County, Utah. Tropic Shale, near top.

D 13021 W.A. Cobban, 1989. SE $^1/_4$ NW $^1/_4$ sec. 25, T. 20 S., R. 66 W., Pueblo County, Colorado. Bed 113 of Greenhorn Limestone section.

D 4443 G.R. Scott & W.A. Cobban, 1964. SE $^1/_4$ NW $^1/_4$ sec. 25, T. 20 S., R. 66 W., Pueblo County, Colorado. Bed 113 of Greenhorn Limestone section.

D 12619 W.A. Cobban, 1984. SW $^1/_4$ sec.. 25, T. 20 S., R. 66., Pueblo County, Colorado. Bed 113 of Greenhorn Limestone section.

22876 J.B. Reeside, Jr., H.R. Christner & W.A. Cobban, 1950. N $^1/_2$ N $^1/_2$ sec. 31, T. 20 S., R. 65 W., Pueblo County, Colorado. Bed 97 of Greenhorn Limestone section.

D 11237 S.C. Hook & W.A. Cobban, 1980. W $^1/_2$ SW $^1/_4$ sec. 25, T. 20 S., R. 66 W., Pueblo County, Colorado. Bed 122 of Greenhorn Limestone section.

D 8831 R.E. Burkholder & W.A. Cobban, 1973. Spillway of Glen Elder Reservoir, Mitchell County, Kansas. Greenhorn Limestone.

22924 J.B. Reeside, Jr., H.R. Christner & W.A. Cobban, 1950. Cottonwood Creek south of Loveland, Larimer County, Colorado. Greenhorn Limestone, from Bridge Creek Member.

D13356 W.A. Cobban, 1992. NE $^1/_4$ NE $^1/_4$ sec. 2, T. 21 S., R. 66 W., Pueblo County, Colorado. From 13 cm-thick shaly limestone bed immediately underlying bed 84 of Greenhorn Limestone section.

D13684. W.A. Cobban, 1995. SW $^1/_4$ NW $^1/_4$ sec. 25, T. 20 S., R. 66 W., Pueblo County, Colorado. Bed 90 of Greenhorn Limestone section.

D10894 W.A. Cobban, 1979. About 1.7 km southwest of railroad cut at Chispa Summit, Jeff Davis County, Texas. Chispa Summit Formation, 55 m above base.

D11721 W.A. Cobban, 1981. SW^1/ $^1/_4$ SW $^1/_4$ sec. 25, T. 20 S., R. 66 W., Pueblo County, Colorado. Bed 97 of Greenhorn Limestone section.

D3736 W.A. Cobban, 1961. NE $^1/_4$ NW $^1/_4$ sec. 30, T. 9 S., R. 5 E., Fall River County, South Dakota. Greenhorn Limestone, from Bridge Creek Member.

3677 T.W. Stanton, 1906. About 3.2 km north of Denmark, Lincoln County, Kansas. Greenhorn Limestone.

D11238 S.C. Hook, G.R. Scott, and W.A. Cobban, 1980. W$^1/_2$ SW$^1/_4$ sec. 25, T. 20 S., R. 66 W., Pueblo County, Colorado. Bed 132 of Greenhorn Limestone section.

TAXONOMY OF THE LOWER AND LOWER MIDDLE TURONIAN INOCERAMIDS FROM PUEBLO

(by I. WALASZCZYK & W.A. COBBAN)

Six inoceramid zones may be distinguished in the topmost Cenomanian and Lower – lower Middle Turonian of the Pueblo succession (Text-fig. 6). With the exception of the lowermost, *Inoceramus pictus* Zone, not defined herein, they are a series of successive interval zones, their lower boundaries defined by first appearance of their index species. Because almost all of the index species have been used in the erection of previous inoceramid zonation of the interval concerned, these zones are discussed below, as is their correlation with the proposed ammonite zonation (Text-fig. 6).

The *Mytiloides hattini* Zone, the base of which is placed in the topmost part of bed 84 at Pueblo, is characterised by the almost exclusive occurrence of the index species. Inoceramids are rare in the underlying bed 83, and represented almost exclusively by *Inoceramus pictus* J. de C. Sowerby, 1829 (see Pl. 4, Figs 1-6). The statement in Lamolda & *al*. (1997) about the occurrence of *Mytiloides wiedmanni* (Lopez) in this part of the Pueblo section is incorrect. This information, taken from Bengtson (1996), is based on Seibertz' (1995) observation, but he interpreted *M. wiedmanni* in a much wider sense than its original concept: he referred to this species all forms earlier referred to *M. submytiloides* and *M. opalensis* auctorum. Both these latter taxa are so variably interpreted in the literature that it is impossible to judge which morphotype he is referring to.

The species *M. hattini* is also common in bed 86 (see Pl. 4, Figs 7-14; Plate 5). This bed, the base of which is taken as the lower boundary of the succeeding *M. puebloensis* Zone is dominated by *Mytiloides puebloensis* (see Plate 6). The rich material coming from this bed is entirely referred to these two species; 70% of specimens are assigned to *M. puebloensis*.

Bed 90, the base of which is taken as the lower boundary of the *M. kossmati* Zone, is marked by the first appearance of *M. kossmati* (Heinz) and *M. goppelnensis* (Badillet & Sornay). The assemblage is still dominated, however, by *M. puebloensis*, and transitional forms between all three species occur. The lower part of the *M. kossmati* Zone corresponds to the *Pseudaspidoceras flexuosum* Zone in ammonite terms. The same inoceramids occur in the *flexuosum* Zone in Texas (see Pl. 5, Figs 1-11).

Mytiloides kossmati comprises the very characteristic double-ridged U.S. Western Interior forms referred formerly to *Mytiloides duplicostatus* (ANDERSON) or to *Mytiloides columbianus* (HEINZ). The latter is here regarded as a junior synonym of *M. kossmati*, whereas ANDERSON's species, described originally from the U.S. Pacific Coasts, is most probably conspecific with "*Inoceramus*" *naumanni* YOKOYAMA (YOKOYAMA 1890, p. 174, Pl. 18, Figs 3-5; NAGAO & MATSUMOTO, 1940, p. 31, Pl. 13, Fig. 4; Pl. 14, Figs 1-10; Pl. 15, Figs 1-2; Pl. 17, Fig. 6, Text-figs 2-4), a very characteristic North Pacific species, sharing with *M. kossmati* only a common ornament type.

The inoceramid assemblage is relatively uniform up to and including bed 107 (Text-fig. 6), and is composed mostly of *M. puebloensis*, *M. kossmati* and *M. goppelnensis* (Pl. 7, Figs 9-11; Pl. 8, Figs 12-14; Pl. 9, Figs 1-3; Pl. 10, Figs 3, 5, 9, 10, 12). A small, highly inflated morphotype, represented by only a few specimens in the material studied, occurs in beds 97 and 105, and is referred here to *Mytiloides labiatus* (SCHLOTHEIM) (see Pl. 12, Figs 1-3). The presence of this small *labiatus*-like morphotype may be the basis for the *submytiloides – labiatus* lineage as interpreted by KAUFFMAN & HARRIES (1996), which from the very beginning of *Mytiloides* history evolved separately from the main early Turonian evolutionary tree of the genus (see KAUFFMAN & HARRIES 1996, text-fig. 5). On the other hand, if we accept such an early appearance of this lineage, and at the same time much later appearance of *M. hattini*, which is the root species of the main evolutionary tree, early Turonian *Mytiloides* are diphyletic. Without further material from the early Late Cenomanian history of the genus, the matter remains unresolved.

The inoceramid assemblage changes markedly in bed 107, as is particularly well seen in the fauna of bed 113. It is dominated by medium- and large-sized representatives of *Mytiloides mytiloides* (MANTELL), *M. goppelnensis* (BADILLET & SORNAY) and *M. ganuzaensis* (LOPEZ) Plates 11-13): these characterise an interval here referred to a *M. mytiloides* Zone. The base of the zone is placed in bed 105, where the first representative of MANTELL's species was found.

It should be noted that in most of the European sections there are gaps and condensation in the boundary interval, and the *M. mytiloides* Zone is the lowest widely recognisable Lower Turonian inoceramid zone. This incompleteness of the European basal Turonian combined with the pattern of evolution of Early Turonian mytiloids, which comprised a series of rapid speciation events followed by stasis and relatively high longevity of particular species (see KAUFFMAN & HARRIES 1996), is the origin of the disagreement between European and North American inoceramid workers concerning the stratigraphical potential of Early Turonian mytiloids, as most of the Early Turonian species co-occur in the European sections, enabling a relatively unrefined zonation. Only much more complete sequences, as in the U.S. Western Interior, show the successive origination of Early Turonian taxa, and the consequent refined sequence of partial range zones.

The first *M. subhercynicus* (SEITZ) (Pl. 15, Fig. 6) appears in the lower part of bed 121 (Text-fig. 6). This species dominates the assemblage starting with bed 130. Collections from the lower part of the zone are characterised, moreover, by axially elongated, alate forms, referred here to *Mytiloides aviculoides* (MEEK & HAYDEN) (Plate 14). These forms have been referred to *Mytiloides mytiloides arcuata* (SEITZ) or early forms of *Mytiloides labiatus* (SCHLOTHEIM) in recent U.S. publications (KAUFFMAN 1977, KAUFFMAN & *al*. 1978; KAUFFMAN & HARRIES 1996). The first appearance of *M. subhercynicus* approximates to and is slightly higher than the first appearance of the ammonite *Collignoniceras woollgari* in the Pueblo section, the candidate marker for the base of the Middle Turonian Substage. The first occurrence of *C. woollgari* and *M. hercynicus* are commonly regarded as synchronous, but *M. hercynicus* actually appears at a markedly higher level in the Pueblo section.

The *M. subhercynicus* Zone can be subdivided into a lower part, where the index taxon is rare, and *M. aviculoides* common, and an upper part, where *M. subhercynicus* is dominant.

The topmost Cenomanian and Lower-lower Middle Turonian inoceramid succession as recognised in the Pueblo section can be applied to the whole U.S. Western Interior and Texas (KAUFFMAN & *al.* 1978, 1993; KAUFFMAN & HARRIES 1996; ELDER 1989, 1991; KIRKLAND 1996). It can also also be applied in Europe (KAUFFMAN 1978, WIEDMANN & KAUFFMAN 1978, TRÖGER 1981, WALASZCZYK 1992, HARRIES & *al.* 1996). Current European schemes question the possibility of applying the refined zonation based on Early Turonian mytiloids (SEITZ 1935, TRÖGER 1967, BADILLET & SORNAY 1980, SORNAY 1982); as noted above this is due to the markedly reduced Early Turonian record in most classic European sections. The same succession is also recognised in Japan (MATSUMOTO & NISHIDA 1995; see also MATSUMOTO & NODA 1975). Almost every species from the Cenomanian/Turonian boundary has been reported from the southern continents, although further work is needed to demonstrate that Southern Hemisphere successions are the same as observed in Northern Hemisphere.

The main stratigraphical results of this study, when compared to former zonal schemes, are as follows:

1. The Brussels proposal defining the base of the Turonian at the first appearance of the ammonite *Watinoceras devonense* in bed 86 of the Pueblo section places the main interval with *M. hattini* (bed 85) still within the topmost Cenomanian. Although ranging into the Lower Turonian, this species is not an important member of Early Turonian inoceramid assemblages.
2. Inoceramids allow the precise location of the base of the Turonian Stage; this boundary lies at the first appearance of *Mytiloides puebloensis* sp. nov., an evolutionary descendant of *M. hattini*.
3. *Mytiloides hercynicus*, is usually considered (particularly in the European literature), as appearing at the level of the first appearance of *Collignoniceras woollgari*, and consequently, commonly taken as the inoceramid marker for the base of the Middle Turonian; however, it appears at Pueblo markedly higher, within the *woollgari* Zone. The base of the Middle Turonian (defined by the FO of *C. woollgari* in bed 120 of the Pueblo section) corresponds approximately to the, but is slightly lower than first appearance of *M. subhercynicus*.

SYSTEMATIC ACCOUNT

Phylum Mollusca
Class Bivalvia LINNÉ, 1758
Order Pterioda NEWELL, 1965
Family Inoceramidae GIEBEL, 1852
Genus *Mytiloides* BRONGNIART, 1822
Type species: *Ostracites labiatus* SCHLOTHEIM (1813, p. 93), by monotypy.

Mytiloides hattini ELDER, 1991
(Plate 4, Figs 7-13; Plate 5, Figs 1-10)

part 1935. *Inoceramus labiatus* var. *mytiloides* Mantell; O. SEITZ, p. 435, Pl. 37, Fig. 5.
1975. *Inoceramus* sp.; D.E. HATTIN, Pl. 5, Fig. T.
1984. *Inoceramus pictus sackensis* KELLER; P.-Y. BERTHOU, Pl. 1, Fig. 1.
1991. *Mytiloides hattini* n.sp.; W.P. ELDER, Fig. 3.1-3.19.
1991. *Mytiloides* aff. *sackensis* (KELLER, 1982); W.J. KENNEDY & W.A. COBBAN, p. 19, Fig. 10.A-C.
1996. ?*Inoceramus pictus* SOWERBY; R. MARCINOWSKI & *al.*, Pl. 17, Fig. 1.
1996. *Mytiloides hattini* ELDER; J.I. KIRKLAND, p. 28, Pl. 28, Fig. A.

TYPE: The holotype by original designation is KU 82132 (illustrated by ELDER 1991, Fig. 3.13) from the upper part of the Hartland Shale Member of the Greenhorn Limestone, Hodgeman County, Kansas, U.S. Western Interior, housed in the University of Kansas Museum of Invertebrate Palaeontology. There are numerous paratypes (ELDER 1991, p. 239).

MATERIAL: Sixteen registered specimens: USNM 507294, USNM 507295, USNM 507298, USNM 507306, USNM 507307, USNM 507308, USNM 507319, USNM 507752; from USGS D 10176; USNM 507302, USNM 507303, USNM 507304, USNM 507305, USNM 507311, USNM 441469, USNM 441470, USNM 441471; from USGS D3975; and USNM 507296, USNM 507299; from USGS D 12460. Numerous unregistered specimens from USGS localities D 10176, D 12460, D 3975, are in the collections of the US Geological Survey in Denver.

DESCRIPTION: Small to moderate sized, inequilateral, equivalved, prosocline. Growth axis almost straight. Posterior auricle poorly separated from disc. Shell outline oval to subquadrate, rarely subrounded. Beak projecting only slightly above hinge line. Hinge line straight, relatively short. Anterior margin long, convex, passing into rounded ventral margin and almost straight posterior margin.

Ornament composed of regularly to sub-regularly spaced raised microrugae, which pass onto posterior auricle.

REMARKS: The species was described and discussed at length by ELDER (1991), based on material from the Cenomanian – Turonian boundary interval of the U.S. Western Interior, and represents one of the better defined mytiloids of this age. In laterally compressed material it may be difficult to separate from specimens of *Inoceramus pictus* J. de C. SOWERBY, 1829, to which ELDER's species is very similar in respect of surface ornament.

The systematic relationship between *M. hattini* and *Inoceramus pictus sackensis*, described by KELLER (1982) from the Lower Turonian of northern Germany remains unclear. ELDER (1991), in his discussion of the relations between the two species, noted the difference in development of the posterior auricle, which is longer, broader, and poorly separated from the disc in *M. hattini*. In *I. pictus sackensis* the auricular sulcus is deep and conspicuous. According to ELDER, KELLER's species possesses, moreover, a larger inclination angle (70° in KELLER's figured specimens, versus 58° as the average value in *M. hattini*). However, the problem is that ELDER's (1991) remarks refer in general to one of KELLER's paratypes, but not to the holotype. The illustrated paratype (KELLER 1982, Pl. 2, Fig. 4a; *see also* ELDER 1991, Fig. 4.6) differs very markedly from *M. hattini*, but this is not the case with the holotype of *I. pictus sackensis* of KELLER (1982, Pl. 2, Fig. 4b), which possesses quite the same characteristics as *M. hattini*, and is indeed a *Mytiloides* species: the two specimens illustrated by KELLER (1982) are thus not conspecific. The paratype differs from the holotype even in the pattern of surface ornament; it is a distinctly rugate form. It seems very probable that *M. hattini* falls into synonymy of *M?. sackensis*, although more material from the type locality of KELLER's species is needed to resolve this problem.

Inoceramus pictus sackensis KELLER as illustrated by BERTHOU (1984) belongs most probably to *M. hattini*. Although the specimen is not completely preserved it has typical *hattini*-like ornament and mytiloid outline. The specimen from Kazakhstan illustrated by MARCINOWSKI & *al*. (1996, Pl. 17, Fig. 1) referred questionably to *I. pictus* SOWERBY, should rather be referred to *M. hattini* ELDER.

OCCURRENCE: From the topmost part of Bed 84 to Bed 99 of the Pueblo section, topmost Cenomanian (*Neocardioceras juddii* Zone and *Nigericeras scotti* Zone) to lowermost Turonian (up to *Vascoceras birchbyi* Zone) of the U.S. Western Interior, Texas and northern Mexico, southern England, Germany, Portugal, and western central Asia (Kazakhstan).

Mytiloides puebloensis sp. nov.
(Pl. 6, Figs 1-11; Pl. 7, Figs 2-3, 5-8, 12, 14; Pl. 8, Figs 1-11, 13; Pl. 10, Figs 1, 4, 6-8)

1894. *Inoceramus labiatus* SCHLOTHEIM; T.W. STANTON, p. 77, Pl. 14, Fig. 2.
part 1977. *Mytiloides mytiloides* (MANTELL); KAUFFMAN, pl. 6, fig. 12 (*non* Pl. 6, Fig. 8).
?1977. *Mytiloides* sp. aff. *M. duplicostatus* (ANDERSON); E.G. KAUFFMAN, Pl. 6, Fig. 11.
part 1978. *Mytiloides mytiloides* (MANTELL); J. WIEDMANN & E.G. KAUFFMAN, Pl. 2, Fig. 2 [*non* Pl. 2, Fig. 7].
1984. *Inoceramus* (*Mytiloides*) *hercynicus* PETRASCHECK; P.-Y. BERTHOU, Pl. 1, Fig. 3.
?1984. *Inoceramus* (*Mytiloides*) *subhercynicus* SEITZ; P.-Y. BERTHOU, Pl. 1, Fig. 4.
part 1987. *Mytiloides columbianus* (HEINZ, 1935); KENNEDY & *al*.; Text-fig. 12A-B (*non* Text-fig. 12C).
1989. *Mytiloides columbianus* (HEINZ, 1935); KENNEDY & *al*.; Fig. 34C-E, G, H. *Mytiloides columbianus* (HEINZ, 1935); W.J. KENNEDY & W.A. COBBAN, Fig. 11A-C.
part 1991. *Mytiloides columbianus* (HEINZ); W.P. ELDER, p. 239, Fig. 4.9. [*non* Fig. 4.2]
?1996. *Mytiloides hattini* ELDER; R. MARCINOWSKI & al., Pl. 17, Figs 3-4.
?1996. *Mytiloides* sp. cf. *M. latus* (SOWERBY); J.I. KIRKLAND, p. 29; Pl. 28, Figs H, I.

TYPE: The holotype is the specimen USNM 507315, from bed 86 of the Pueblo section (Pl. 6, Fig. 9), *Watinoceras devonense* Zone of the lowermost Turonian.

DERIVATION OF THE NAME: After the town of Pueblo, SE Colorado, located close to the Rock Canyon Anticline, the locality of the proposed Cenomanian/Turonian boundary stratotype.

DIAGNOSIS: Small- to medium-sized member of the *Mytiloides hattini* group with regularly spaced, round-topped rugae, covered with regular, raised growth lines. Disc oval in outline to subquadrate, weakly inflated, with dorsal maximum inflation. Hinge-line relatively short, straight.

TYPE LOCALITY: Rock Canyon Anticline. Bed 86 in the Bridge Creek Limestone Member of the Greenhorn Limestone.

MATERIAL: Nine specimens, USNM 507292, USNM 507300, USNM 507309, USNM 507307, USNM 507310, USNM 507313, USNM 507314, USNM 507316, USNM 507317, USNM 507318; from USGS Mesozoic locality D 10176; four specimens, USNM 507293, USNM 507301, USNM 507297, USNM 507312, from USGS Mesozoic locality D 3975; USNM 507315, from USGS Mesozoic locality D 12460; three specimens, USNM 507468, USNM 507378, USNM 507372, from USGS Mesozoic locality D 11758; USNM 507373, from USGS Mesozoic locality D 12461; USNM 507371, from USGS Mesozoic locality D 3976; five specimens, USNM 507354, USNM 507350, USNM 441478, USNM 441477, USNM 441476, from USGS Mesozoic locality D 6147; two specimens, USNM 507330 and USNM 507331, from USGS Mesozoic locality D 3977; USNM 507457 from USGS Mesozoic locality D 11183; nine specimens, USNM 507458, USNM 507459, USNM 507460, USNM 507461, USNM 507463, USNM 507465, USNM 507462, USNM 507466, from USGS Mesozoic locality D 10899; USNM 507329 and USNM 507337, from the USGS Mesozoic locality 22876, USNM 507332 and USNM 507333, from USGS Mesozoic locality 22924, USNM 507340 from USGS Mesozoic locality D 11721; numerous unregistered specimens from listed localities in the collections of the Geological Survey in Denver.

DESCRIPTION: Of small to moderate size for genus, inequilateral, equivalved. Valves weakly inflated, with maximum inflation in umbonal part. Growth axis straight or slightly convex anteriorly. Posterior auricle small, poorly separated from disc. Beak projecting slightly above hinge line. Umbonal flanks steep to moderately steep. Hinge line straight, of moderate length. Anterior margin moderately long, convex, passing into narrowly rounded ventral margin and thence into straight or very weakly convex posterior margin.

Shell ornamented with quite regularly spaced rugae. Rugae with rounded edges, slightly asymmetrical with ventral slopes slightly steeper than dorsal ones. They weaken markedly or disappear toward the anterior and posterior margins. Rugae covered with *hattini*-like microrugae, evenly spaced, round-topped. The microrugae range from fine, closely spaced to more distant, wider. Rugate part of shell of variable length, referred to here as the juvenile stage, is followed by the adult stage, which differs in respect of ornament; it bears wide, low distinctly asymmetrical rugae, irregularly spaced, with steep ventral and gentle dorsal slopes.

REMARKS: *Mytiloides puebloensis* sp. nov. is morphologically very similar to *Mytiloides hattini* ELDER. It differs from ELDER's species in its juvenile part, which bears regularly spaced, round-topped rugae. A range of transitional forms occur. Some more axially elongated specimens resemble *Mytiloides mytiloides* (MANTELL), which differs, however, in much lower l/h values, in possessing less regular ornament, and usually distinctly lower anterior hinge angle values. It differs moreover, in the development of the posterior auricle, which is wide and well developed in *M. mytiloides*. *M. puebloensis* is interpreted as an evolutionary descendent of *M. hattini* ELDER.

M. columbianus (HEINZ, 1935), to which representatives of *M. puebloensis* were formerly referred to (*see* KENNEDY & *al.* 1987, 1989; KENNEDY & COBBAN, 1991; ELDER 1991) possesses a different type of ornament, composed of double-ridged rugae (see Pl. 9, Fig. 7), the same type of ornament as occurs in *M. kossmati* (HEINZ, 1930) (see Pl. 9, Figs 4-5); *M. columbianus* falls into the synonymy of *M. kossmati* (HEINZ). Numerous juvenile *M. puebloensis* display the tendency to double-ridged rugae (e.g. KENNEDY & COBBAN 1991, Fig. 11B) (see e.g. Pl. 8, Figs 9-11, 13; Pl. 10, figs 4, 7). Some may be interpreted as transitional forms between *M. puebloensis* and *M. kossmati* (=*M. columbianus*) (e.g. Pl. 7, Figs 1, 4, 13).

OCCURRENCE: *M. puebloensis* appears in bed 86 in the Pueblo section, where it is the most common form, as is the case also in bed 90, where it is accompanied by rare *M. goppelnensis* (BADILLET & SORNAY), *M. kossmati* (HEINZ), and transitional forms between *M. puebloensis* and *M. kossmati*. It occurs more or less consistently up to bed 105. Outside the Western Interior the species is known from Texas (KENNEDY & *al*. 1989).

The species has been only rarely recorded in Europe. BERTHOU (1984) illustrated *M. puebloensis* from the very basal Turonian from Portugal, referring it to *M. subhercynicus* and *M. hercynicus*. A single specimen was illustrated by WIEDMANN & KAUFFMAN (1978) from Spain, from the Ganuza III level, and referred to *M. mytiloides*, but it possesses the very characteristic *puebloensis* ornament. To *M. puebloensis* also probably belong two specimens illustrated by MARCINOWSKI & *al*. (1996) from Mangyshlak, Western Kazakhstan, and referred by them to *M. hattini* ELDER. The two specimens concerned, although not completely preserved, have a distinctly rugate juvenile part.

Mytiloides kossmati (HEINZ, 1930)
(Pl. 9, Figs 4-9)

1928b *Inoceramus plicatus* D'ORB.; R. HEINZ, p. 63, Pl. 4, Fig. 4.
1930. *Inoceramus naumanni* YOK. var. *Kossmati* HEINZ; R. HEINZ *in* BESAIRE, pp. 94 and 121.
1932. *Striatoceramus kossmati* HEINZ; R. HEINZ, p. 4.
1933. *Striatoceramus kossmati* HEINZ; R. HEINZ, p. 247, Pl. 18, Fig. 4.
1935. *Orpheoceramus columbianus* n.sp.; R. HEINZ, p. 304.
1980. *Inoceramus* (*Mytiloides*) *modeliaensis* n.sp.; SORNAY, p. 136, Pl. 1, Figs 1, 3-4; Pl. 2, Figs 1, 3-4.

TYPE: The holotype, by original designation, is the left valve of the specimen from the Lower Turonian of Anontsy, Madagascar, illustrated by HEINZ (1933, Pl. 18, Fig. 4; and reillustrated herein – Pl. 9, Figs 4-5). The original is in the Muséum National d'Histoire Naturelle in Paris.

MATERIAL: Three specimens, USNM 507453, USNM 507451, and USNM 507454; from USGS Mesozoic locality D 13621, Utah; numerous specimens from USGS Mesozoic locality D 6147, D 12636, and D 13022, in the collections of the US Geological Survey, Denver.

DESCRIPTION: Small to moderate sized for the genus. Shell outline subquadrate to subrounded. Posterior auricle weakly developed, very poorly separated from the disc. Disc weakly inflated with maximum inflation in the umbonal part. Anterior and ventral margins rounded, posterior margin straight to weakly rounded. Hinge line straight, relatively short, representing about 50 to 60 % of the respective axial length. Beak projecting slightly above the hinge line.

Umbonal ornament consists of growth lines or closely spaced concentric rugae. The rest of the juvenile stage is characterised by double-ridged rugae, with doubling well developed only in the axial part of the disc, disappearing gradually toward the posterior and anterior margins. Juvenile ornament succeeded by *Mytiloides*-like adult ornament.

REMARKS: Intraspecific variation concerns mostly shell outline and surface ornament. The shells vary from subrounded to relatively highly axially elongated forms. Convexity of the growth axis also varies to some extent, although in most forms it is only weakly convex. Juvenile ornament varies in respect of spacing of rugae and point of appearance of double ridged rugae, which usually appear in the middle juvenile stage, as in the holotype of the species (HEINZ 1933, Pl. 18, Fig. 4; and illustration herein Pl. 9, Figs 4-5), but may appear distinctly earlier, as in the case of the type of HEINZ' *M. columbianus* (=HEINZ 1928b, Pl. 4, Fig. 4) (*see* Pl. 9, Fig. 7).

The presence of the paired concentric ornament elements in the *M. labiatus* group is not restricted to representatives of *M. kossmati* (HEINZ) only; although rare, it occurs in most species of the genus. However, in most forms the paired elements are represented by a pair of raised growth lines, occurring at the edge of the round-topped rugae, slightly more pronounced than the others.

Forms with double-ridged rugae, referred here to *M. kossmati*, were compared by KAUFFMAN & POWELL (1977; *see also* KAUFFMAN 1977 and more recently KIRKLAND 1996) to *Inoceramus duplicostatus* described by ANDERSON (1958) from the United States Pacific Coast. Although ANDERSON's species indeed displays great similarity to *M. kossmati* in respect of surface ornament, it differs markedly in all other respects. *Inoceramus duplicostatus* ANDERSON is axially elongated with a weak posterior disc sulcus and very long posterior margin of the disc. The latter suggests the presence of a distinctly separated posterior auricle with, moreover, a relatively long hinge line. It resembles closely the well-known and widely distributed North Pacific species "*Inoceramus*" *naumanni* YOKOYAMA (*see* YOKOYAMA 1890, Pl. 18, Figs 3-5). This is particularly the case with forms possessing double rugae, referred by NAGAO & MATSUMOTO 1940, Pl. 13, Fig. 4; Pl. 14, Figs 1, 3-8, 10 as type β ornament.

The type of *M. columbianus* (HEINZ 1935)(=*M. plicatus* in HEINZ 1928b, Pl. 4, Fig. 4). also falls in the synonymy of *M. kossmati*. The only difference concerns the earlier appearance of the paired concentric rugae in the type of *M. columbianus* when compared to the type of *M. kossmati* (*compare* Pl. 9, Figs 4-5 and Pl. 9, Fig. 7). Also worthy of mention is the fact that the type of *M. columbianus* is represented by a mould of the outer shell surface and thus it may have had more chance for better preservation of the details of the ornament than the internal mould holotype of *M. kossmati*. The pattern of ornament as well as the general shell outline in both forms is identical.

M. columbianus (HEINZ) as interpreted by KENNEDY & *al*. (1987, Text-fig. 12 A-C), KENNEDY & *al*. (1989, Fig. 34C-E, G, H) and KENNEDY & COBBAN (1991, Fig. 11 A-C) is different from *M. columbianus* (HEINZ) [= *M. kossmati* (HEINZ)].. Most of these specimens are characterised by the regular, round-topped rugae covered with raised growth lines that are characteristic of *Mytiloides puebloensis* sp. nov.

Mytiloides goppelnensis (BADILLET & SORNAY, 1980)(=*M. opalensis* sensu SEITZ 1935) differs from *M. kossmati* (HEINZ) in the lack of double-ridged rugae. Although WALASZCZYK (1992) synonymised both forms, he treated HEINZ' species very widely, including forms with and without double-ridged rugae in a single species.

When these two forms are treated as separate species, it is *M. goppelnensis* that is the proper name for *M. opalensis* sensu SEITZ; the name *M. kossmati* should be applied to double-ridged forms, referred hitherto variably to *M. columbianus* (HEINZ) or to *M. duplicostatus* (ANDERSON).

OCCURRENCE: Lower Turonian, beds 90 to 113 in the Pueblo section, North America (U.S. Western Interior and Texas), South America (Colombia), Europe (England, France, Germany, Spain, Poland, Czech Republic, Ukraine), Asia (Japan, Kazakhstan), and Madagascar.

Mytiloides goppelnensis (BADILLET & SORNAY 1980)
(Pl. 7, Figs 9-11; Pl. 8, Figs 12, 14; Pl. 9, Figs 1-3; Pl. 10, Figs 2, 5, 9-10, 12; Pl. 11, Figs 2, 5, 7, 10; Pl. 12, Fig. 6; Pl. 13, Fig. 6)

1935. *Inoceramus labiatus* var. *opalensis* BÖSE; O. SEITZ, p. 457, Pl. 39, Fig. 1.
1935. *Inoceramus labiatus* var. *opalensis* BÖSE n.f. *elongata*; O. SEITZ, p. 458, Pl. 38, Figs 4-6; Pl. 39, Figs 2-4; Text-figs 14-15.
part 1935. *Inoceramus labiatus* n. var. *subhercynica*; O. SEITZ, p. 465, Text-fig. 18, Pl. 40, Figs 2, 4-5.
1977. *Mytiloides opalensis* (BÖSE); E.G. KAUFFMAN, Pl. 6, Fig. 10.
1978. *Mytiloides opalensis elongata* (SEITZ); J. WIEDMANN & E.G. KAUFFMAN, Pl. 2, Figs 5, 11.
part 1978. *Inoceramus hercynicus* PETRASCHECK; F. ROBASZYNSKI, Pl. 2, Fig. 3 [*non* Pl. 2, Fig. 2].
1980. *Inoceramus goppelnensis* nom. nov.; BADILLET & SORNAY, p. 324.
1988. *Mytiloides modeliaensis* (SORNAY); M.H.R. HESSEL, p. 19, Text-fig. 30C.
1989. *Mytiloides* cf. *subhercynicus* (SEITZ, 1935); W.J. KENNEDY & *al*., p. 109, Text-fig. 34I.
1991. *Mytiloides* sp.; W.J. KENNEDY & W.A. COBBAN, pp. 17-18, Figs 11D, 11E.
1991. *Mytiloides opalensis* (*sensu* KAUFFMAN); W.P. ELDER, Fig. 4.3-5.
1992. *Inoceramus* (*Mytiloides*) *goppelnensis goppelnensis* BADILLET & SORNAY; G. LÓPEZ, p. 496, Pl. 1, Fig. 2.

part 1992. *Mytiloides kossmati* (HEINZ, 1930); I. WALASZCZYK, p. 10, pl. 1, figs 1-8 [non Pl. 1, fig. 9]

1997. *Mytiloides kossmati kossmati* (HEINZ); M.A. LAMOLDA & *al*., Fig. 8c.

TYPE: The holotype by original designation is SEITZ' specimen No. 78 (SEITZ 1935, Text-fig. 14c, 15c; and pl. 39, fig. 4) from Goppeln, near Dresden, Germany.

MATERIAL: One specimen USNM 507456, from USGS Mesozoic locality D 10899; six specimens, USNM 507346, USNM 507347, USNM 507349, USNM 441479, USNM 507343, USNM 507344, and USNM 441480, from USGS Mesozoic locality D 6147; three specimens, USNM 507369, USNM 507368, and USNM 507398, from USGS Mesozoic locality D 13021; USNM 507328, from USGS Mesozoic locality D 112721; USNM 507420, from USGS Mesozoic locality D 3980; four specimens, USNM 507425, USNM 507424, USNM 507432, and USNM 507421, from USGS Mesozoic locality D 4443; USNM 507413, from USGS Mesozoic locality D 12619; USNM 507430, from USGS Mesozoic locality 22876. Numerous unregistered specimens from the same localities in the collections of the US Geological Survey in Denver.

DESCRIPTION: Small to moderate size for genus, inequilateral, equivalved. Shell outline subquadrate to elongated oval. Disc weakly inflated, with maximum inflation dorso-central; poorly separated from the posterior auricle. Beak usually only slightly projecting above hinge line. Hinge-line straight, short to moderately long. Anterior margin weakly convex, long, passing into rounded ventral margin, and thence into almost straight posterior margin.

Juvenile ornament composed of raised, single rugae, variably spaced. Rugae weaken toward anterior and posterior margins. Adult ornament *Mytiloides*-like.

REMARKS: BADILLET & SORNAY (1980), who correctly recognised the difference between *M. opalensis* (BÖSE) and *M. opalensis* (*sensu* SEITZ 1935), renamed the latter *Inoceramus goppelnensis*. They referred to their new species both *I. labiatus* var. *opalensis* sensu SEITZ and *I. labiatus* var. *opalensis* forma *elongata* SEITZ. Both morphotypes differ, according to SEITZ (1935, p. 458) only in the presence in the latter of a *Mytiloides*-like adult stage and, consequently, *I. labiatus* var. *opalensis* sensu SEITZ may represent nothing more than the juvenile part of forms referred to *I. labiatus* var. *opalensis* forma *elongata* SEITZ. This view is accepted here. The variation in h/l ratio in juveniles is regarded as intra-specific variability. The remarkable variation in the h/l ratio in the juvenile part is observed even in valves of the same specimen (specimen no. 76 *in* SEITZ 1935, p. 461), as stressed by SEITZ himself.

From *M. kossmati* (HEINZ), *M. goppelnensis* (BADILLET & SORNAY) differs in juvenile ornament. HEINZ' species exhibits distinct pairing of concentric rugae. WALASZCZYK (1992) synonymised both species, regarding this difference as mere intraspecific variability and partly also a result of preservation; the doubling may easily be destroyed (see e.g. the original two specimens illustrated by HEINZ 1933 where the type bears well preserved paired rugae, and the other specimen with slightly weathered surface looks very much like *M. goppelnensis* – see Pl. 9, Fig 4). These remarks, as well as the stratigraphical position of both species suggest that *M. goppelnensis* may be conspecific with *M. kossmati*. For the time being, however, when the difference in the ornament is not fully understood, they are treated as separate species.

Mytiloides subhercynicus (SEITZ 1935), also referred by BADILLET & SORNAY (1980) to *M. goppelnensis*, as a separate subspecies, differs from *M. goppelnensis* in possessing a distinctly separated posterior auricle, and should be treated as a separate species.

OCCURRENCE: Lower Turonian, from bed 90 to 113 in the Pueblo section. Also known from Europe (England, Spain, France, Germany, Poland, Russia) and Japan.

Mytiloides ganuzaensis (LÓPEZ, 1992)
(Pl. 11, Figs 1, 3, 6, 8-9; Pl. 13, Figs 1-5)

part 1977. *Mytiloides mytiloides* (MANTELL); E.G. KAUFFMAN, Pl. 6, Fig. 8 [*non* Pl. 6, Fig. 12 – *M. puebloensis*].

1989. *Inoceramus* (*Mytiloides*) *goppelnensis* (BADILLET & SORNAY) sic! n.ssp.; LAMOLDA & *al*., Text-fig. 4.3.

1992. *Inoceramus* (*Mytiloides*) *goppelnensis ganuzaensis* subsp. nov.; G. LÓPEZ, p. 503, Pl. 2, Fig. 2.

TYPE: The holotype by original designation is the specimen 38219, illustrated by LÓPEZ (1992, Pl. 2, Fig. 2; *see also* LAMOLDA & *al*. 1989, Text-fig. 4.3) from the level 5 of series GA-IV of Ganuza (Navarra, Spain). The specimen is housed in the collections of the Institute of Palaeontology of the Geology Department of the University of Barcelona at Bellaterra.

MATERIAL: Specimens USNM 507429, USNM 507418, USNM 507419, USNM 507423, USNM 507427, USNM 507431, USNM 507474, USNM 507417, USNM, USNM 507473; all from USGS Mesozoic locality D 4443; USNM 507415, from USGS Mesozoic locality D 12619; USNM 507416, from USGS Mesozoic locality D 3980. Numerous unregistered specimens from the same localities in the collections of the US Geological Survey, in Denver.

DESCRIPTION: Medium-sized to large for genus. Outline subrounded trapezoidal with beak curved posteriorly, projecting only slightly above the hinge-line. Anterior margin distinctly convex, rounded evenly, passing into wide, long antero-ventral margin, and then into more narrow ventral margin. Posterior margin almost straight. Disc weakly to moderately inflated with maximum inflation dorso-central. Disc passes gradually into posterior auricle, which is well-developed although not very distinctly separated from disc.

Surface covered with rugae, of moderate size, regularly spaced, weakening in the anteriormost part, as well as when passing onto the surface of the posterior auricle. Rugae are covered with regularly to sub-regularly spaced growth lines. Sometimes a pair of growth lines strengthen at the edges of rugae, give a doubling effect, usually occurring irregularly and limited to the central part of the disc.

REMARKS: *Mytiloides ganuzaensis* (López, 1992) through its outline and surface ornament most closely resembles *Mytiloides mytiloides* (Mantell). It differs in its higher h/l ratio (having a more subquadrate outline in the juvenile and middle ontogenetic stages) (Table 3), and its higher convexity in the juvenile part. Moreover, Mantell's species usually possesses less regular ornament. In the absence of juvenile growth stages the separation of fragmentary adults of the species may be difficult.

López (1992) stressed the similarity of his new taxon to *Mytiloides goppelnensis* (Badillet & Sornay), attaching *M. ganuzaensis* to it as a subspecies. Judging from his synonymy list, however, he interpreted *M. ganuzaensis* very widely, a concept that would also embrace forms referred here to *Mytiloides puebloensis* [e.g. specimens figured by Kauffman (1977, pl. 6, fig. 12), or Kennedy & *al*. (1987, text-fig. 12B), which are typical *M. puebloensis*]. Both *M. puebloensis* and *M. goppelnensis* (as well as *M. kossmati*) differ from *M. ganuzaensis* in being more prosocline, less convex in the juvenile parts, and less inflated. All these forms differ moreover in the surface ornament. Although *M. puebloensis* possesses regular rugae, as does *M. ganuzaensis*, it has raised, round-topped micro-rugae, a very characteristic element of the ornamentation.

OCCURRENCE: In the Pueblo section *M. ganuzaensis* occurs from bed 113 to 116. Known from the *Mytiloides mytiloides* Zone of Spain and France in Europe; and in North America.

Mytiloides mytiloides (Mantell, 1822)

(Pl. 12, Figs 4-5, 7-12; Pl. 13, fig. 7)

part 1822. *Inoceramus mytilloides*, G. Mantell, p. 215, Pl. 28, Fig. 2.
part 1911. *Inoceramus labiatus* (Schotheim); H. Woods, p. 283, Text-fig. 37 [only].
part 1935. *Inoceramus labiatus* var. *mytiloides* Mantell; O. Seitz, p. 435, Pl. 36, Figs 1-4; Text-fig. 2a-f; Text-fig. 3a-c.
1965. *Inoceramus paramytiloides* n.sp.; J. Sornay, p. 13, Pl. C, Figs 1-4, Text-figs 6-7.
part 1975. *Mytiloides labiatus* (Schlotheim); D.E. Hattin, Pl. 7, Figs B, D [*non* pl. 7, figs A, C-F]
1977. *Mytiloides mytiloides* (Mantell); E.G. Kauffman & J.D. Powell, Pl. 6, Figs 11-16.
non 1978. *Mytiloides mytiloides* (Mantell); E.G. Kauffman & al., Pl. 10, Figs 8 and 12.
1980. *Inoceramus* (*Mytiloides*) aff. *paramytiloides* Sornay; J. Sornay, p. 140, Pl. 2, Fig. 2.
1984. *Mytiloides mytiloides* (Mantell); W.A. Cobban, p.35, Fig. 1.
1987. *Mytiloides mytiloides* (Mantell); D.E. Hattin, Fig. 13A-B.
1991. *Mytiloides mytiloides* (Mantell); W.J. Kennedy & W.A. Cobban, Fig. 11F-I.
part 1992. *Mytiloides labiatus* (Schlotheim); I. Walaszczyk, p. 13, Pl. 1, Fig. 10; Pl. 2, figs 4, ?5-6; Pl. 4, Figs 1, 3.

TYPE: Lectotype is Mantell's specimen (1822, Pl. 28, Fig. 2; illustrated by Woods 1911, Text-fig. 37), in the collection of the Natural History Museum, London (G.A. Mantell Collection, unnumbered), from the Middle Chalk (*Mammites nodosoides* ammonite Zone) of Plumpton, Sussex, England.

MATERIAL: 11 specimens, USNM 441484, 507440, 507439, 441481-441483, 507436, 507428, 507443, 507471 from USGS Mesozoic locality D 4443; USNM 507408 and USNM 507409 from USGS D 12620; other unregistered specimens from the same locality in the collections of the Geological Survey in Denver.

DESCRIPTION: Of moderate to large size for the genus, inequilateral, equivalved. Shell outline oval, markedly elongated axially, prosocline. Disc narrow, axially elongated, with beak projected above hinge line, well separated from posterior auricle along well developed auricular sulcus. Posterior auricle large, flat, elongated parallel to growth axis. Disc weakly to moderately inflated with maximum inflation dorso-central. Anterior margin long, slightly convex, low, passing into narrowly rounded ventral margin. Posterior margin straight. Hinge line straight and relatively long (with respect to the axial length). Growth axis usually slightly convex, particularly in juvenile part, sometimes straight. Inclination angle small, usually ranging between 45 and 50°.

Ornament composed of irregularly spaced co-marginal rugae, usually very low, covered with fine, sometimes slightly raised growth lines. Ornament most prominent on axial part of disc, weakening toward anterior and posterior margins. No well-defined ontogenetic stages recognised.

REMARKS: Although the type of MANTELL's species is incomplete, the part preserved suggest rather convincingly that it is a slender, axially elongated form, weakly inflated with pointed beak, and large, axially elongated posterior auricle. Such typical representatives are relatively common in the material studied from beds 113, 116, and 118 of the Pueblo section (Pl. 12, Figs 4-5, 9, 11-12). There are, however, numerous specimens transitional to either *Mytiloides ganuzaensis* (LÓPEZ) (*see* Pl. 10, Fig. 11; Pl. 12, Figs 8-10), or to *Mytiloides aviculoides* (MEEK & HAYDEN) (Pl. 11, Fig. 4).

WALASZCZYK (1992) interpreted *M. mytiloides* (MANTELL) as an extreme variant of *M. labiatus* (SCHLOTHEIM). As it is now demonstrated by the North American record both species are clearly distinct and, moreover very probable had quite distinct evolutionary origin.

Inoceramus paramytiloides described by SORNAY (1965) from Madagascar falls in the synonymy of *M. mytiloides* (MANTELL). All characters cited to distinguish *M. paramytiloides* from *M. mytiloides* are key characters of MANTELL's species: relatively long hinge line, weakly convex anterior margin and almost straight growth axis.

OCCURRENCE: *Mytiloides mytiloides* ranges from bed 105 to bed 126 in the Pueblo section. Upper part of the Lower Turonian and lowermost Middle Turonian of North America (Western Interior, Texas), South America (Columbia, Brazil) Europe (England, Spain, Germany, Poland, Ukraine, Czech Republic, southern Russia), Madagascar, Japan.

Mytiloides aviculoides (MEEK & HAYDEN 1860)
(Pl. 14, Figs 1-8)

1860. *Inoceramus aviculoides*, F.B. MEEK & F.V. HAYDEN, p. 181.
1876. *Inoceramus problematicus* var. *aviculoides* MEEK & HAYDEN; F.B. MEEK, p. 63, Pl. 9, Fig. 4.
?1911. *Inoceramus labiatus* (SCHLOTHEIM); H. WOODS, p. 281 (pars), Pl. 50, Fig. 1.
1965. *Inoceramus labiatus* (SCHLOTHEIM); D.E. HATTIN, p. 12, Fig. 3.10.
1977. *Mytiloides aviculoides* (MEEK & HAYDEN); E.G. KAUFFMAN, Pl. 12, Fig. 1; Pl. 13, Fig. 2.
1978. *Mytiloides aviculoides* (MEEK & HAYDEN); E.G. KAUFFMAN & al., Pl. 16, Fig. 1; Pl. 17, Fig. 2.
1978. *Mytiloides mytiloides arcuata* (SEITZ)?; E.G. KAUFFMAN & *al*. Pl. 10, Fig. 9.
1992. *Mytilodies labiatus* (SCHLOTHEIM); I. WALASZCZYK, p. 13 (pars), Pl. 4, Fig. 6.

TYPE: The holotype, USNM 242a, is the original specimen of MEEK & HAYDEN, illustrated by MEEK (1876, Pl. 9, Fig. 4; reillustrated herein in Pl. 14, Fig. 4), from Little Blue River bluffs, near the Kansas-Nebraska state line.

MATERIAL: USNM 507444 and USNM 507445, from USGS Mesozoic locality D 11237; two specimens, USNM 507446 and USNM 507447, from USGS Mesozoic locality 3677; three specimens, USNM 507449, USNM 507450, and USNM 507448, from USGS Mesozoic locality D 8831.

DESCRIPTION: Of medium to large size for genus, inequilateral, equivalved. Shell elongated parallel to growth axis, which is distinctly convex in juveniles, becoming progressively straighter through ontogeny. Large, posteriorly extended posterior auricle, triangular in shape, well separated from disc along well-developed auricular sulcus. Hinge line long or very long in relation to axial length. Beak rounded, projecting above hinge line. Anterior margin rounded, distinctly convex, passing into less convex anterior-ventral margin, and thence into narrowly rounded ventral margin. Posterior margin concave, or nearly straight.

Ornament composed of rugae and fine, slightly raised, sharp-edged growth lines. Rugae more or less regularly spaced in juveniles, outline rounded, becoming less regular in adults, where they are also more axially elongated. Rugae become much weaker on posterior auricle. Approaching the hinge line, they usually curve outward towards posterior margin of auricle.

REMARKS: *Mytiloides aviculoides* (MEEK & HAYDEN, 1860) was regarded by KAUFFMAN (1977), and KAUFFMAN & *al*. (1978, 1993) as a Late Turonian species, some of which it closely resembles (see WALASZCZYK & COBBAN 2000). However, the forms accompanying the type are clearly representatives of the "early Turonian" mytiloids (see MEEK 1876, Pl. 9, Figs 3a, 3b), and, moreover, the Upper Turonian is absent at the type locality, i.e. "bluff along Little Blue River" in Nebraska. The type of MEEK & HAYDEN's species closely matches elongate, alate forms occurring in the basal *woollgari* Zone (Plate 14). Taking into account all of these arguments, *M. aviculoides* should be regarded as a species of the *labiatus* group, occurring in the basal part of the Middle Turonian *C. woollgari* ammonite Zone at least in the Pueblo succession, and in the lower part of the *M. subhercynicus* inoceramid Zone. The species was reported from the Lower Turonian of Wyoming by COBBAN & REESIDE (1952).

M. aviculoides is similar to *M. mytiloides* (MANTELL), from which it differs in its distinctly convex growth axis, convex and rounded anterior margin, and nearly circular juvenile outline. Transitional forms are observed. It may be difficult to separate specimens that have been secondarily compressed in an anterior-posterior direction.

More inflated specimens (Pl. 14, Figs 2, 7) resemble *Mytiloides labiatus* (SCHLOTHEIM) (see SEITZ 1935, Text-fig. 9a, 11a-b). The latter, however, at least as interpreted by SEITZ (1935) does not show an outwardly curved ornament on the posterior auricle and is distinctly more inflated.

To *M. aviculoides* should probably be referred the large specimen of "*I. labiatus*" from the Middle Chalk of England, figured by WOODS (1911, Pl. 50, fig. 1).

OCCURRENCE: Known from bed 122 in the Pueblo section. ?Topmost Lower and lowermost Middle Turonian of North America (US Western Interior) and from Europe (England, Germany, Poland).

Mytiloides labiatus (SCHLOTHEIM, 1813)
(Pl. 12, Figs 1-3)

1813. *Ostracites labiatus* VON SCHLOTHEIM, p. 93.
1935. *Inoceramus labiatus* v. SCHLOTHEIM var. *labiata*; O. SEITZ, p. 448, Pl. 38, Figs 1, ?3; Text-fig. 9a [*non* Text-fig. 9b-c]
1965. *Inoceramus labiatus* VON SCHLOTH. var. *antsaronaensis* n. var.; J. SORNAY, p. 12, Pl. B, Fig. 1; Pl. C, Fig. 5.
1978. *Mytiloides labiatus labiatus* (SCHLOTHEIM); E.G. KAUFFMAN, Pl. 2, Figs 1, 6; Pl. 4, Fig. 9.
1982. *Mytiloides labiatus* (SCHLOTHEIM, 1813); S. KELLER, p. 119, Pl. 3, Fig. 3.
?1982. *Mytiloides goppelnensis* (BADILLET & SORNAY, 1980); S. KELLER, p. 128, Pl. 3, Fig. 1.
part 1992. *Mytiloides labiatus* (SCHLOTHEIM); I. WALASZCZYK, p. 13, Pl. 2, Figs 1-3; Pl. 3, Figs 1-4; Pl. 4, Fig. 4.

TYPE: The holotype is the specimen illustrated by WALCH (1768, pl. BIIb, fig. 2) referred by SCHLOTHEIM (1813, p. 93) to *Ostracites labiatus*. The type is lost. According to SEITZ (1935, p. 450) it was probably in the Geological Institute in Jena, Germany before the Second World War. The type corresponds to the two specimens illustrated by SEITZ (1935, Pl. 38, Fig. 1; Text-fig. 9a).

MATERIAL: Three specimens; USNM 507336 and USNM 507335, from USGS Mesozoic locality 22924, and USNM 507400 from USGS Mesozoic locality D 4305.

REMARKS: Only some small-sized specimens are here referred to *Mytiloides labiatus* (SCHLOTHEIM). They occur in beds 97 through 105 of the Pueblo section and seems to occur sporadically only. This material is represented by strongly inflated, irregularly rugate forms, with well separated posterior auricle and pointed beak. The anterior margin is slightly convex, with very high and steep anterior wall, the ventral margin rounded.

The other possible interpretation of these small forms, suggested by Christopher J. WOOD (personal communication, July, 2000) is that they represent *Inoceramus apicalis* WOODS (non TRÖGER, 1967), a form co-occurring in the English Lower Turonian with *Mytiloides* species. A much more detailed comparison with the English material is, however, required to resolve the problem.

This morphotype, corresponding to specimens illustrated by SEITZ (1935, Pl. 38, Fig. 1, and Text-fig. 9a) is extremely rare in the U.S. Western Interior. Illustrated specimens referred to SCHLOTHEIM's species (e.g. KAUFFMAN 1977, Pl. 6, Fig. 13; Pl. 7, Fig. 14; also in KAUFFMAN & *al*. 1978, Pl. 11, Fig. 14; KIRKLAND, 1996, Pl. 30, Fig. E and Pl. 31, Fig. A), are much more slender, axially elongated, and represent rather what is referred here to *M. aviculoides* (MEEK & HAYDEN). *M. labiatus* differs from this latter species in being more robust; i.e. having a higher h/l ratio, particularly in the juvenile part, and in being more convex, and markedly more inflated in juveniles. There are transitional forms.

WALASZCZYK (1992) interpreted *M. labiatus* very widely, including all forms referred here to *M. mytiloides* through transitional forms to *M. labiatus* into a single species, regarding the variability as infraspecific. As is demonstrated by the North American record, *M. mytiloides* and *M. labiatus* are quite distinct forms, and may possibly represent two different lineages.

KAUFFMAN & HARRIES (1996) interpreted the *M. labiatus* lineage as separate from the lineage leading though *M. hattini* – *M. kossmati* – *M. goppelnensis* (as here interpreted) to *M. mytiloides*. To keep these two lineages within a single clade, they accepted a very early appearance of the *M. hattini* group. But *M. hattini* appears just below the Cenomanian/Turonian boundary in the Pueblo sequence, and the "*labiatus*" group may be polyphyletic.

OCCURRENCE: From bed 97 to bed 105 in the Pueblo section. Topmost Lower and lowermost Middle Turonian of North America, Europe (Germany, Poland, Czech Republic), and Madagascar.

Mytiloides subhercynicus (SEITZ, 1935)
(Pl. 15, Figs 1-7)

part 1935. *Inoceramus labiatus* n.var. *subhercynica*; O. SEITZ, p. 465, Pl. 40, Fig. 1 [non Pl. 40, Figs 2, 5; Text-fig. 18a-f].

part 1935. *Inoceramus labiatus* n. var. *subhercynica* n.f. *transiens*; O. SEITZ, p. 468, Pl. 40, Fig. 3 [non Pl. 40, Fig. 4]

non 1955. *Inoceramus subhercynicus* sp.nov.; V.L. EGOYAN, p. 213, Pl. 6, Fig. 1.

1977. *Mytiloides subhercynicus transiens* (SEITZ); E.G. KAUFFMAN, Pl. 7, Figs 9, 13.

part 1977. *Mytiloides subhercynicus* (SEITZ) n. subsp. transitional to *M. mytiloides* (MANTELL); E.G. KAUFFMAN, Pl. 7, Fig. 10 [non Pl. 7, Fig. 12].

1978. *Mytiloides subhercynicus transiens* (SEITZ); E.G. KAUFFMAN, Pl. 1, Fig. 6; Pl. 2, Figs 2, 7.

non 1982. *Mytiloides transiens* (SEITZ); S. KELLER, p. 133, Pl. 3, Fig. 5.

1988. *Mytiloides transiens* (SEITZ, 1935); M.H.R. HESSEL, p. 21, Fig. 31A-B.

1988. *Mytiloides hercynicus* (PETRASCHECK, 1904); M.H.R. HESSEL, p. 21, Fig. 31D-F.

1988. *Mytiloides* aff. *goppelnensis* (BADILLET & SORNAY, 1980); M.H.R. HESSEL, p. 20, Fig. 31C.

non 1992. *Inoceramus* (*Mytiloides*) *transiens* SEITZ; G. LÓPEZ, p. 507, Pl. 2, Fig. 5.

1992. *Mytiloides opalensis* (Böse); I. WALASZCZYK, p. 19 (pars), Pl. 6, Figs1-2, 4; Pl. 7, Figs 1-3; Pl. 8, Figs 2, ?3.

TYPE: The holotype by original designation is specimen 112 from Lengerich (Germany) illustrated by SEITZ (1935, Pl. 40, Fig. 1).

MATERIAL: USNM 507472, USNM 507470, USNM 507455, USNM 507362, USNM 507363, USNM 507469, all from USGS Mesozoic locality D 11328; USNM 507464 (bed 121 from the exposure illustrated in Text-fig. 10); numerous unregistered specimens from the same locality in the collections of the Geological Survey in Denver.

DESCRIPTION: Medium to large-sized for genus, obliquely elongated. Disc moderately to weakly inflated. Posterior auricle well-developed, separated from the disc in the umbonal part along a step-like fold. Umbo terminal, projecting only weakly above hinge line. Hinge line straight, relatively short. Anterior and ventral margins convexly rounded. Posterior margin weakly convex or straight. Juvenile part subcircular or axially elongated.

Ornament usually different in juvenile and adult stages. Juvenile ornament composed of fine, closely spaced rugae, whereas adult rugae are more widely spaced and slightly asymmetrical; ventral slopes are steeper. Rugae covered with raised growth lines. Growth lines usually of equal size but sometimes slightly more distinct at edges of rugae, giving the doubling effect (see Pl. 15, Fig. 4). In some specimens adult rugae distinctly wider spaced than in the juveniles (Pl. 15, Fig. 1).

REMARKS: The specimens from Pueblo (Plate 15) display a relatively wide range of variation in respect of surface ornament. At one extreme are forms with wide rugae, wide interspaces covered with raised growth lines, and a relatively weak distinction between juvenile and adult stages (e.g. Pl. 15, Figs 1, 7). In the middle and adult parts of the shell in some of these forms paired growth lines occur at the edges of rugae, giving a characteristic doubling effect (see Pl. 15, Fig. 4). Such forms are similar in ornament to BÖSE's *Inoceramus opalensis* (BÖSE 1923, Pl. 13, Figs 2-3; *see also* KENNEDY & *al*. 1987, Fig. 12). At other extreme are forms with more delicate ornament. These are characterised by markedly finer rugae and two distinct growth stages (Pl. 15, Fig. 2, 6). They closely resemble the type of *M. subhercynicus* as well as the type of forma *transiens* in SEITZ (1935, Pl. 40, Figs 1, 3).

In SEITZ' (1935) definition of the variety *subhercynicus* the critical character was shell outline in the juvenile part: he referred to *M. subhercynicus* all representatives of the *hattini* group with L>H in the juveniles, i.e. with oval outline. With such a definition many forms from the lowermost Turonian, e.g. *M. kossmati* or *M. goppelnensis* possessing oval or nearly rounded shell outline in the juvenile would be referred to *M. subhercynicus*. Many of the forms illustrated in SEITZ' original description do represent these older species. All of forms illustrated from Ziegenberg near Wolfsdorf (SEITZ 1935, Text-fig. 18; Pl. 40, Figs 2, 4-5) are from a horizon well below the first occurrence of *M. subhercynicus* as represented by the type specimen (WALASZCZYK 1992); they should be referred to *M. goppelnensis*. A very important characteristic of *M. subhercynicus* is the step-like boundary between the posterior auricle and the disc in the juvenile part. It produces a distinct separation of the posterior auricle in the dorsal part of the shell.

The small specimen 507455 (Pl. 15, Fig. 3) represents only the juvenile part and shows distinct geniculation. It closely resembles the form described by BADILLET & SORNAY (1982; *see also* SORNAY 1982, Pl. 7, Fig. 3) as *Inoceramus goppelnensis tourtenayensis*, and is here referred to as *Mytiloides subhercynicus tourtenayensis* (BADILLET & SORNAY).

The nature of the transition between *M. subhercynicus* (SEITZ) and *M. hercynicus* (PETRASCHECK) has been poorly characterised. Both *M. hercynicus* and *M. subhercynicus* possess a characteristic step-like boundary between disc and posterior auricle in the juvenile part, but differ in that the juvenile part of *hercynicus* is distinctly oval, the long axis of the oval parallel to the hinge-line. Of the three specimens, illustrated by PETRASCHECK (1903, pl. 8, figs 1-3), this oval juvenile outline is best developed in the two paralectotypes, whereas the lectotype itself (PETRASCHECK 1903, pl. 8, fig. 3) is moderately characteristic in this respect. None of the material studied here, which comes from the interval between beds 121 and 132 (inclusive) includes specimens referable to *M. hercynicus*, although this species occurs higher in the succession.

Specimens with more vigorous ornament (e.g. our USNM 507472 or USNM 507411 – Pl. 15, Figs 1 and 4) are very similar to Böse's (1913) *Mytiloides opalensis*, in particular his specimen from Opal (Zacatecas, Mexico) evidently regarded as the type by Böse (1923, Pl. 13, Figs 2-3 non Pl. 13, fig. 1; see also Kennedy & al. 1987, text-fig. 12E). In contrast to *M. subhercynicus*, which is markedly elongated postero-ventrally, Böse's specimen is much less oblique, with the disc forming an almost equilateral triangle, as in case of *Mytiloides hercynicus*. A revision of topotype material of the Mexican species is needed to establish whether or not *M. opalensis* (Böse) represents a weakly ovate *M. hercynicus* or an atypical *M. subhercynicus*.

Badillet & Sornay (1980) noted that the name *subhercynicus*, used by Seitz (1935) as a variety name, was used independently for a species-level taxon by Egoyan (1955). They proposed, consequently, the name *transiens* for Seitz' concept of variety *subhercynicus*. This name was used by Seitz (1935) to distinguish a form of *M. subhercynicus* with two distinct ontogenetic stages. As it was already stressed by Kennedy & *al*. (1989) this is nomenclaturally invalid. Seitz' *subhercynica* was proposed as a variety and according to the Rules the term variety introduced before 1961 is not to be interpreted as an express statement of infrasubspecific rank. Seitz (1935) clearly interpreted his *subhercynica* as a subspecies, as subsequently indicated (Seitz 1961), and his name is available. Seitz (1961) regarded all of the taxa distinguished by him in 1935 as of infrasubspecific rank. Thus the name *transiens* is not available.

OCCURRENCE: From bed 121 to at least bed 132 in the Pueblo section. Known from the lowermost Middle Turonian of North America (US Western Interior), South America (Brazil), Europe (England, France, Spain, Germany, Poland, Czech Republic, Romania, Ukraine, southern Russia), Japan.

Acknowledgements

Kennedy acknowledges the technical support of the staff of the Department of Earth Sciences and University Museum of Natural History, Oxford.

Walaszczyk would like to express his sincere thanks to G. López, Barcelona, for providing specimens of *M. ganuzaensis* and discussion on the species. He acknowledges with many thanks award of a fellowship from the Fulbright Foundation to study in the United States, and the agreement of the USGS Survey that enabled him to study the Pueblo section and the Survey collections.

We thank P. Dodsworth (Alton), W.P. Elder (San Francisco), A.S. Gale (Greenwich), J.M. Hancock (Shaftesbury), J.I. Kirkland (Salt Lake City), G.R. Scott (Denver), and K.-A. Tröger (Freiberg) for helpful advice. A.V. Dhondt (Brussels), J.M. Hancock (Shaftesbury) and C.J. Wood (London) critically reviewd the manuscript and saved us from many errors.

REFERENCES

Accarie, H., Emmanuel, L., Robaszynski, F., Baudin, F. Amédro, F., Caron, M. & Deconinck, J.-F. 1996. La géochimie isotopique du carbone ($\delta^{13}C$) comme outil stratigraphique. Application ą la limite Cénomanien/Turonien en Tunisie central. *Comptes Rendus de l'Academie des Sciences de Paris* Série 2a, **322**, 579-586. Paris.

Anderson, F. M. 1958. Upper Cretaceous of the Pacific Coast. *Memoir of the Geological Society of America*, **71**, 378 pp. Boulder.

Arthur, M.A., Dean, W.E. & Pratt, L.M. 1988. Geochemical and climatic effects of increased marine organic carbon burial at the Cenomanian/Turonian boundary. *Nature* **335**, 714-717. London.

Badillet, G. & Sornay, J. 1980. Sur quelques formes du groupe d'*Inoceramus labiatus* décrites par O. Seitz. Impossibilité d'utiliser ce groupe pour une datation stratigraphique du Turonien inférieur du Saumurois (France). *Compte Rendu Academie Science Paris, Serie D*, **290**, 323-325. Paris.

Barrois, C. & Guerne, J. de. 1878. Description de quelques espèces nouvelles de la Craie de l'Est du Bassin de Paris. *Annales de la Société géologique du Nord* **5**, 42-64.

Bengtson, P. 1996. The Turonian stage and substage boundaries. *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre* **66** (supplément), 69-79. Bruxelles.

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. *Bulletin of the Geological Society of Denmark*, **33** (1-2), 41-55. Copenhagen.

Besairie, H. 1930. Recherches géologiques à Madagascar. Contribution à l'étude des ressources minérales. *Thèses présentées a la Faculté des Sciences de l'Université de Paris*, 272pp. Toulouse.

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. Copenhagen.

Black, M. 1967. New names for some coccolith taxa. *Proceedings of the Geological Society of London* **1640**, 139-145. London.

BÖSE, E. 1923. Algunas faunas Cretacicas de Zacatecas, Durango y Guerrero. *Boletin Insituto Geologico de Mexico*, **42**, 181-189. Mexico.

BRALOWER, T.J. 1988. Calcareous nannofossil biostratigraphy and assemblages at the Cenomanian-Turonian boundary interval : implications for the origin and timing of oceanic anoxia. *Palaeoceanography* **3**, 275-316.

COBBAN, W.A. 1984. The Upper Cretaceous guide fossil, *Mytiloides mytiloides* (MANTELL) in New Mexico. In KOTTLOWSKI, J.E. et al. *New Mexico Bureau of Mines and Mineral Resources Annual Report* **1982-1983**, 35-36. Socorro.

— 1985. Ammonite record from Bridge Creek Member of Greenhorn Limestone at Pueblo Reservoir State Recreation Area, Colorado. *Society of Economic Paleontologists and Mineralogists Field Trip Guidebook* **4**, Midyear Meeting, Golden, Colorado, 135-138.

COBBAN, W.A., HOOK, S.C. & KENNEDY, W.J. 1989. Upper Cretaceous rocks and ammonite faunas of south-western New Mexico. *Memoir of the New Mexico Bureau of Mines and Mineral Resources* **45**, 137 p.

COBBAN, W.A. & REESIDE, J.B. JR. 1952. Frontier Formation, Wyoming and adjacent areas. *Bulletin of the American Association of Petroleum Geologists* **36**, 1913-1961.

COBBAN, W.A. & SCOTT, G.R. 1973. Stratigraphy and ammonite fauna of the Graneros Shale and Greenhorn Limestone near Pueblo, Colorado. *United States Geological Survey Professional Paper* **645**, 108 p. Washington. (1972 imprint).

CONRAD, T.A. 1855. Descriptions of eighteen new Cretaceous and Tertiary fossils, etc. *Proceedings of the Philadelphia Academy of Natural Sciences* **7**, 265-268. Philadephia.

DODSWORTH, P. 2000, in press. Trans-Atlantic dinoflagellate cyst stratigraphy across the Cenomanian-Turonian (Cretaceous) stage boundary. *Journal of Micropalaeontology*

EGOYAN, V.L. 1955. The Upper Cretaceous deposits of the southwestern part of the Armenian SSR. 270pp. *Academy of Sciences of the Armenian SSR*; Erevan.

EICHER, D.L. & DINER, R. 1985. Foraminifera as indicators of water mass in the Cretaceous Greenhorn Sea, Western Interior. *Society of Economic Paleontologists and Mineralogists Field Trip Guidebook* **4**, Midyear Meeting, Golden, Colorado, 60-7 1.

ELDER, W.P. 1985. Biotic patterns across the Cenomanian Turonian extinction boundary near Pueblo, Colorado. *Society of Economic Paleontologists and Mineralogists Field Trip Guidebook* **4**, Midyear Meeting, Golden, Colorado, 157-169.

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

— 1988. Geometry of Upper Cretaceous bentonite beds; Implications about volcanic source areas and paleowind patterns, Western Interior, United States. *Geology* **16**, 835-838.

— 1989. Molluscan extinction patterns across the Cenomanian-Turonian stage boundary in the Western Interior of the United States. *Paleobiology* **15**, 299-320. Chicago.

— 1991. *Mytiloides hattini* n. sp., a guide fossil for the base of the Turonian in the Western Interior of North America. *Journal of Paleontology* **65**, 234-241. Tulsa.

ELDER, W.P. & KIRKLAND, J.I. 1985. Stratigraphy and depositional environments of the Bridge Creek Limestone Member of the Greenhorn Limestone at Rock Canyon anticline near Pueblo, Colorado. *Society of Economic Paleontologists and Mineralogists Field Trip Guidebook* **4**, Midyear Meeting, Golden, Colorado, 122-134.

GALE, A.S., JENKYNS, H.C., KENNEDY, W.J. & CORFIELD, R.M. 1993. Chemostratigraphy versus biostratigraphy: data from around the Cenomanian-Turonian boundary. *Journal of the Geological Society of London* **150**, 29-32. London.

HAGESAWA, T. (1995). Correlation of the Cenomanian/Turonian boundary between Japan and Western Interior of United States. *Journal of the Geological Society of Japan* **101**, 2-12. Tokyo.

HANCOCK, J.M. 1984. Some possible boundary-stratotypes for the base of the Cenomanian and Turonian Stages. *Bulletin of the Geological Society of Denmark* **33**, 123-128. Copenhagen.

HANCOCK, J. M., KENNEDY, W. J. & COBBAN, W. A. 1993. A correlation of the Upper Albian to basal Coniacian sequences of northwest Europe, Texas and the United States Western Interior. *In*: CALDWELL W. G. E. & KAUFFMAN, E. G. (*Eds*). Evolution of the Western Interior Basin. *Special Paper of the Geological Association of Canada*, **39**, 397-434. Ottawa.

HARRIES, P.J. 1993. Dynamics of survival following the Cenomanian-Turonian mass extinction event. *Cretaceous Research* **14**, 563-583. London.

HARRIES, P.J. & KAUFFMAN, E.G. 1990. Patterns of survival and recovery following the Cenomanian-Turonian (Late Cretaceous) mass extinction event in the Western Interior Basin, United States. *In*: E.G. KAUFFMAN & O.H. WALLISTER (*Eds*), *Lecture Notes in Earth History* **30**, 277-298.

HARRIES, P. J., KAUFFMAN, E. G. & CRAMPTON, J. S. (*Redactors*). 1996. Lower Turonian Euramerican Inoceramidae: a morphologic, taxonomic, and biostratigraphic overview. A report from the First Workshop on Early Turonian Inoceramids (Oct. 5-8, 1992) in Hamburg, Germany; organized by Heinz HILBRECHT and Peter HARRIES. *Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg* **77**, 641-671. Hamburg.

HART, M.B. & BIGG, P.J. 1981. Anoxic events in the late Cretaceous shelf seas of northwest Europe. *In*: J.W. NEALE & M.D. BRASIER (*Eds*), *Microfossils from Recent and fossil shelf seas,* 117-185. *Ellis Horwood Limited*; Chichester.

HATTIN, D.E. 1965. Upper Cretaceous stratigraphy, paleontology, and paleoecology of western Kansas, with a section on the Pierre Shale, by W.A. Cobban. *Geological Society of America Field Conference Guidebook 18th Annual Meetings*. 69 pp.

— 1971. Widespread, synchronously deposited, burrow-mottled limestone beds in Greenhorn Limestone (Upper Cretaceous) of Kansas and southeastern Colorado. *Bulletin of the American Association of Petroleum Geologists* **55**, 412-431.

— 1975. Stratigraphy and depositional environment of Greenhorn Limestone (Upper Cretaceous) of Kansas. *Bulletin of the Kansas Geological Survey* **209**, 1-128. Lawrence, Kansas.

— 1987. Pelagic/hemipelagic rhythmites of the Greenhorn Limestone (Upper Cretaceous) of northeastern New Mexico and southeastern Colorado. New Mexico Geological Society Guidebook, 38th Field Conference, Northeastern New Mexico, 1987, pp. 237-247.

HEINZ, R. 1928a. Cenoman und Turon bei Wünstorf westlich von Hannover. *Jahresbericht des Niedersächsischen geologischen Vereins zu Hannover* **21**, 18-38.

— 1928b. Über die Oberkreide-Inoceramen Süd-Amerikas und ihre Beziehungen zu denen Europas und anderer Gebiete. Beiträge zur Kenntnis der oberkretazischen Inoceramen V. *Mitteilungen aus dem Mineralogisch-Geologischen Staatsinstitut, Hamburg*, **10**, 42-97. Hamburg.

— 1930. Zur stratigraphischen Stellung der Sonnenbergschichten bei Waltersdorf i Sa. (west-südwestlich von Zittau). Beiträge zur Kenntnis der oberkretazischen Inoceramen IX. *Jahresbericht des Niedersächsischen geologischen Vereins zu Hannover* **23**, 23-29.

— 1932. Sur les Inocerames de Madagascar. Leur relations avec les Inocerames d'Europe et d'autres region et leur importance pour l'etude stratigraphique du Crétacé. Contribution à la connaissance des Inocerames XIII. Gouvernement Général de Madagascar et Dépendances. *Annales Géologiques du Service des Mines* **2**, 3-7. Tananarive.

— 1933. Inoceramen von Madagascar und ihre Bedeutung für die Kreide-Stratigraphie. *Zeitschrift der Deutschen Geologischen Gesellschaft* **85**, 241-259. Berlin.

— 1935. Unterkreide-Inoceramen von der Kapverden-Insel Maio. Beiträge zur Kenntnis der Inoceramen XVIII. *Neues Jahrbuch für Mineralogie und Geologie, Beilage-Band* **73**, Abteilung B, 302-311. Berlin.

HESSEL, M.H.R. 1988. Lower Turonian inoceramids from Sergipe, Brazil: systematics, stratigraphy and palaeoecology. *Fossils and Strata* **22**, 1-49. Oslo.

JARVIS, I., CARSON, G., COOPER, M.K.E., HART, M.B., LEARY, P.N., TOCHER, B.A., HORNE, D. & ROSENFELD, A. 1988. Microfossil assemblages and the Cenomanian-Turonian (Late Cretaceous) oceanic anoxic event. *Cretaceous Research* **9**, 3-103. London.

JENKYNS, H.C. 1980. Cretaceous anoxic events: from continents to oceans. *Journal of the Geological Society of London* **137**, 171-188. London.

KAUFFMAN, E.G. 1977. Illustrated guide to biostratigraphically important Cretaceous macrofossils, Western Interior Basin, USA. *Mountain Geologist* **14**, 225-274. Boulder.

— 1978. An outline of Middle Cretaceous marine history and inoceramid biostratigraphy in the Bohemian Basin, Czechoslovakia. *Annales du Museum d'Histoire Naturelle de Nice* **4** (XIII), 1-12. Nice.

— 1984. Paleobiogeography and evolutionary response dynamic in the Cretaceous Western Interior seaway of North America*.* *Geological Association of Canada, Special Paper* **27**, 273-306. Ottawa.

KAUFFMAN, E.G., COBBAN, W. A. & EICHER, D. L. 1978. Albian through Lower Coniacian strata. Biostratigraphy and principal events in Western Interior states. *Annales du Museum d'Histoire Naturelle de Nice* **4** (XXIII), 1-52. Nice.

KAUFFMAN, E.G. & HARRIES, P.J. 1996. The importance of crisis progenitors in recovery from mass extinction. *In*: M.B. HART (*Ed*.), Biotic recovery from mass extinction events. *Special Publication of the Geological Society* **102**, 15-39. London.

KAUFFMAN, E.G. & POWELL, J.D. 1977. Paleontology. *In*: KAUFFMAN, E.G., HATTIN, D.E. & POWELL, J.D. Stratigraphic, paleontologic, and paleoenvironmental analysis of the Upper Cretaceous rocks of Cimarron County, Oklahoma. *Geological Society of America Memoir* **149**, 47-114. Boulder.

KAUFFMAN, E.G., SAGEMAN, B. B., KIRKLAND, J. I., ELDER, W. P., HARRIES, P. J. & VILLAMIL, T. 1993. Molluscan biostratigraphy of the Cretaceous Western Interior Basin, North America. *In* CALDWELL W. G. E. AND KAUFFMAN, E. G. (*Eds*). Evolution of the Western Interior Basin. *Special Paper of the Geological Association of Canada* **39**, 397-434. Ottawa.

KELLER, S. 1982. Die Oberkreide der Sack-Mulde bei Alfeld (Cenoman – Unter-Coniac). Lithologie, Biostratigraphie und Inoceramen. *Geologisches Jahrbuch* **A64**, 1-171. Hannover.

KENNEDY, W.J., AMÉDRO, F., BADILLET, G. & HANCOCK, J.M. 1984. Notes on late Cenomanian and Turonian ammonites from Touraine, western France. *Cretaceous Research* **5**, 29-45. London.

KENNEDY, W.J. & COBBAN, W.A. 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. *Newsletters on Stratigraphy* **24**, 1-33. Berlin-Stuttgart.

KENNEDY, W.J., COBBAN, W.A., ELDER, W.F. & KIRKLAND, J.I. 2000. Lower Turonian (Upper Cretaceous) *Watinoceras devonense* Zone ammonite fauna in Colorado. *Cretaceous Research* **21**, 629-639. London.

KENNEDY, W.J., COBBAN, W.A., HANCOCK, J. M. & HOOK, S. C. 1989. Biostratigraphy of the Chispa Summit Formation at its type locality: a Cenomanian through Turonian reference section for Trans-Pecos Texas. *Bulletin of the Geological Institutions of the University of Uppsala, New Series* **15**, 39-119. Uppsala.

KENNEDY, W.J., WRIGHT, C.W. & HANCOCK, J.M. 1987. Basal Turonian ammonites from west Texas. *Palaeontology* **30**, 27-74. London.

KIRKLAND, J.I. 1991. Lithostratigraphic and biostratigraphic framework for the Mancos Shale (Late Cenomanian to Middle Turonian) at Black Mesa, northeastern Arizona.

Geological Society of America Special Paper **260**, 85-111.

— 1996. Paleontology of the Greenhorn cyclothem (Cretaceous: late Cenomanian to middle Turonian) at Black Mesa, northeastern Arizona. *Bulletin of the New Mexico Museum of Natural History and Science* **9**, pp. 1-131. Albuquerque.

KOWALLIS, B.J., CHRISTIANSEN, E.H., DEINO, A.L., KUNK, M.J. & HEAMAN, L.M. 1995. Age of the Cenomanian-Turonian boundary in the Western Interior of the United States. *Cretaceous Research* **16**, 109-129. London.

KUHNT, W., HERBIN, J.P., THUROW, J. & WIEDMANN, J. 1990. Distribution of Cenomanian-Turonian organic facies in the western Mediterranean and along the adjacent Atlantic margin. *American Association of Petroleum Geologists, Studies in Geology* **30**, 133-160.

LAMOLDA, M.A., LOPEZ, G. & MARTINEZ, R. 1989. Turonian integrated biostratigraphy in the Estella Basin (Navarra, Spain). *In*: J. WIEDMANN (*Ed.*), Cretaceous of the Western Tethys. *Proceedings 3rd International Cretaceous Symposium, Tübingen* 1987, pp. 145-159. *E.Schweizerbart'sche Verlagsbuchhandlung*; Stuttgart.

LAMOLDA, M.A., GOROSTIDI, A., MARTINEZ, R., LOPEZ, G. & PERYT, D. 1997. Fossil occurrences in the Cenomanian-Lower Turonian at Ganuza, northern Spain: an approach to Cenomanian/Turonian boundary chronostratigraphy. *Cretaceous Research* **18**, 331-353. London.

LEARY, P.N. & PERYT, D. 1991. The late Cenomanian-Oceanic Anoxic Event in the western Anglo-Paris Basin and southeast Danish-Polish trough: survival strategies of and recolonisation by benthonic foraminifera. *Historical Biology* **5**, 321-338.

LECKIE, R.M. 1985. Foraminifera of the Cenomanian-Turonian boundary interval, Greenhorn Formation, Rock Canyon Anticline, Pueblo, Colorado. *Society of Economic Paleontologists and Mineralogists Field Trip Guidebook* **4**, Midyear Meeting, Golden, Colorado, 139-155.

LÓPEZ, G. 1982. Paleontología y bioestratigrafía de los inocerámidos (Bivalvia) del Cretácico Superior de la Cuenca Navarro-Cántabra y de la Plataforma Norcastellana. Parte II: Estudio sistemático de los subgéneros *Mytiloides* BRONGNIART y *Magadiceramus* SEITZ. *Boletín Geológico y Minero* **103**, 478-543. Madrid.

MANTELL, G.A. 1822. *The fossils of the South Downs; or illustrations of the geology of Sussex*. xvi + 327 p. *Lupton Relfe*, London.

MARCINOWSKI, R., WALASZCZYK, I. & OLSZEWSKA-NEJBERT, D. 1996. Stratigraphy and regional development of the mid-Cretaceous (Upper Albian through Coniacian) of the Mangyshlak Mountains, Western Kazakhstan. *Acta Geologica Polonica* **46**, 1-60. Warszawa.

MATSUMOTO, T. & NISHIDA, T. 1995. Stratigraphic occurrences of *Mytiloides* (Bivalvia) in the mid-Upper Cretaceous sequence of Hokkaido. *Fossils*, **59**, 47-66. Tokyo.

MATSUMOTO, T. & NODA, M. 1975. Notes on *Inoceramus labiatus* (Cretaceous Bivalvia) from Hokkaido. *Transactions and Proceedings of the Palaeontological Society of Japan, N.S.* **100**, 188-208. Tokyo.

MEEK, F.B. 1876. A report on the invertebrate Cretaceous and Tertiary fossils of the Upper Missouri Country. *Department of the Interior. Report of the United States Geological Survey of the Territories* **9**, 1-629. Washington.

MEEK, F.B. & HAYDEN, F.V. 1860. Description of new organic remains from the Tertiary, Cretaceous and Jurassic rocks of Nebraska. *Proceedings of the Academy of Natural Sciences of Philadelphia* **12**, 175-185. Philadelphia.

MORROW, A.L. 1934. Foraminifera and Ostracoda from the Upper Cretaceous of Kansas. *Journal of Paleontology* **8**, 186-205. Tulsa.

NAGAO, T. & MATSUMOTO, T. 1940. A monograph of the Cretaceous Inoceramus of Japan. Part II. *Journal of Science, Hokkaido Imperial University* (4) **6**, 1-64, pls. 1-22. Hokkaido.

OBRADOVICH, J. 1993. A Cretaceous time scale. *Geological Association of Canada Special Paper* **39**, 379-396. Ottawa.

ORTH, C.J., ATTREP, M., MAO, X., KAUFFMAN, E.G., DINER, R. & ELDER, W.P. 1988. Iridium abundance maxima in the Upper Cenomanian extinction interval. *Geophysical Research Letters* **15**, 346-349.

ORBIGNY, A. D'. 1850. *Prodrome de Paléontologie stratigraphique universelle des animaux Mollusques et rayonnés faisant suite au cours élémentaire de Paléontologie et de Géologie stratigraphiques* **2**, 427 p. Masson, Paris.

— 1852. *Cours Elementaire de Paléontologie et de Géologie Stratigraphique* **2**, 383-847. Masson, Paris.

PAUL, C.R.C., MITCHELL, S., LAMOLDA, M. & GOROSTIDI, A. 1994. The Cenomanian-Turonian boundary event in northern Spain. *Geological Magazine* **131**, 801-817. London.

PETRASCHECK, W. 1903. Ueber Inoceramen aus der Kreide Böhmens und Sachsens. *Jahrbuch der Kaiserlich-Königlichen Geologischen Reichsanstalt, Wien*. **58**, 153-168. Wien.

POWELL, J.D. 1963. Cenomanian-Turonian (Cretaceous) ammonites from Trans-Pecos Texas, and northeastern Chihuahua, Mexico. *Journal of Paleontology* **37**, 309-322. Tulsa.

PRATT, L. 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 carbonates in mid-Cretaceous strata near Pueblo, Colorado. *Penrose Conference on Paleoclimates, Florissant, Colorado, Excursion Guidebook*, 77-98.

— 1984. Influence of paleoenvironmental factors on preservation of organic matter in Middle Cretaceous Greenhorn Formation, Pueblo, Colorado. *Bulletin of the American Association of Petroleum Geologists* **68**, 1146-1149.

— 1985. Isotopic studies of organic matter and carbonate in rocks of the Greenhorn marine cycle. *Society of Economic Paleontologists and Mineralogists Field Trip Guidebook* **4**, Midyear Meeting, Golden, Colorado, 38-48. Boulder.

PRATT, L.M., ARTHUR, M.A., DEAN, W.E. & SCHOLLE, P.A. 1993. Paleo-oceanographic cycles and events during the Late Cretaceous in the Western Interior Seaway of North America. *Geological Association of Canada Special Paper* **39**, 333-353. Ottawa.

PRATT L.M., KAUFFMAN, E.G. & ELDER, W.P. 1983. Paleontologic and geochemical resolution of the Cenomanian-Turonian (Cretaceous) extinction event in the Western Interior of North America. *Geological Society of America, Abstracts with Programmes* **15**, 664.

PRATT, L.M., KAUFFMAN, E.G. & ZELT, F.B. (*Eds*) 1985. Fine-grained deposits and biofacies of the Cretaceous Western Interior Seaway: evidence of a cyclic sedimentary process. *Society of Economic Paleontologists and Mineralogists Field Trip Guidebook* **4**, Midyear Meeting, Golden, Colorado, 249 + 26 p. of field reference sections.

PRATT, L.M. & THRELKELD, C.N. 1984. Stratigraphic significance of $\delta^{13}C/\delta^{12}C$ ratios in mid Cretaceous rocks of the Western Interior. *Memoir of the Canadian Society of Petroleum Geologists* **9**, 305-312.

REMANE, J., BASSETT, M.G., COWIE, J.W., GOHRBANDT, K.H., LANE, H.R., MICHELSEN, O. & NAIWEN, W. 1996. Revised guidelines for the establishment of global chronostratigraphic standards by the International Commission on Stratigraphy (ICS). *Episodes* **19**, 77-80.

ROBASZYNSKI, F. 1978. Approche biostratigraphique du Cénomano-Turonien dans le Hainaut Franco-Belge et le Nord de la France. *Annales du Muséum d'Histoire Naturelle de Nice* **4**, VIII.1-VIII.19. Nice.

ROBASZYNSKI, F. (*coord.*), ALCAYDÉ, G., AMÉDRO, F., BADILLET, G., DAMOTTE, R., FOUCHER, J.C., JARDINÉ, S., LEGOUX, O., MANIVIT, H., MONCIARDINI, C. & SORNAY, J. 1982. Le Turonian de la région-type: Saumurois et Touraine. Stratigraphie, biozonation, sédimentologie. Bulletin des Centres Recherches Exploration-Production Elf-Aquitaine **6**, 119-225. Pau.

ROBASZYNSKI, F. & GALE, A.S. 1993. The Cenomanian-Turonian boundary – a discussion held at the final session of the colloquium on Cenomanian-Turonian events, Grenoble, 26 May 1991 (France). *Cretaceous Research* **14**, 607-611. London.

SCHLANGER, S.O., ARTHUR, M.A., JENKYNS, H.C.. & SCHOLLE, P.A. 1987. The Cenomanian-Turonian Oceanic Anoxic Event, 1. Stratigraphy and distribution of organic carbon-rich beds and the marine excursion. *Special Publication of the Geological Society of London* **26**, 371-99. London.

SCHLANGER, S.O. & JENKYNS, H.C. 1976. Cretaceous oceanic anoxic sediments: causes and consequences. *Geologie en Mijnbouw* **55**, 179-84.

SCHLOTHEIM, VON, E.T. 1813. Beiträge zur Naturgeschichte der Versteinerungen in geognostischer Hinsicht. Leonhard's Taschenbuch für Mineralogie **5-7**, 93pp. Frankfurt am Main.

SCHLÜTER, C. 1871-1876. Cephalopoden der oberen deutschen Kreide. *Palaeontographica*. **21**, 1-24 (1871); **21**, 25-120 (1872); **24**, 1-144 (121-264) + x (1876). Cassel.

SCHOLLE, P.A. & ARTHUR, M.A. 1980. Carbon isotope fluctuations in Cretaceous pelagic limestones: potential stratigraphic and petroleum exploration tool. *American Association of Petroleum Geolgists Bulletin* **64**, 67-87.

SCOTT, G.R. 1964. Geology of the Northwest and Northeast Pueblo Quadrangles, Colorado. *United States Geological Survey Miscellaneous Geological Investigations* Map **1-408**. Washington, D.C.

— 1970. Geologic map of the Southwest and Southeast Pueblo Quadrangles, Colorado. *United States Geological Survey Miscellaneous Geological Investigations* Map **1-597**. Washington, D.C.

SEIBERTZ, E. 1995. Turonian inoceramid evolution and its use for stage and zonal boundary definition. In: Second International Symposium on Cretaceous Stage Boundaries, Brussels, 8-16 September 1995, *Abstract Volume*, p. 113. Brussels.

SEITZ, O. 1935. Die Variabilität des *Inoceramus labiatus* v. SCHLOTH. *Jahrbuch der Preußichen Geologischen Landesamt* **55**, 429-474. Berlin.

— 1961. Die Inoceramen des Santon von Nordwestdeutschland. I. Teil: Die Untergattungen *Platyceramus*, *Cladoceramus* und *Cordiceramus*. *Beihefte zum Geologischen Jahrbuch* **46**, 1-186. Hannover.

SORNAY, J. 1965. La faune d'Inocérames du Cénomanien et du Turonien inférieur du sud-ouest de Madagascar. *Annales de Paléontologie* **51**, 3-18. Paris.

— 1980. Inocérames (Bivalvia) du Turonien inférieur de Colombie (Amérique de Sud). *Annales de Paléontologie (Invertébrés)* **67**, 135-144. Paris.

— 1982. Les Inocérames du Turonien Francáis et leur répartition stratigraphique. *Mémoires du Muséum National d'Histoire Naturelle* N.S. **49**, 183-187. Paris.

SOWERBY, J. 1812-1822. *The Mineral Conchology of Great Britain*. The author, London.

SOWERBY, J. DE C. 1823-1846. *The Mineral Conchology of Great Britain* (continued). The author, London.

STANTON, T.W 1894. The Colorado Formation and its invertebrate fauna. *United States Geological Survey Bulletin* **106**, 288 p. Washington, D.C. [1893 imprint]

TRÖGER, K.-A. 1967 Zur Paläontologie, Biostratigraphie und faziellen Ausbildung der unteren Oberkreide (Cenoman bis Turon). Teil I: Paläontologie und Biostratigraphie Inoceramen des Cenomans bis Turons. *Abhandlungen des Staatlichen Museums für Mineralogie und Geologie zu Dresden* **12,** 13-208. Dresden.

— 1981. Zu Problemen der Biostratigraphie der Inoceramen und der Untergliederung des Cenomans und Turons in Mittel- und Osteuropa. *Newsletters on Stratigraphy* **9**, 139-156. Berlin – Stuttgart.

WALASZCZYK, I. 1992. Turonian through Santonian deposits of the Central Polish Uplands; their facies development, inoceramid paleontology and stratigraphy. *Acta Geologica Polonica* **42**, 1-122. Warszawa.

WALASZCZYK, I. & COBBAN, W.A. 2000. Inoceramid faunas and biostratigraphy of the Upper Turonian-Lower Coniacian of the United States Western Interior. *Special Papers in Palaeontology*, **54**. London.

WALCH, J.E.I. 1768. Die Naturgeschichte der Versteinerungen zur Erläuterung der Knorrischen Sammlung von Merkwürdigkeiten der Natur. **2**, p. 84. Nürnberg.

WATKINS, D.K. 1985. Biostratigraphy and paleoecology of calcareous nannofossils in the Greenhorn marine cycle. *Society of Economic Paleontologists and Mineralogists Field Trip Guidebook* **4**, Midyear Meeting, Golden, Colorado, 151-156. Boulder.

WIEDMANN, J. & KAUFFMAN, E.G. 1978. Mid-Cretaceous stratigraphy of northern Spain. *Annales du Muséum d'Histoire Naturelle de Nice* **4**, III1-III34. Nice.

WOODS, H. 1911. A monograph of the Cretaceous Lamellibranchia of England. *Palaeontographical Society*, *Monograph* **2**, 261-284. London.

WRIGHT, C.W. & KENNEDY, W.J. 1981. The Ammonoidea of the Plenus Marls and the Middle Chalk. *Palaeontographical Society Monographs* 148 p. London.

YOKOYAMA, M. 1890. Versteinerungen der Japanischen Kreide. *Paleontographica* **36**, 159-202. Cassel.

Manuscript submitted: 15th March 2000
Revised version accepted: 15th July 2000

PLATES 1-15

PLATE 1

Ammonites from the *Watinoceras devonense* zone fauna of bed 86 of the Bridge Creek Member of the Greenhorn Limestone

1-4, 14-18, 20, 21 – *Watinoceras praecursor* WRIGHT & KENNEDY, 1981. 1, USNM 441443, from locality D12715. 2, USNM 441441, from locality D12715. A latex cast. 3, USNM 441440, from locality D12715. A latex cast. 4, USNM 460750, from locality D12715. A latex cast. 14, USNM 460735, from locality D13246. 15, 16, USNM 460736, from locality D13246. 17, USNM 441438, from locality D6123. 18, USNM 442106, from locality D3975. A latex cast. 20, USNM 441442, from locality D12460. A latex cast. 21, USNM 460737, from locality D13246

5-7, 12 – *Watinoceras devonense devonense* WRIGHT & KENNEDY, 1981; 5, 6, USNM 441445, from locality D3975. Figure 5 is a latex cast. 7, USNM 441447, from locality D3975. 12, USNM 441446, from locality D10176

9-11, 13, 19 – *Watinoceras depressum* WRIGHT & KENNEDY, 1981. 9, USNM 441450, from locality D12715. 10, USNM 441452, from locality D12715. 11, USNM 441451, from locality D12715. 13, USNM 441448, from locality D12715. 19, USNM 460749, from locality D12715

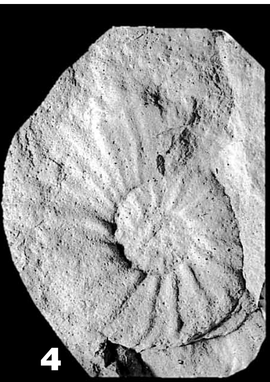
8 – *Quitmaniceras reaseri* POWELL, 1963, USNM 441468, from locality D12715

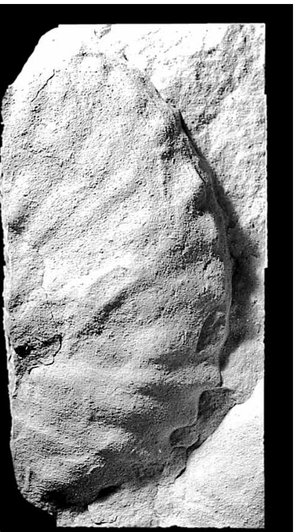
All figures are × 1


1

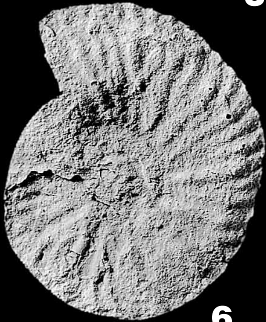

2


3


4


14


5


6


7


8

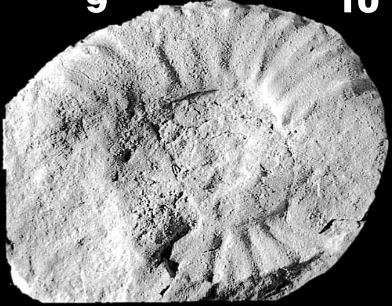

13


9


10


11


12

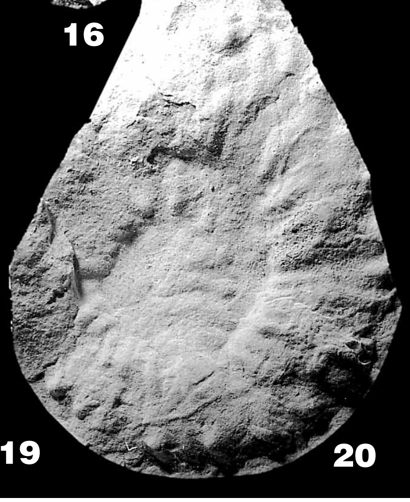

15


16


17


18


19


20

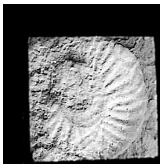

21

PLATE 2

Watinoceras devonense Zone ammonites from bed 86 of the Bridge Creek Member of the Greenhorn Limestone

1, 6-7, 24-25 – *Watinoceras praecursor* WRIGHT & KENNEDY, 1981; 1 – USNM 441439, from locality D12715; 6-7 – USNM 460738, from locality D13246; 24 – USNM 460739, from locality D13246; 25 – USNM 460740, from locality D12715
2-4, 8, 9, 11-13, 16-20, 26-28 – *Quitmaniceras reaseri* POWELL, 1963; 2 – USNM 441462, from locality D12715; 3 – USNM 441463, from locality D12715, a latex cast; 4 – USNM 441461, from locality D12715, a latex cast; 8 – USNM 441460, from locality D12715; 9 – USNM 460741, latex cast of a specimen from the Chispa Summit Formation at USGS Mesozoic locality D10936 in Hudspeth County, Texas, shown for comparison to typical specimens from Colorado; 11-12 – USNM 460742, from locality D13246, figure 12 is a latex cast; 13 – USNM 460743, from locality D13246; 16 – USNM 460744, from locality D13247; 17-18 – USNM 441459, from locality D12715; 19 – USNM 441458, from locality D12715; 20 – USNM 441466, from locality D12715, a latex cast; 26 – USNM 460745, from locality D13246; 27 – USNM 460746, from locality D13246, a latex cast; 28 – USNM 441457, from locality D12715
5, 10 – *Watinoceras devonense devonense* WRIGHT & KENNEDY, 1981; USNM 460747, from locality D13246, 5 is a latex cast
14-15 – *Watinoceras depressum* WRIGHT & KENNEDY, 1981; USNM 460748, from locality D13246, 14 is a latex cast
21 – *Hamites cimarronensis* (KAUFFMAN & POWELL, 1977); USNM 441467, from locality D12715
22-23 – *Allocrioceras larvatum* (CONRAD, 1855); 22 – USNM 441454, from locality D12715; 23 – USNM 441455, from locality D12715

All figures are × 1


1

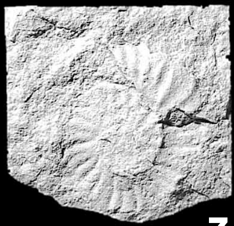

4


3


2

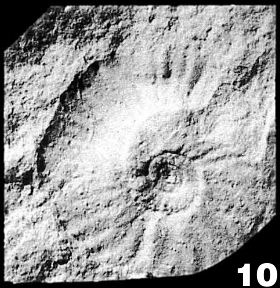

5


6


7


8

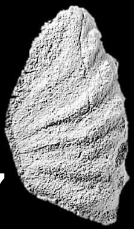

9


10


11


12


13


17


18

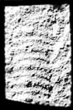

20

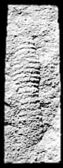

15

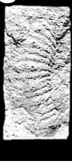

14


16


19


22


21


23


24


25


26


27


28

PLATE 3

1-7 – *Hamites cimarronensis* (KAUFFMAN & POWELL, 1977); 1, USNM 460752, from locality D13246. 2, USNM 460753, from locality D12715. 3, USNM 441464, from locality D12715. 4, USNM 460754, from locality D13246. 5, USNM 460755, from locality D13246. 6, USNM 460751, from locality D13246. 7, USNM 441465, from locality D12715. All from the *Watinoceras devonense* Zone fauna of Bed 86 of the Bridge Creek Member of the Greenhorn Limestone
8-11 – Elements of the Upper Cenomanian *Neocardioceras juddii* Zone fauna of bed 79 of the Bridge Creek Member of Greenhorn Limestone. 8, 10, 11, *Neocardioceras juddii* (BARROIS & GUERNE, 1878); 8, USNM 508032; 10, USNM 508033, a latex cast; 11, USNM 508034; 9, *Euomphaloceras costatum* COBBAN, HOOK & KENNEDY, 1989, USNM 508030; All specimens are from bed 79 at USGS Mesozoic locality 12563, SW$^1/_4$ sec. 25, T. 20S., R. 66W., Pueblo County, Colorado
12-14 – *Collignoniceras woollgari* (MANTELL, 1822); The first appearance of this species in bed 120 of the Bridge Creek Member of the Greenhorn Limestone is the marker proposed for the base of the Middle Turonian Substage. All specimens are in the collections of the University of Southern Colorado, and are from bed 131 of the section in the SW$^1/_4$ SE$^1/_4$ NE$^1/_4$ sec. 30, T. 20S., R. 65W., Pueblo County, Colorado

All figures are × 1


1

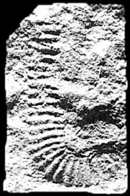

2


3


4


5


6

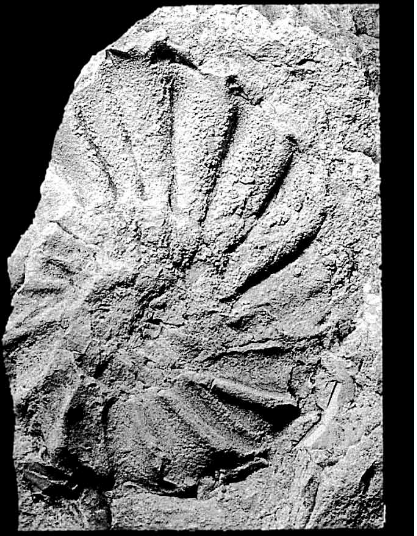

7

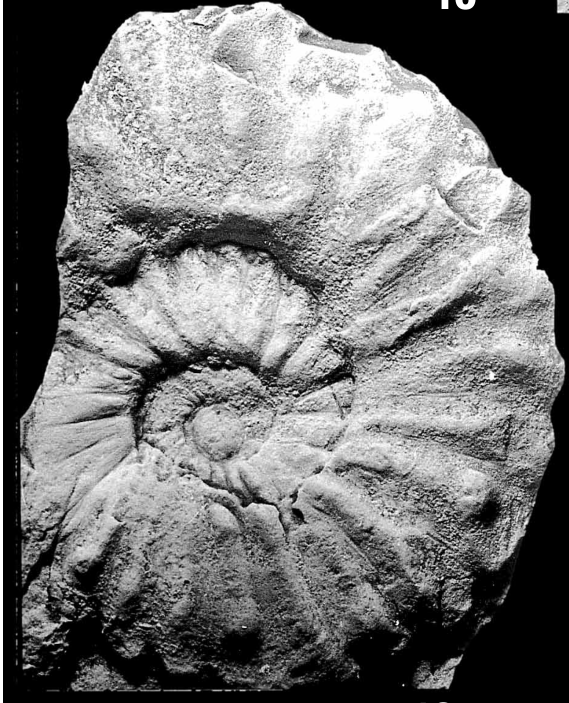

8


9


10


11


12


13


14

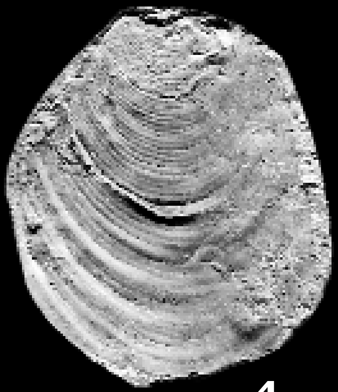
PLATE 4

1-6 – *Inoceramus pictus* SOWERBY, 1829. 1 – USNM 507325, 2 – USNM 507321, 3 – USNM 507324, 4 – USNM 507320, 5 – USNM 507326, 6 – USNM 507322. All specimens from USGS Mesozoic locality D 13356, Pueblo section, bed 83
7-13 – *Mytiloides hattini* ELDER 1991. 7 – USNM 507303, 8 – USNM 507304, a latex cast, 9 – USNM 507308, a latex cast, 10 – USNM 507306, 11 – USNM 507311, 12 – USNM 507302, 13 – USNM 507305, a latex cast; 7-8, 11-13 – USGS Mesozoic locality D 3975; 9-10 – USGS Mesozoic locality D10176. All × 1

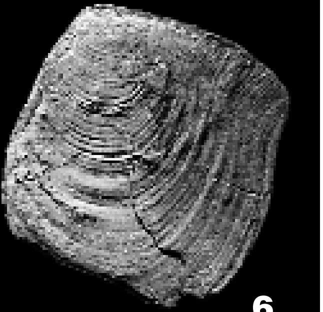

1


2


3


4

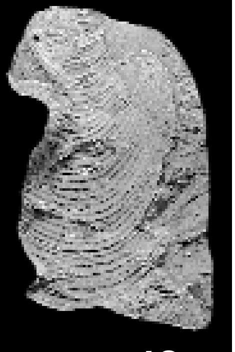

5


6

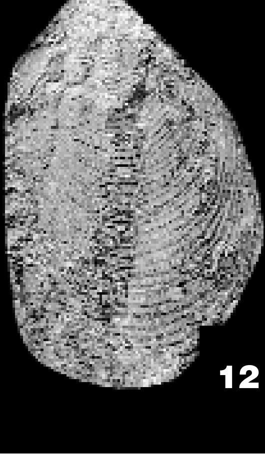

7


8


9


10


11


12

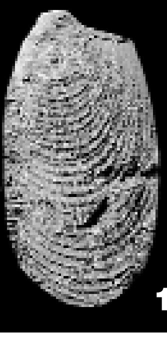

13

PLATE 5

1-10 – *Mytiloides hattini* ELDER 1991. 1 – USNM 441470, 2 – USNM 507319, 3 – USNM 507296, 4 – USNM 507752, 5 – USNM 441471, 6 – USNM 507295, 7 – USNM 507298, 8 – USNM 441469, 9 – USNM 507294, 10 – USNM 507299. 1,5, 8 – USGS Mesozoic locality D 3975, 7, 10 – USGS Mesozoic locality D 12460; 2-4, 6, 9, 10 – are from USGS Mesozoic locality D 10176. All × 1

1

2

3

4

5

6

7

8

9

10

PLATE 6

1-11 – *Mytiloides puebloensis* sp. nov. 1 – USNM 507297, 2 – USNM 507309, 3 – USNM 507312, 4 – USNM 507310, 5 – USNM 507307, 6 – USNM 507318, 7 – USNM 507313, 8 – USNM 507301, 9 – holotype, USNM 507315, 10 – USNM 507293, 11 – USNM 507317. 1, 3, 8 – USGS Mesozoic locality D 3975, 2, 4-7, 11 – USGS Mesozoic locality D 10176; 9-10 – USGS Mesozoic locality D 12460. All × 1

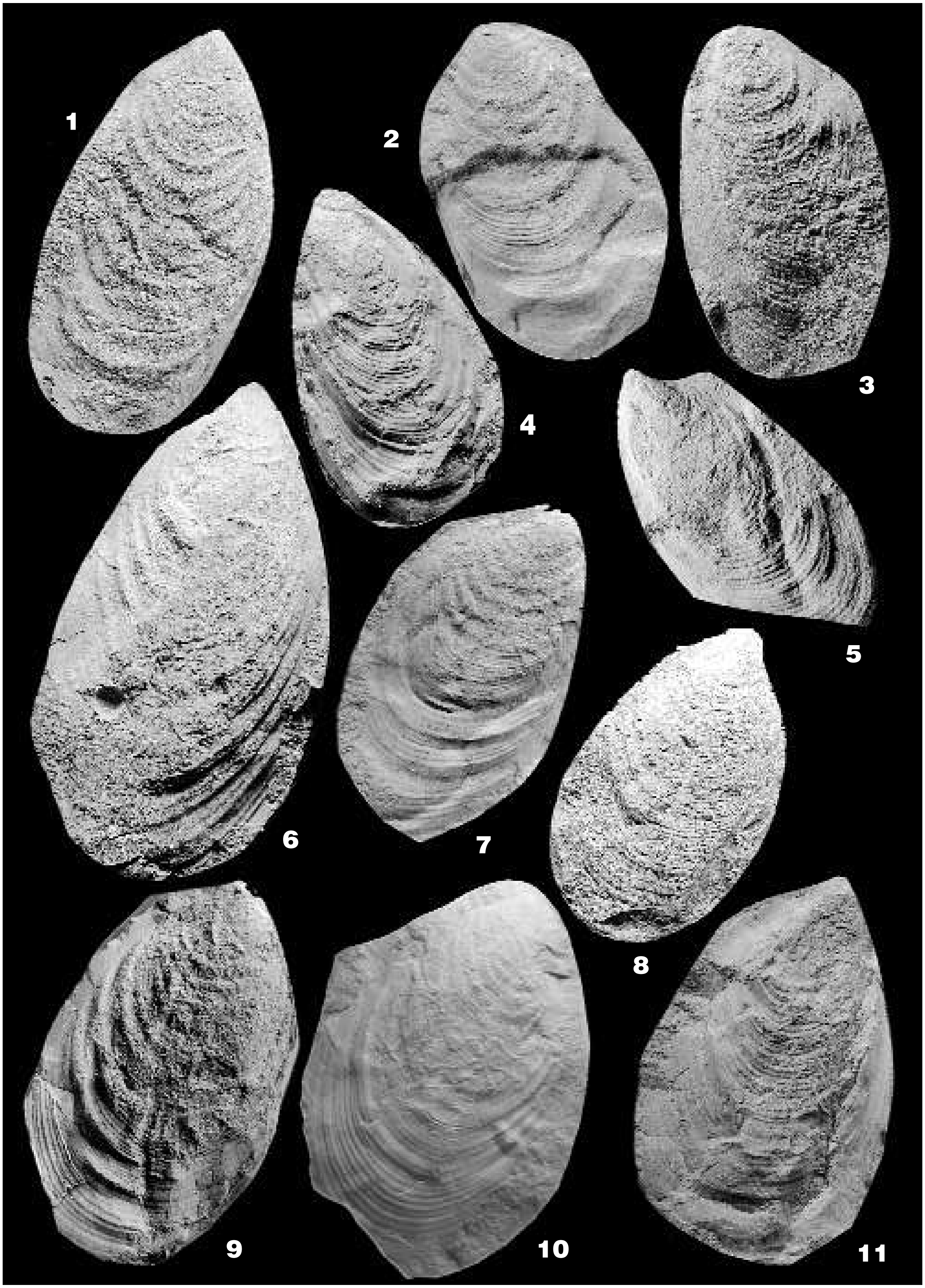

1
2
3
4
5
6
7
8
9
10
11

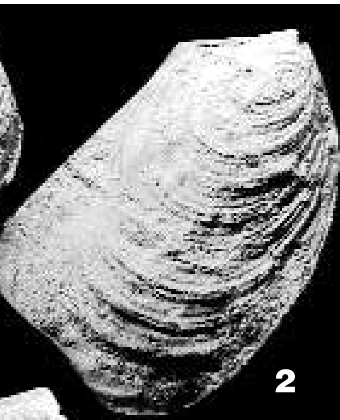
PLATE 7

1, 4, 13 – transitional morphotypes between *Mytilodies puebloensis* sp.nov. and *Mytiloides kossmati* (HEINZ, 1930); 1 – USNM 507377, 4 – USNM 507374, 13 – USNM 507355. 1 – USGS Mesozoic locality D 11758, 4 – USGS Mesozoic locality D 13684, 13 – USGS Mesozoic locality D 6147.

2-3, 5-8, 12, 14 – *Mytiloides puebloensis* sp.nov. 2 – USNM 507468, 3 – USNM507373, 5 – USNM 507378, 6 – 507371, 7 – USNM 507372, 8 – USNM 507354, 12 – USNM 507330, 14 – USNM 507331. 2, 5, 7 – USGS Mesozoic locality D 11758; 3 – USGS Mesozoic locality D 12461; 6 – USGS Mesozoic locality D 3976; 8 – USGS Mesozoic locality D 6147; 12, 14 – USGS Mesozoic locality D 3977.

9-11 – *Mytiloides goppelnensis* (BADILLET & SORNAY 1980). 9 – USNM 507456, USGS Mesozoic locality D 10894; 10 – USNM 507346, 11 – USNM 507349, both USGS Mesozoic locality D 6147. All × 1

1



2

3

4

5

6

7

8

9

10

11

12

13

14

PLATE 8

1-11, 13 – *Mytiloides puebloensis* sp.nov. 1 – USNM 507457, 2 – USNM 507458, 3 – USNM 507459, 4 – USNM 507461, 5 – USNM 507460, 6 – USNM 507463, 7 – USNM 507465, 8 – USNM 507462, 9 – USNM 507466, 10 – USNM 441478, 11 – USNM 441477, 13 – USNM 441476. 1 – USGS Mesozoic locality D 11183; 2-9 – USGS Mesozoic locality D 10899; 10-11, 13 – USGS Mesozoic locality D 6147
12, 14 – *Mytiloides goppelnensis* (BADILLET & SORNAY 1980). 12 – USNM 441479, 14 – USNM 441480; both specimens USGS Mesozoic locality D 6147. All × 1


1


2

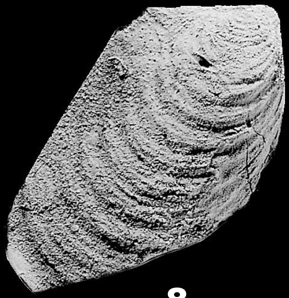

3


4


5


6


7


8


9


10


11


12


13


14

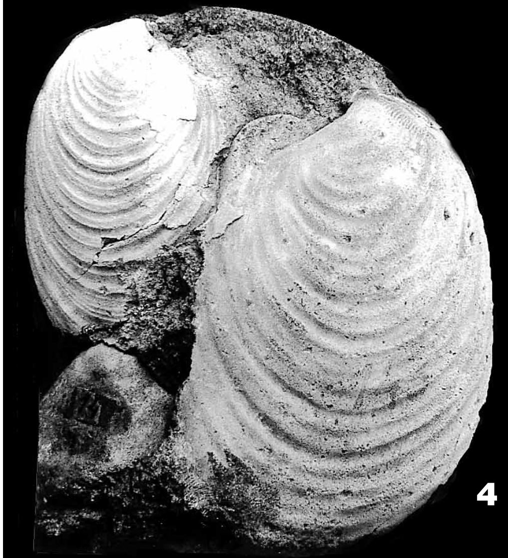
PLATE 9

1-3 – *Mytiloides goppelnensis* (BADILLET & SORNAY, 1980). 1 – USNM 507369, 2 – USNM 507398, 3 – USNM 507328. 1 – USGS Mesozoic locality D13021; 2, locality D4305; 3, locality D11721
4-9 – *Mytiloides kossmati* (HEINZ, 1930). 4-5 – Holotype of *M. kossmati* (LV) (see HEINZ 1933, Pl. 18, Fig. 4), 6, 8-9 – specimens from the Lower Turonian from Utah, USGS Mesozoic locality D 13621; 6 – USNM 507453, 8 – USNM 507451, 9 – USNM 507454. 7 – holotype of *Mytiloides columbianus* (HEINZ, 1936)(=*Inoceramus plicatus* in HEINZ 1928, Pl. 4, Fig. 4). All × 1


1


2


3


4


5


6


7


8


9

PLATE 10

1, 4, 6-8 – *Mytiloides puebloensis* sp.nov. 1 – USNM 507329, USGS Mesozoic locality 22876; 4 – USNM 507350, USGS Mesozoic locality D 6147; 6 – USNM 507340, USGS Mesozoic locality D 11721; 7 – USNM 507333, USGS Mesozoic locality 22924; 8 – USNM 507337, USGS Mesozoic locality D 6147

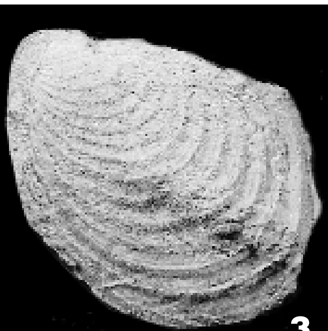
2, 5, 9-10, 12 – *Mytiloides goppelnensis* (BADILLET & SORNAY 1980); 2 – USNM 507343, USGS Mesozoic locality D 6147; 5 – USNM 507420, USGS Mesozoic locality D 3980; 9 – USNM 507368, USGS Mesozoic locality D 13021; 10 – USNM 507344, USGS Mesozoic locality D 6147;12 – USNM 507422, USGS Mesozoic locality D 4443

3 – transitional morphotype between *Mytiloides goppelnensis* (BADILLET & SORNAY, 1980) and *M. kossmati* (HEINZ, 1930); USNM 507396, USGS Mesozoic locality D 4305

11 – transitional morphotype between *Mytiloides mytiloides* (MANTELL, 1822) and *Mytiloides goppelnensis* (BADILLET & SORNAY, 1980); USNM 441484, from USGS Mesozoic locality D 4443. All × 1


1


2

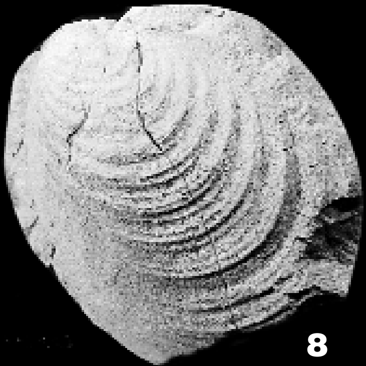

3

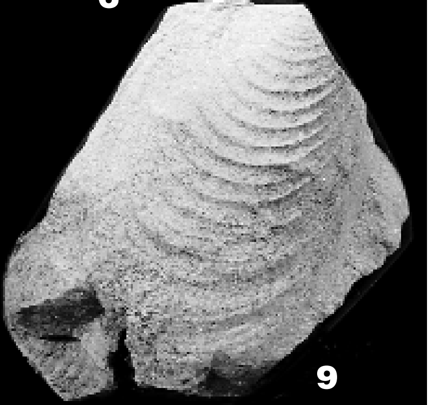

4


5

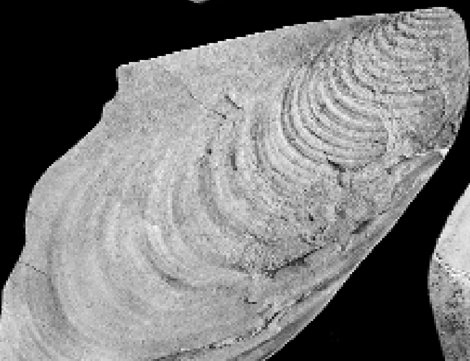

6


7


8


9

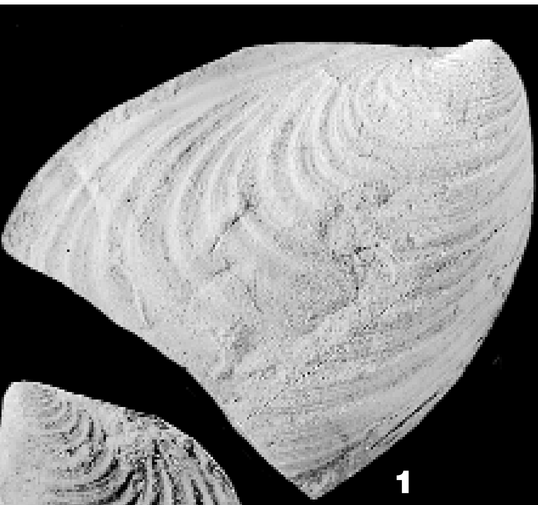

10

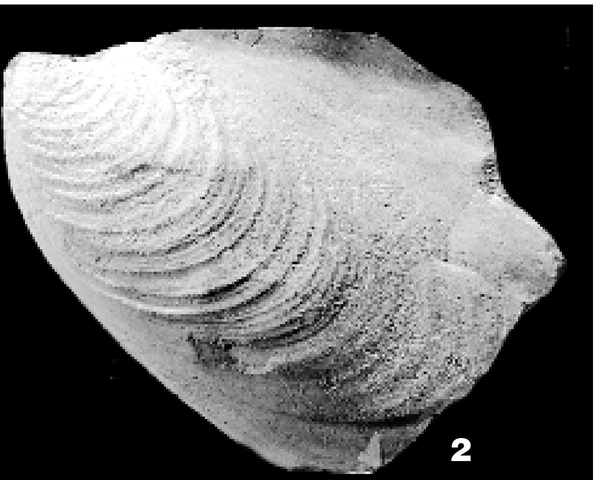

11


12

PLATE 11

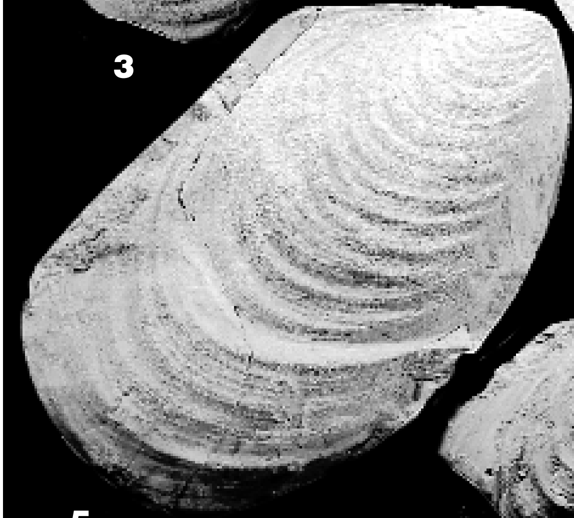
1, 3, 6, 8-9 – *Mytiloides ganuzaensis* (LOPEZ, 1992). 1 – USNM 507429, USGS Mesozoic locality D 4443; 3 – USNM 507418, USGS Mesozoic locality D 3736; 6 – USNM 507419, USGS Mesozoic locality D 3736; 8 – USNM 507423, USGS Mesozoic locality D 4443; 9 – USNM 507427, USGS Mesozoic locality D 4443
2, 5, 7, 10 – *Mytiloides goppelnensis* (BADILLET & SORNAY, 1980). 2 – USNM 507425, 5 – USNM 507424; both specimens USGS Mesozoic locality D 4443; 7 – USNM 507421, USGS Mesozoic locality D 3980; 10 – USNM 507413, USGS Mesozoic locality D 12619
4 – transitional morphotype between *Mytiloides mytiloides* (MANTELL, 1822) and *Mytiloides goppelnensis* (BADILLET & SORNAY, 1980); USNM 507440 from USGS Mesozoic locality D 4443. All × 1


1

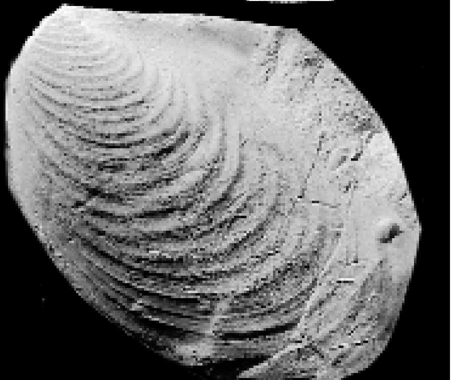

2

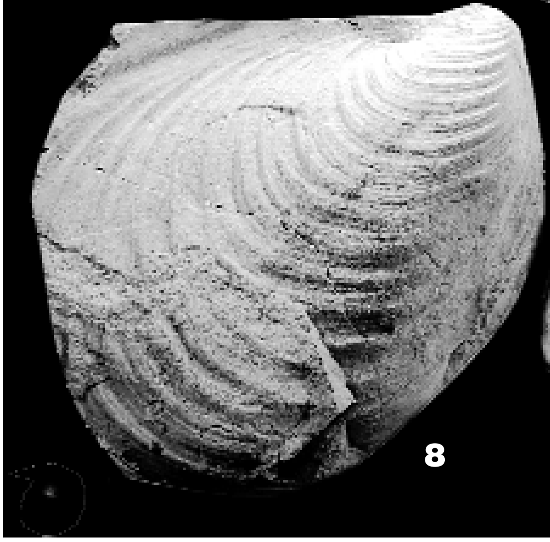

3


4


5


6


7


8


9

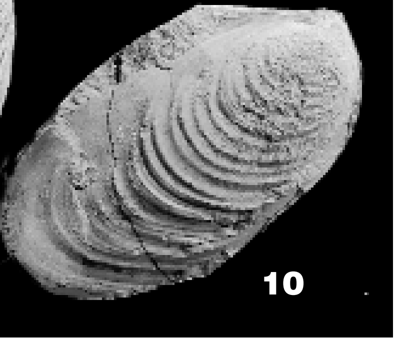

10

PLATE 12

1-3 – *Mytiloides labiatus* (SCHLOTHEIM, 1822). 1 – USNM 507336, USGS Mesozoic locality 22924; 2 – USNM 507335, USGS Mesozoic locality 22924; 3 – USNM 507400, USGS Mesozoic locality D 4305

4-5, 7-12 – *Mytiloides mytiloides* (MANTELL, 1822). 4 – USNM 507439, 5 – USNM 441481, 7 – USNM 441483, 8 – USNM 441482, 9 – USNM 507471, 10 – 507436, 11 – USNM 507428, 12 – 507443. All from USGS Mesozoic locality D 4443

6 – *Mytiloides goppelnensis* (BADILLET & SORNAY, 1980). USNM 507432, USGS Mesozoic locality D 4443. All × 1

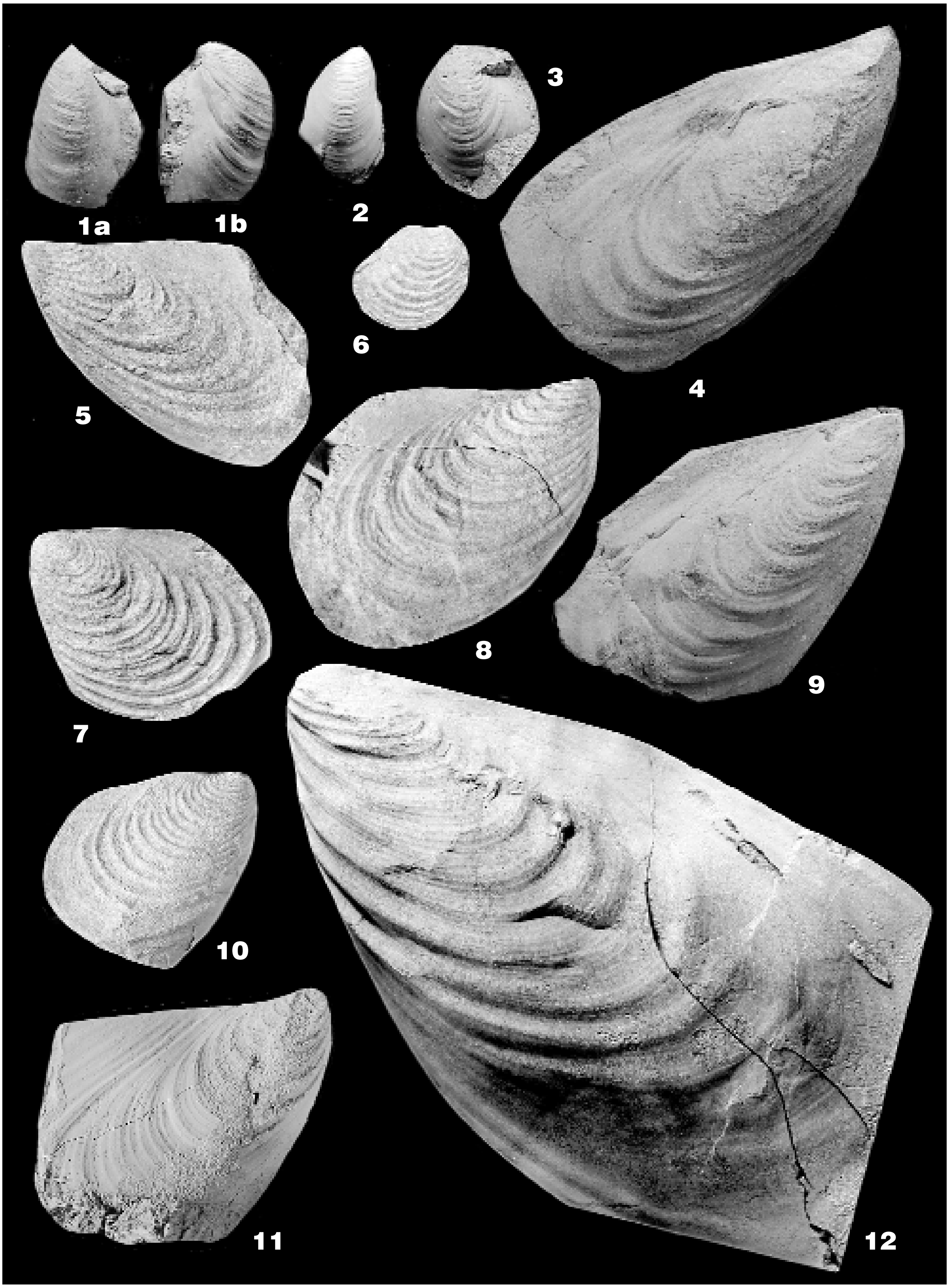

1a
1b
2
3
4
5
6
7
8
9
10
11
12

PLATE 13

1-5 – *Mytiloides ganuzaensis* (LOPEZ, 1992). 1 – USNM 507417, USGS Mesozoic locality D 4443; 2 – USNM 507474, USGS Mesozoic locality D 4443; 3 – USNM 507415, USGS Mesozoic locality D 12619; 4 – USNM 507473, USGS Mesozoic locality D 4443; 5 – USNM 507416, USGS Mesozoic locality D 3980
6 – *Mytiloides goppelnensis* (BADILLET & SORNAY, 1980); USNM 507430 from USGS Mesozoic locality D 4443
7 – *Mytiloides mytiloides* (MANTELL, 1822). USNM 507414 USGS Mesozoic locality D 4443. All × 1

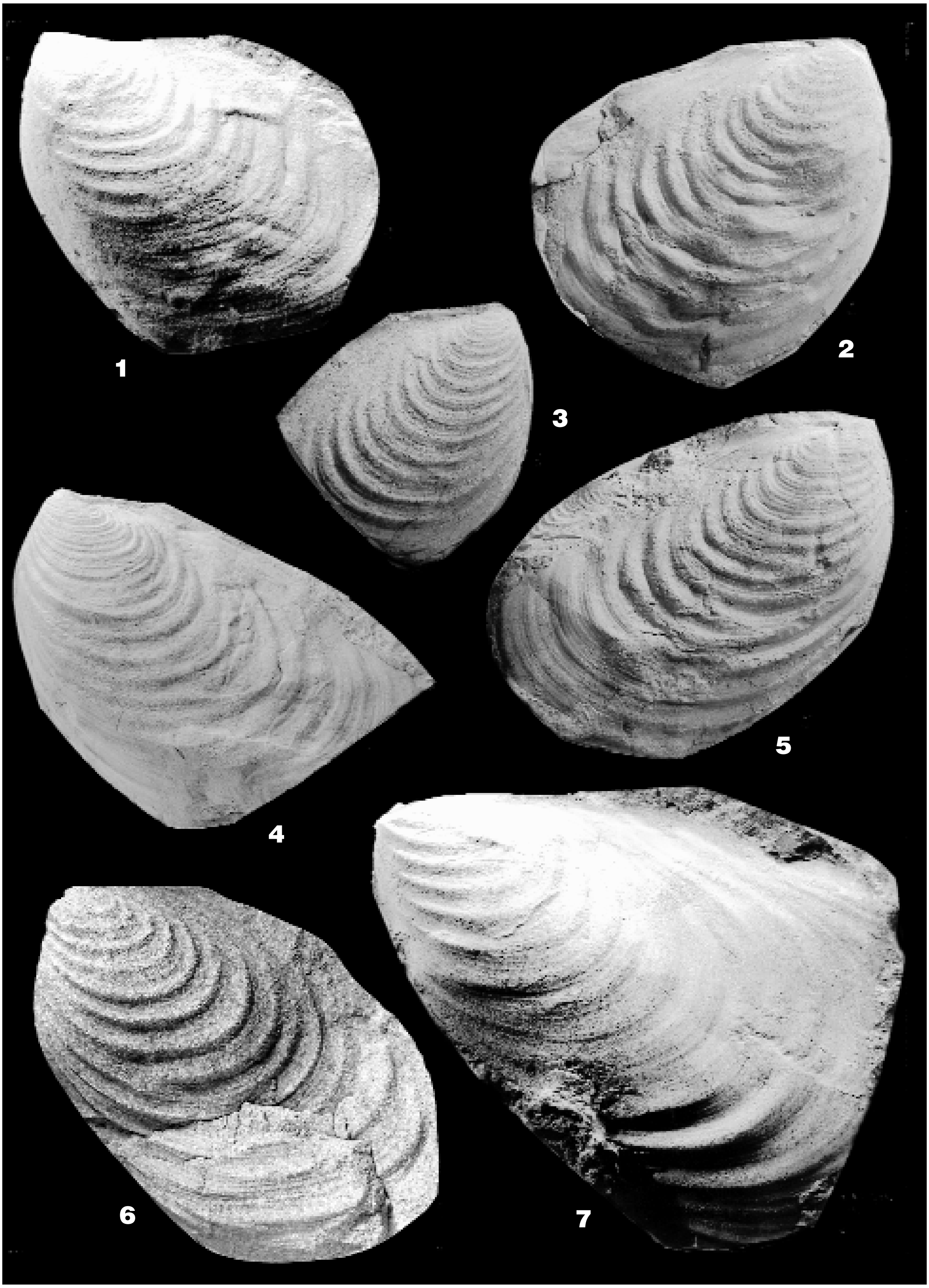
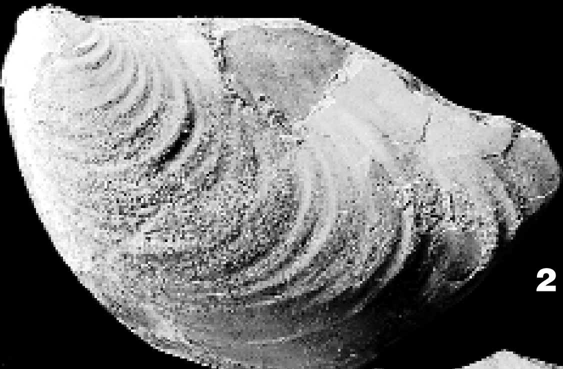
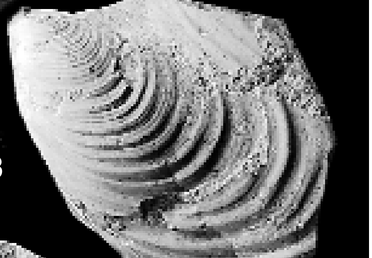

1
2
3
4
5
6
7

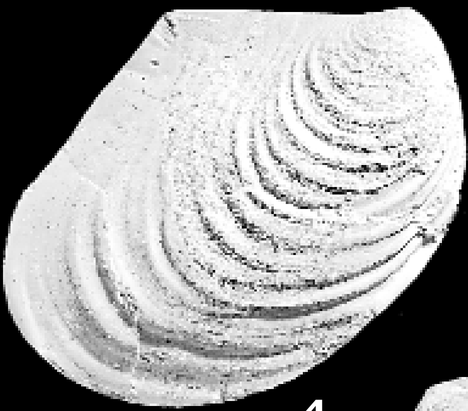
PLATE 14

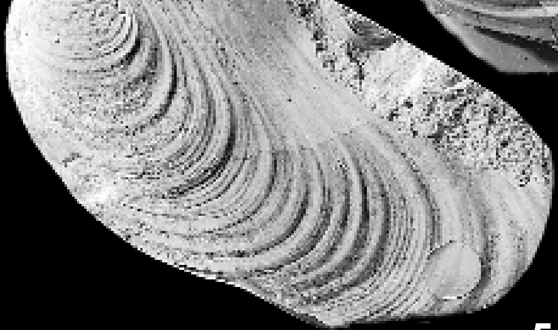
1-8 – *Mytiloides aviculoides* (MEEK). 1 – USNM 507445, USGS Mesozoic locality D 11237; 2 – USNM 507446, USGS Mesozoic locality 3677; 3 – USNM 507449, USGS Mesozoic locality D 8831; 4 – type of *Mytiloides aviculoides*, USNM 242a, the original of MEEK, 1876, p. 9, Fig. 4, from Little River bluff, or the Kansas-Nebraska state line, 5 – USNM 507447, USGS Mesozoic locality 3677; 6 – USNM 507444 from USGS Mesozoic locality D 11237; 7 – USNM 507450, USGS Mesozoic locality D 8831; 8 – USNM 507448, USGS Mesozoic locality D 8831. All × 1


1

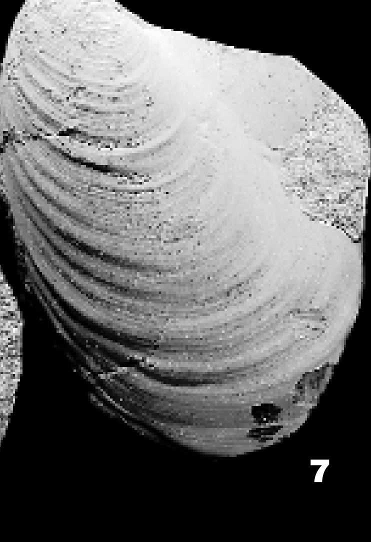

2


3


4


5


6


7

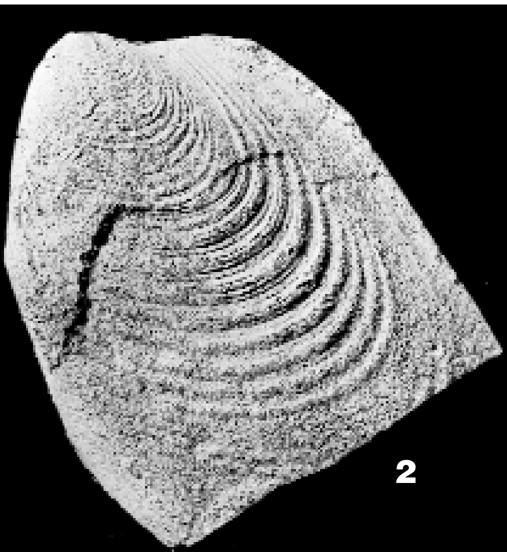

8

PLATE 15

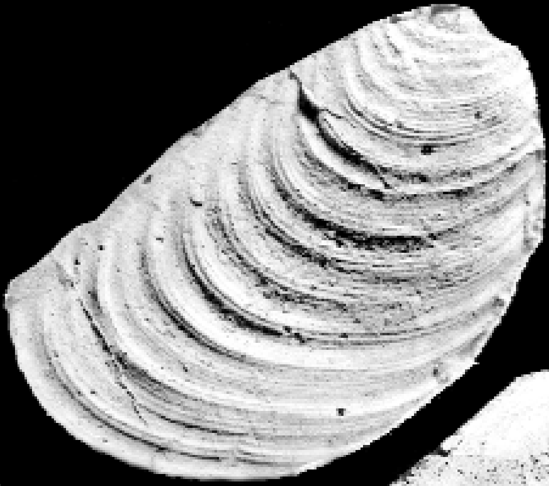
1-2, 4-7 – *Mytiloides subhercynicus* (SEITZ, 1935); 1 – USNM 507472, 2 – USNM 507470, 4 – latex USNM 507362, 5 – USNM 507411, 6 – USNM 507464 (bed 121, from exposure shown in Text-fig. 10), 7 – USNM 507469. All from USGS Mesozoic locality D 11238

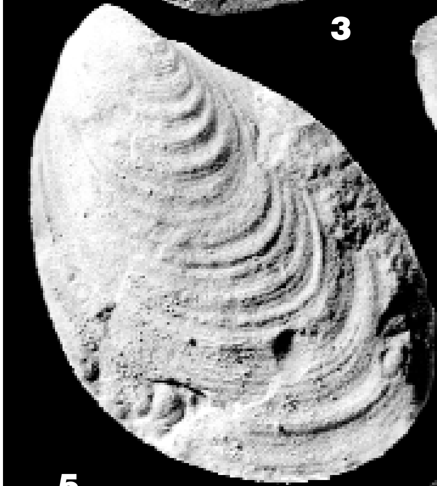
3 – *Mytiloides subhercynicus tourtenayensis* (BADILLET & SORNAY, 1980); USNM 507455, USGS Mesozoic locality D 11238


1

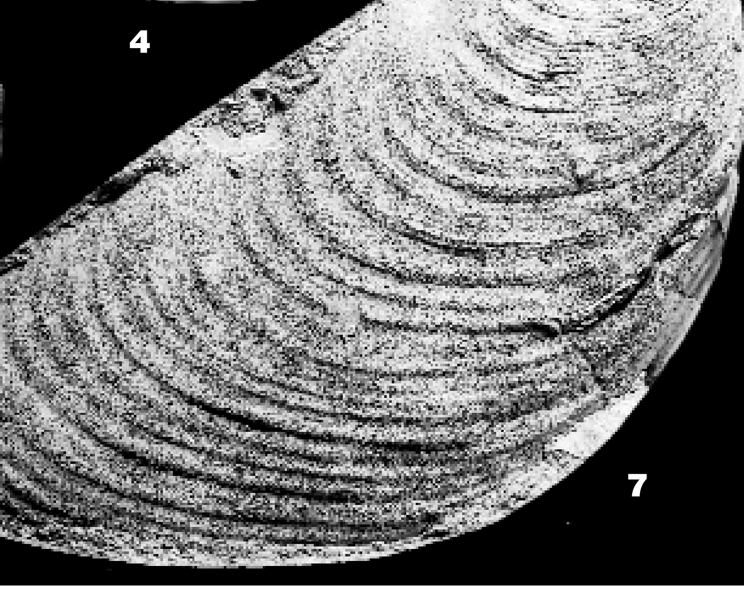

2


3


4


5


6


7