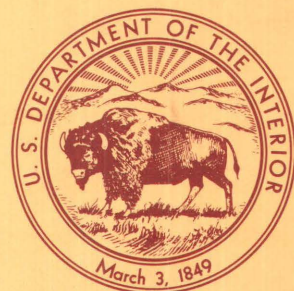


Shorter Contributions to Paleontology and Stratigraphy

U.S. GEOLOGICAL SURVEY BULLETIN 1934



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Edited by WILLIAM J. SANDO

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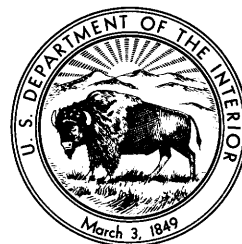
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- (B) Evolution and Biogeography of the Cenomanian (Upper Cretaceous) Ammonite *Metoicoceras* Hyatt, 1903, with a Revision of *Metoicoceras praecox* Haas, 1949, by William A. Cobban and W. James Kennedy
- (C) *Baculites thomi* Reeside, 1927, an Upper Cretaceous Ammonite in the Western Interior of the United States, by William A. Cobban and W. James Kennedy
- (D) Discovery of Early Ordovician Fossils in Bucks County, Pennsylvania, by John E. Repetski and Avery Ala Drake, Jr.
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Chapter A

A Giant Scaphite from the Turonian (Upper Cretaceous) of the Western Interior of the United States

By WILLIAM A. COBBAN and W. JAMES KENNEDY

Description and illustrations of a new species from the
Carlile Shale of South Dakota

U.S. GEOLOGICAL SURVEY BULLETIN 1934

SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

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PLATE

[Plate follows references cited]

1. *Scaphites borealis* n.sp.

A Giant Scaphite from the Turonian (Upper Cretaceous) of the Western Interior of the United States

By William A. Cobban¹ and W. James Kennedy²

Abstract

A new giant species of scaphite, *Scaphites borealis*, is described from the upper Turonian *Scaphites whitfieldi* zone of the Carlile Shale of South Dakota. The ornament of the new species is comparable in style to that of co-occurring *S. whitfieldi* Cobban, 1952, but its shell volume is 17 times greater than the largest macroconch of *S. whitfieldi* Cobban, of which it is believed to be a hypermorphic giant derivative.

INTRODUCTION

Heteromorph ammonites of the Family Scaphitidae are important stratigraphic indicators in Turonian rocks of the Western Interior of the United States and Canada. The fauna was monographed by Cobban (1952), and some additional taxa were described by Crick (1978, 1979) and Cobban (1983). Landman (1987) provided a recent review of several of the Turonian species. We describe below a remarkable new giant species, herein named *Scaphites borealis*, from the upper Turonian *Scaphites whitfieldi* zone of Butte County, South Dakota. The general style of ornament of the new species, marked by nontuberculate, crowded, narrow ribs on the phragmocone and body chamber, is the same as that of co-occurring *Scaphites whitfieldi* Cobban, 1952. But, whereas the latter species has adult macroconchs that never exceed 50 mm in length, the holotype of *S. borealis* is a macroconch 130 mm long, a size exceeded among scaphitids only by the *Jeletzkytes*, *Rhaeboceras*, and *Acanthoscaphites* of the Campanian and Maastrichtian. Because of the co-occurrence and comparable ornament of *S. whitfieldi* and *S. borealis*, we believe that the former, which is part of a long-ranging Western Interior lineage, gave rise to the latter. Whereas other

Scaphites show progressive size increase and decrease within lineages (Cobban, 1952, fig. 2), the evolution of *S. borealis* involved a sudden jump and a seventeenfold volume increase. The new species is presumably a hypermorphic giant (McNamara, 1986) in which the delayed onset of the maturity and development of the uncoiled body chamber allowed prolonged growth.

The holotype and paratypes are at the Black Hills Institute of Geological Research, Hill City, S. Dak. We thank N.L. Larson and P.L. Larson of the Institute for providing these specimens for our study. Kennedy acknowledges the financial support of the Natural Environment Research Council (U.K.), the Royal Society, and the Astor Fund (Oxford) and the technical assistance of the staff of the Geological Collections, Oxford University Museum, and the Department of Earth Sciences, Oxford, U.K.

SYSTEMATIC PALEONTOLOGY

Family SCAPHITIDAE Gill, 1871

Subfamily SCAPHITINAE Gill, 1871

Genus SCAPHITES Parkinson, 1811

Type species.—*Scaphites equalis* J. Sowerby, 1813.

Scaphites borealis n.sp.

Plate 1

1952. *Scaphites whitfieldi* Cobban, p. 24 (*pars*), pl. 5, fig. 1 only.

Derivation of name.—*Boreas*, the Greek word for the north wind, in reference to the northerly occurrence of the species.

Types.—Holotype is BHI (Black Hills Institute of Geological Research) 1962; paratypes are BHI 1963 and BHI 1964. All are from the upper Turonian *Scaphites whitfieldi* zone in the Turner Sandy Member of the Carlile Shale on the western side of Belle Fourche Reservoir in Butte County, South Dakota. Other specimens are represented by the following plaster casts at the National

Manuscript approved for publication February 27, 1990.

¹U.S. Geological Survey, Denver, CO 80225.

²Geological Collections, University Museum, Parks Road, University of Oxford, Oxford OX1 3PW, U.K.

Museum of Natural History (USNM), Washington, D.C.: USNM 420321, collected by M.J. Evetts from 32.6 m above the base of the Turner Sandy Member of the Carlile Shale, Wild Cat Creek, in the NE¼ sec. 8, T. 9 N., R. 3 E., Butte County, South Dakota; and USNM 420320, collected by P.S. Warren from the Morden Shale, Vermilion River, southern Manitoba, Canada. USNM 106738a is Cobban's (1952, pl. 5, fig. 1) original from a ferruginous concretion about 78 m above the base of the Carlile Shale 9.6 km north of Belle Fourche in the N½ sec. 10, T. 9 N., R. 2 E., Butte County, South Dakota.

Description.—The holotype (pl. 1, fig. 4) is a macroconch 130 mm long, preserved in a ferruginous concretion. The phragmocone is crushed, but the body chamber is partially preserved in relief. Traces of the original nacreous shell are present. The very involute septate coil has an estimated diameter of 88 mm. Distant, narrow, sharp primary ribs arise on the umbilical wall. These ribs are straight and slightly prorsiradiate on the flank and divide into two or three secondary ribs on the outer flank, where shorter intercalated ribs are inserted; all pass straight across the venter without interruption.

The shaft is straight and exhibits a slight bulge that partially occludes the umbilicus of the spire; the final hook is well detached from the spire. The body chamber occupies all of the hook and shaft. The mature aperture is marked by a flare preceded by a prominent annular constriction. Primary ribs number 28 on the body chamber. The ribs arise on the dorsal wall, where they are weak and feebly concave, and sweep forward over the dorsolateral shoulder; ribs become progressively more prorsiradiate toward the aperture of the shell. Ribs are low and distant on the shaft and straight to feebly convex on the flank and split into two or three weak secondaries at the juncture of the outer flank with the ventrolateral shoulder. Secondaries, plus occasional intercalatories, are weak and pass straight across the venter. Ribbing crowds and becomes relatively stronger on the hook, and the secondaries become quite sharp. Primary ribs bifurcate once they are on the inner flank and a second time on the outer flank in some cases. About 75 ribs cross the venter of the body chamber.

Paratype BHI 1963 is a nearly complete adult 119 mm long. Because the umbilicus and dorsolateral area of the shaft are missing, it is not possible to assign the specimen to either macroconch or microconch with any certainty. The specimen shows all the features of ornament of the holotype to advantage, and the ventral decoration is well seen (pl. 1, figs. 1–3).

What we take to be the microconch of the species is represented by casts USNM 420320 and 420321. The latter shows the umbilicus not occluded by the shaft and has a slender body chamber and quite sharp ribbing. Its original length is estimated at 110 mm. The suture is only imperfectly visible but shows the lobes to have plump, subphylloid folioles, as they do in *S. whitfieldi*.

Discussion.—The fragment figured by Cobban (1952, pl. 5, fig. 1) as a very large *Scaphites whitfieldi* is certainly a part of a body chamber of the present species. Large size alone separates *S. borealis* from all other Turonian *Scaphites*, and we know of no other contemporary or near-contemporary species with which it is likely to be confused.

Occurrence.—The few specimens from the Western Interior of the United States are from the northeastern flank of the Black Hills uplift in western South Dakota. The Turner Sandy Member of the Carlile Shale, which yielded these specimens, crops out extensively along all the flanks of the Black Hills. *Scaphites whitfieldi* has been found all around the Black Hills as well as at many localities in Montana, Wyoming, Colorado, Utah, and New Mexico. The presence of *S. borealis* in the *S. whitfieldi* zone in only one small area on the northeastern flank of the Black Hills suggests a northeastern source for the species, a theory that is further supported by the occurrence of *S. borealis* in Manitoba, Canada. A plaster cast (USNM 420320) of a crushed adult 116 mm in length from the Morden Shale of the Vermilion River area is in the National Museum of Natural History in Washington, D.C. The original specimen was submitted by S.R. Kirk in 1932 to J.B. Reeside, Jr., for identification. The whereabouts of the specimen is now unknown.

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PLATE 1

Contact photographs of the plate in this report are available, at cost, from the
U.S. Geological Survey Photographic Library, Federal Center, Denver, CO 80225.

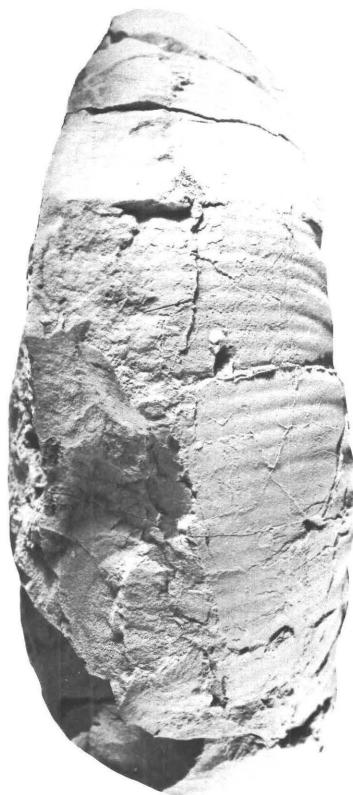
PLATE 1

Scaphites borealis n.sp.

[All figures natural size]

Figures 1–4. From the Turner Sandy Member of the Carlile Shale on the western side of Belle Fourche Reservoir, Butte County, South Dakota.

- 1–3. Bottom, side, and top views of paratype BHI 1963.
4. Side view of holotype BHI 1962.



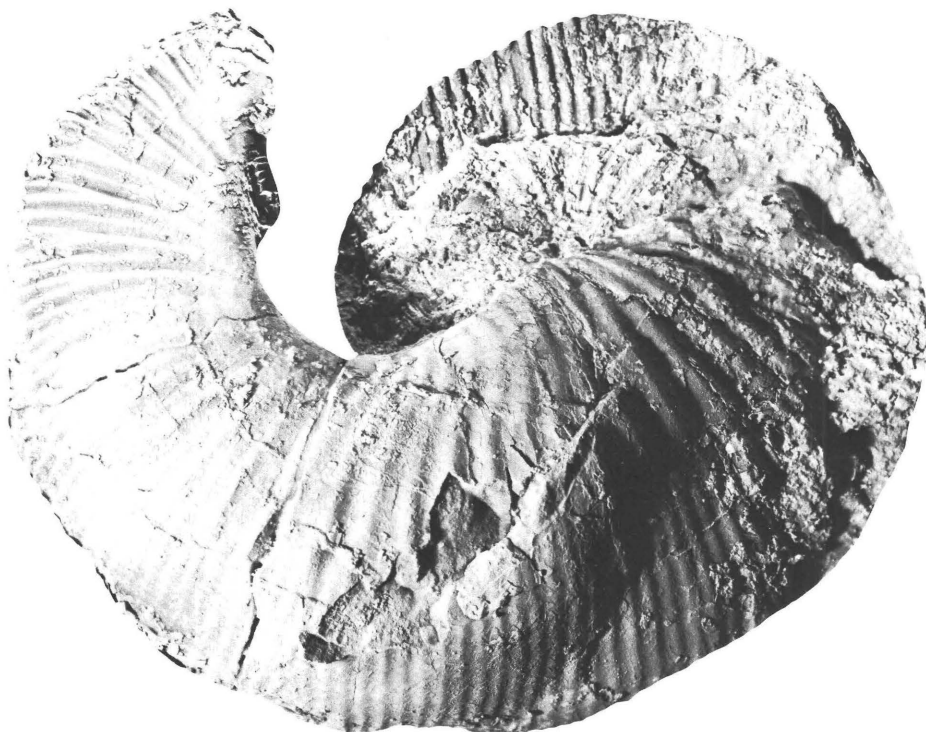
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SCAPHITES BOREALIS

Chapter B

Evolution and Biogeography of the
Cenomanian (Upper Cretaceous) Ammonite
Metoicoceras Hyatt, 1903, with a Revision of
Metoicoceras praecox Haas, 1949

By WILLIAM A. COBBAN and W. JAMES KENNEDY

Descriptions and illustrations of an important lineage of ammonites
from Texas and the Western Interior of the United States

U.S. GEOLOGICAL SURVEY BULLETIN 1934

SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

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6. *Metoicoceras geslinianum* (d'Orbigny), *Metoicoceras frontierense* Cobban, and *Metoicoceras* aff. *frontierense* Cobban

FIGURES

1. Chart showing sequence of *Metoicoceras* species in the Western Interior and northern Texas and their placement in part of the Cenomanian ammonite zones of the Western Interior **B2**
- 2, 3. Drawings showing:
 2. External sutures of *Metoicoceras* **B5**
 3. Costal whorl sections of various species of *Metoicoceras* **B6**

TABLE

1. Dimensions and ratios of *Metoicoceras praecox* Haas from U.S. Geological Survey Mesozoic locality 21850 **B4**

Evolution and Biogeography of the Cenomanian (Upper Cretaceous) Ammonite *Metoicoceras* Hyatt, 1903, With a Revision of *Metoicoceras praecox* Haas, 1949

By William A. Cobban¹ and W. James Kennedy²

Abstract

Metoicoceras is an important genus, especially in the Western Interior of the United States. Five chronologic species can be recognized in Wyoming (from oldest to youngest): *M. sp. A*, *M. praecox* Haas, *M. frontierense* Cobban, *M. mosbyense* Cobban, and *M. geslinianum* (d'Orbigny). *Metoicoceras praecox*, which is described in detail, has several features in common with *M. latoventer* Stephenson, a middle Cenomanian species known from the Gulf Coast region. The origin of *Metoicoceras* probably lies in some contemporary acanthoceratid ammonite such as *Plesiaceratoceras*, which occurs with the earliest *Metoicoceras* in Texas, and involved sutural simplification and profound modification of adult ornament. Early members of the lineage are known from a limited area in Texas, but, during the early part of the late Cenomanian, members of the genus spread throughout the Western Interior. The latest species, *M. geslinianum* (d'Orbigny), migrated out beyond the Western Interior during the late Cenomanian *Sciponoceras gracile* zone and became an important international guide fossil known from the Western Interior and Gulf Coast region, Mexico, Brazil, Africa, western Europe, Israel, Iran, and the U.S.S.R.

INTRODUCTION

The genus *Metoicoceras* Hyatt, 1903 (type species *Ammonites swallovi* Shumard, 1860), is an involute, compressed, and generally ribbed ammonite of medium size that is an important fossil of the middle and late Cenomanian faunas in the Western Interior of the United States. A succession of species that is of great stratigraphic value is recognized (text fig. 1). Most of these species are endemic

to the Western Interior, but, near the close of Cenomanian time, the final species, *M. geslinianum* (d'Orbigny), spread out beyond the region and is known from Texas, Mexico, Brazil, Africa, western Europe, Israel, Iran, and the U.S.S.R. *Metoicoceras geslinianum* is a valuable guide fossil for international correlation of late Cenomanian rocks.

One of the oldest species of *Metoicoceras*, *M. praecox* Haas, 1949, is widely distributed in the Western Interior but is a little known form. We describe herein the ontogeny and variation of this species on the basis of a large collection of topotypes from the basal part of the Cody Shale of Big Horn County, Wyoming. This description provides the basis for our discussion of the evolution and biogeography of the genus.

The large collection of topotypes was gathered by J.B. Reeside, Jr., and D.A. Andrews of the U.S. Geological Survey (USGS) in 1938 and by the late W.D. Greene of Greybull, Wyo. Some topotypes were also supplied by N.H. James of Greybull. All topotypes have been assigned USGS Mesozoic locality number 21850.

The specimens described in this report are in the National Museum of Natural History (USNM) in Washington, D.C., and have USNM catalog numbers. All photographs were made by Robert E. Burkholder (USGS). The drawings of sutures and whorl sections were made by Cobban. Kennedy acknowledges the financial support of the Natural Environment Research Council (U.K.), the Royal Society, and the Astor Fund (Oxford, U.K.).

CONVENTIONS

Repositories of Specimens

The following abbreviations are used to indicate the repositories of specimens cited in the text: USNM, National

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¹U.S. Geological Survey, Denver, CO 80225.

²Geological Collections, University Museum, Parks Road, University of Oxford, Oxford OX1 3PW, U.K.

STAGE		ZONE	WESTERN INTERIOR	NORTH TEXAS
CENOMANIAN (PART)	UPPER PART	<i>Sciponoceras gracile</i>	<i>M. geslinianum</i>	<i>M. geslinianum</i>
		<i>Metoicoceras mosbyense</i>	<i>M. mosbyense</i>	
		<i>Dunveganoceras problematicum</i>	<i>M. frontierense</i>	
		<i>Dunveganoceras pondi</i>	<i>M. praecox</i> <i>M. sp. A</i>	
	MIDDLE PART	<i>Plesiacanthoceras wyomingense</i>		<i>M. swallowi</i> <i>M. latoventer</i> <i>M. crassicostrae</i>

Figure 1. Sequence of *Metoicoceras* species in the Western Interior and northern Texas and their placement in part of the Cenomanian ammonite zones of the Western Interior.

Museum of Natural History, Washington, D.C.; AMNH, American Museum of Natural History, New York, N.Y.; UMIP, University of Minnesota Invertebrate Paleontology collections, Minneapolis, Minn.

Suture Terminology

The system of Wedekind (1916) as propounded by Kullmann and Wiedmann (1970) is followed, where E is the external lobe, L is the lateral lobe, and U is the umbilical lobe.

SYSTEMATIC PALEONTOLOGY

Order AMMONOIDEA Zittel, 1884

Suborder AMMONITINA Hyatt, 1889

Superfamily ACANTHOCERATACEAE de Grossouvre, 1894

Family ACANTHOCERATIDAE de Grossouvre, 1894

Genus METOICOCERAS Hyatt, 1903

Type species.—*Ammonites swallowi* Shumard, 1860, p. 591, by subsequent designation of Shimer and Shrock (1944, p. 591).

Diagnosis.—This genus includes moderately involute ammonites that have compressed whorls and ornament of primary and secondary ribs, umbilical bullae, inner and outer ventrolateral tubercles, and (in the early species) weak siphonal tubercles on the innermost whorls. The venter on the inner whorls is flattened and bordered by the outer ventrolateral tubercles, whereas the venter on the body chamber is usually rounded, at least near the aperture. Ribs are straight to slightly flexuous; they may flatten on the outer part of the flanks or on the ventrolateral shoulder. Inner ventrolateral tubercles usually weaken and disappear near the end of the phragmocone. The suture is quite

simple, displaying little-divided saddles and a rectangular bifid lateral lobe that is narrower than the first lateral saddle.

Metoicoceras praecox Haas

Plates 1–3; text figures 2B–D, 3C, 3E

1949. *Metoicoceras whitei* Hyatt *praecox* Haas, p. 15, pls. 5–7, text figs. 5–9.

1952. *Metoicoceras praecox* Haas. Cobban and Reeside, p. 1017.

1970. *Metoicoceras praecox* Haas. Ilyin, fig. 2e.

1977. *Metoicoceras* cf. *M. praecox* Haas. Cobban, p. 25, pl. 16, fig. 25; pl. 21, figs. 8, 9.

1981. *Metoicoceras praecox* Haas. Kennedy and others, p. 58.

Types.—Holotype AMNH 26415, from the upper Cenomanian zone of *Dunveganoceras pondi* in the basal part of the Cody Shale northeast of Greybull, Big Horn County, Wyoming. Hypotypes USNM 427905 through 427937, from the same locality as the holotype and paratypes at USGS Mesozoic locality 21850 in the SE¼ sec. 9, T. 53 N., R. 92 W.

Material.—About 60 topotypes from USGS Mesozoic locality 21850 were available for study, as were a few specimens from other localities in the Western Interior. The specimens from locality 21850 are mostly uncrushed internal molds from calcareous sandstone concretions. Body chambers are infilled by indurated, very fine grained sandstone, and phragmocones are calcite filled. Ornament and sutures are well preserved.

Description.—The holotype (Haas, 1949, pl. 5, figs. 1, 5, 8) is most of an adult body chamber that partly encloses some of the septate coil. The whorl height at the larger end of the body chamber is 50 mm. Diameter of the body chamber is estimated at 116 mm, and the umbilical ratio is estimated at 0.23. Whorls are much higher than they are wide and have somewhat flattened flanks and a well-rounded venter. The umbilicus is shallow and has a gently sloping wall. Ornament on the inner whorls consists of

rather widely spaced primary ribs that arise in pairs from umbilical bullae; secondary ribs arise farther out on the flank. All ribs on the inner whorls bear a row of ventrolateral tubercles. According to Haas (1949, p. 16), these ribs number 24 per whorl. Ornament on the preserved part of the body chamber consists of fairly widely spaced, rectiradial, foldlike ribs that cross the venter transversely; there are no umbilical or ventrolateral tubercles.

Several topotype specimens from locality 21850 ranging from 20 to 35 mm in diameter reveal details in ornament that Haas did not record in his collection of the holotype and five paratypes. Haas mentioned the presence of a row of clavate ventrolateral tubercles on the small whorls but did not note the presence of siphonal tubercles. All our topotypes from 25 to 35 mm in diameter (seven specimens: USNM 427905–427909, 427938, 427939) have weak siphonal clavi at some diameter (see pl. 1, figs. 3–7, for 427905 and 427906). These clavi weaken and disappear at diameters (rounded) of about 24, 28, 30, 31, 32, and 34 mm on these specimens. Siphonal tubercles persist on another specimen (USNM 427918) to a diameter of 43 mm. In addition, the ribs of some of these inner whorls are accentuated a little at the position where inner ventrolateral tubercles should appear, but distinct tubercles are not present.

The only small whorl (USNM 427939) observed in our collection from locality 21850 has a diameter of 8.3 mm and an umbilicus of 1.0 mm (ratio of 0.12). This inner whorl is somewhat distorted, but the whorl section is higher than it is wide and has a rounded umbilical shoulder, flattened flanks, and a broadly rounded venter. The only ornament visible is a row of prominent conical, rounded, inner ventrolateral tubercles. The venter is too poorly preserved to reveal siphonal tubercles. Larger whorls of the specimen that yielded the small whorl have weak siphonal clavi out to a diameter of 28.5 mm, where they disappear; low nodate to somewhat clavate outer ventrolateral tubercles continue out to a diameter of about 42 mm before disappearing.

At diameters of 20 to 40 mm, whorls from locality 21850 are moderately compressed and fairly involute and have umbilical ratios of 0.20 to 0.21. The umbilicus is shallow and displays a rounded umbilical shoulder and sloping walls. Whorl sections have a breadth-to-height ratio of about 0.8, the greatest breadth being low on the flank's intercostal section or at the umbilical bullae (where present) in costal section. Flanks are broadly rounded and convergent to the narrow venter, which is flattened on both the costal and the intercostal sections. Seven to nine low, blunt umbilical bullae are present per whorl. The bullae give rise to low, broad, slightly flexuous, prorsiradial ribs that usually are paired. Secondary ribs arise at or below mid-flank to make a total of 11 or 12 ribs per half whorl. All ribs

support clavate outer ventrolateral tubercles that border the flat venter. A low, broad swelling connects the ventrolateral clavi across the venter.

On specimens 40 to 60 mm in diameter from locality 21850, the umbilical wall flattens, and the shoulder becomes indistinct. Umbilical bullae and ventrolateral tubercles weaken and disappear, but ribs that cross the venter become stronger. One specimen (USNM 427915) has a low, weakly undulated siphonal ridge that persists out to a diameter of about 54 mm. Ribs increase in number to 12 to 15 per half whorl.

Body chambers begin at diameters ranging from 31 to 94 mm and occupy a little more than half a whorl (pl. 3). Maturity is indicated by marked excentricity of the umbilical seam (pl. 2, figs. 8, 11, 14), further flattening of the umbilical wall, disappearance of umbilical bullae, and broadening of the venter; specimens that have weakly ribbed phragmocones become nearly smooth except near the aperture, where strong foldlike ribs may appear. The more strongly ornamented specimens 70 mm in diameter or larger have 13 to 19 ribs per half whorl. Ribs are rectiradial to prorsiradial and are broadest and strongest where they cross the venter. Secondary ribs lengthen, and, when the umbilical bullae disappear, primaries and secondaries are poorly differentiated or undifferentiated (pl. 1, fig. 8; pl. 2, fig. 15). The aperture is normal.

Thirty-three specimens from locality 21850 are suitable for measurements of the diameter, whorl breadth, whorl height, umbilicus, and base of the body chamber (table 1).

The specimens from locality 21850 have a considerable size range at the base of the body chamber, but no distinct size groups suggestive of sexual dimorphism can be demonstrated. Diameters at the base of body chambers range from 31.0 to 94.1 mm (table 1). The smallest specimen (table 1, USNM 427908; pl. 2, figs. 6, 7) is probably a juvenile inasmuch as ventrolateral clavi are present on the preserved part of the body chamber, and the last sutures are not crowded. Another small specimen (table 1, USNM 427910), however, may be a true microconch; it has a basal body chamber diameter of just 32.2 mm, and ornament on the body chamber consists only of ribs like those on larger specimens.

Much variation in ornament is also apparent in the specimens from locality 21850. The more robust individuals tend to have coarsely ribbed body chambers (pl. 3), whereas the more slender forms have weakly ribbed to almost smooth body chambers (pl. 1, figs. 13–15). Some slender specimens have exceptionally smooth body chambers except for a few coarse, foldlike ribs near the aperture and weaker undulations farther back along the venter.

Sutures (text figs. 2B–D) are fairly simple. The external (E) and lateral (L) lobes are about the same size and somewhat squarish to rectangular. L and E/L saddles are usually bifid, but L may assume a pseudotrifid appearance

Table 1. Dimensions and ratios of *Metoicoceras praecox* Haas from U.S. Geological Survey Mesozoic locality 21850¹
[D, diameter; Wb, whorl breadth; Wh, whorl height; U, umbilicus; --, no measurement]

USNM No.	D (mm) (ratio)	Wb (mm) (ratio)	Wh (mm) (ratio)	Wb:Wh	U (mm) (ratio)	Diameter at base of body chamber
427905	23.7 (100)	10.6 (44.7)	12.3 (51.9)	0.86	5.0 (21.1)	--
427906	30.0 (100)	12.2 (40.7)	15.1 (50.3)	.81	6.0 (20.0)	--
427907	31.6 (100)	12.9 (40.8)	15.5 (49.1)	.83	6.5 (20.6)	--
427908	43.7 (100)	15.3 (35.0)	21.5 (49.2)	.71	7.2 (16.5)	31.0
427909	47.5 (100)	16.4 (34.5)	25.5 (53.7)	.64	8.0 (16.8)	--
427910	54.3 (100)	18.4 (33.9)	25.9 (47.7)	.71	10.4 (19.1)	32.2
427911	56.3 (100)	18.0 (32.0)	26.3 (46.7)	.68	14.5 (25.8)	55.7
427912	61.4 (100)	19.6 (31.9)	32.5 (52.9)	.60	11.0 (17.9)	--
427913	64.2 (100)	19.8 (30.8)	32.0 (49.8)	.62	13.6 (21.2)	36.2
427914	65.3 (100)	22.0 (33.7)	37.8 (57.8)	.58	13.0 (19.9)	--
427915	65.5 (100)	20.5 (31.3)	33.0 (50.4)	.62	10.0 (15.2)	53.6
427916	71.0 (100)	20.4 (28.7)	30.2 (42.5)	.68	20.0 (28.1)	57.0
427917	71.7 (100)	21.3 (29.7)	34.9 (48.7)	.61	15.0 (20.9)	45.5
427918	82.7 (100)	23.0 (27.8)	44.0 (53.2)	.52	12.0 (14.5)	51.0
427919	84.0 (100)	24.0 (28.5)	37.0 (44.0)	.65	19.2 (22.8)	52.2
427920	84.6 (100)	26.0 (30.7)	33.9 (40.0)	.76	19.4 (22.9)	54.0
427921	91.4 (100)	23.5 (25.7)	45.6 (49.9)	.51	14.8 (16.2)	62.5
427922	94.1 (100)	24.3 (25.8)	49.9 (53.0)	.49	18.8 (20.0)	94.1
427923	97.8 (100)	32.4 (33.1)	50.2 (51.3)	.64	19.0 (19.4)	61.0
427924	104.3 (100)	29.3 (28.1)	51.7 (49.6)	.57	20.3 (19.5)	76.5
427925	105.5 (100)	26.2 (24.8)	50.8 (48.1)	.52	20.3 (19.2)	68.5
427926	105.5 (100)	29.3 (27.8)	52.8 (50.0)	.55	21.0 (19.9)	76.4
427927	107.0 (100)	28.0 (26.2)	54.3 (50.7)	.52	22.0 (20.6)	79.0
427928	107.0 (100)	30.0 (28.0)	43.8 (40.9)	.68	24.0 (22.4)	70.0
427929	108.5 (100)	30.0 (27.6)	51.6 (47.6)	.58	21.3 (19.6)	70.0
427930	113.3 (100)	25.0 (22.1)	53.8 (47.4)	.46	23.2 (20.5)	84.7
427931	114.0 (100)	31.6 (27.7)	46.5 (40.8)	.68	20.7 (18.2)	72.0
427932	116.0 (100)	28.5 (24.6)	36.7 (31.6)	.78	23.5 (20.3)	62.0
427933	116.5 (100)	32.7 (28.1)	57.5 (49.4)	.57	23.0 (19.7)	80.8
427934	122.0 (100)	35.7 (29.3)	56.0 (45.9)	.64	27.7 (22.7)	85.0
427935	122.5 (100)	32.0 (26.1)	54.6 (44.6)	.59	28.0 (22.8)	80.0
427936	129.0 (100)	36.5 (28.3)	51.5 (39.9)	.28	35.4 (27.4)	87.0
427937	135.5 (100)	36.7 (27.1)	56.2 (41.5)	.65	32.4 (23.9)	93.0

¹From basal part of Cody Shale in the SE¼ sec. 9, T. 53 N., R. 92 W., Big Horn County, Wyoming.

(text fig. 2D) (Haas, 1949, fig. 9). Umbilical lobes tend to be narrow, and the adjacent saddles are broad and little divided (text fig. 2) (Haas, 1949, figs. 5–9).

Discussion.—*Metoicoceras praecox* differs from other species of the genus in its lack of inner ventrolateral tubercles, except for a brief appearance on one of the innermost whorls. The species also differs from most other forms in its more evolute coiling and in its possession of siphonal tubercles on the early whorls. *Metoicoceras lato-venter* Stephenson (1953, p. 209, pl. 53, figs. 1–9; pl. 54, figs. 9–11) has siphonal tubercles on the innermost whorls, but that species has more robust whorls displaying squarish sections (text fig. 3H) and a simpler suture (text fig. 2A). *Metoicoceras swallowi* (Shumard, 1860, p. 591) has faint siphonal clavi on the innermost whorls, and the adults are as evolute as *M. praecox*, but *M. swallowi* has both inner and

outer ventrolateral tubercles and retains the outer ones on the body chamber (Stephenson, 1953, pl. 52, figs. 2–5). The suture of *M. swallowi* is also more simplified (text fig. 2E) (Stephenson, 1953, pl. 52, figs. 2, 3). Slender forms of *M. praecox* that have nearly smooth body chambers except for coarse ribs near the aperture are like *M. frontierense* Cobban (1988, pl. 14); the latter differs mainly in that both inner and outer ventrolateral tubercles are present on most of the phragmocone.

SEQUENCE OF *METOICOCERAS* IN THE WESTERN INTERIOR

The oldest *Metoicoceras* in the Western Interior may be represented by some juvenile whorls (pl. 4, figs. 1–6) from the Belle Fourche Shale at USGS Mesozoic locality

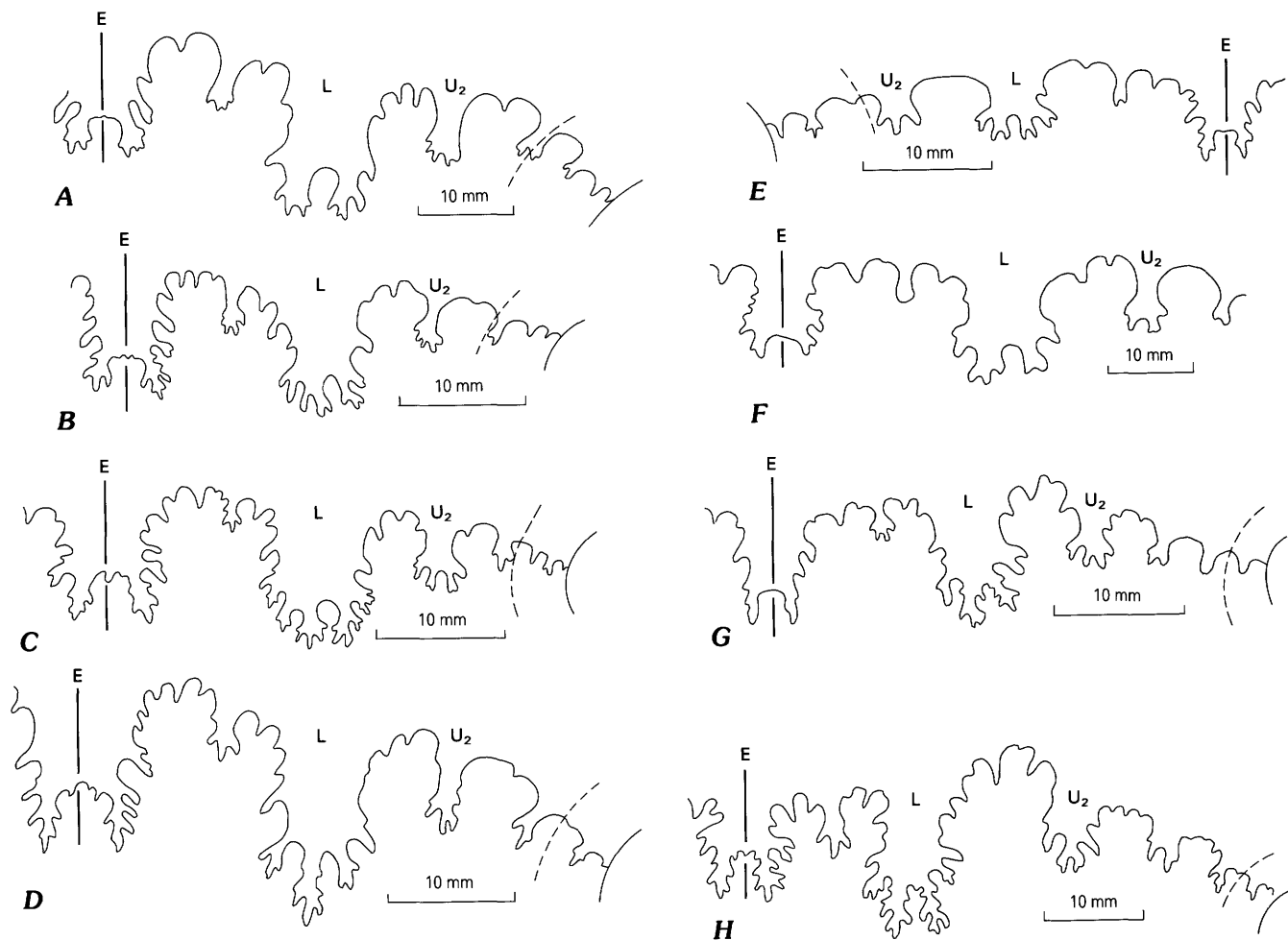
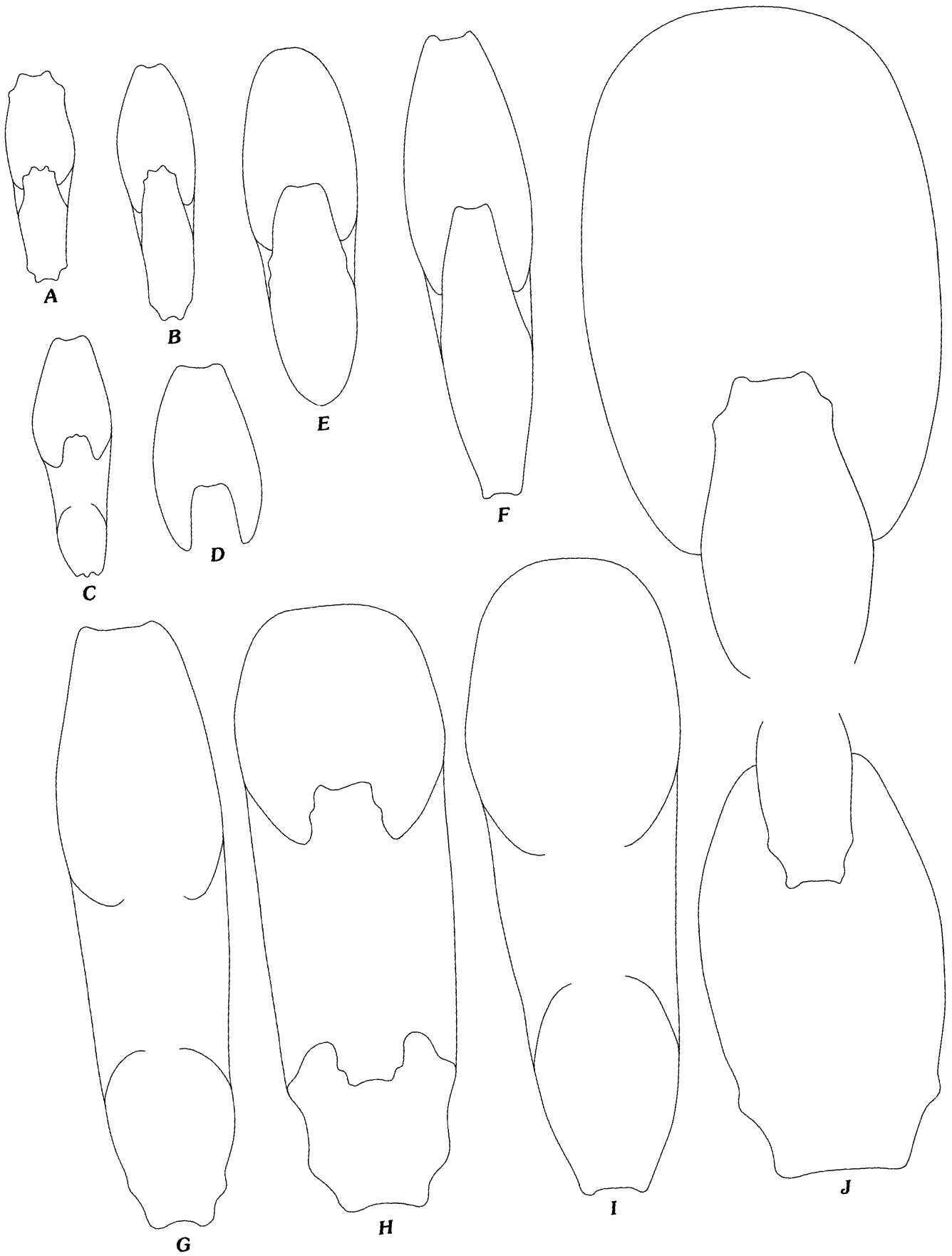


Figure 2. External sutures of *Metoicoceras*. *A*, *M. latoventer* Stephenson, hypotype USNM 427945 at a diameter of 116 mm, from the Templeton Member of the Woodbine Formation at USGS Mesozoic locality 17163 about 4.5 km southeast of the center of Whitesboro, Grayson County, Texas. *B–D*, *M. praecox* Haas, from the basal part of the Cody Shale at USGS Mesozoic locality 21850 about 16 km northeast of Greybull, Big Horn County, Wyoming. *B*, Hypotype USNM 427944, fourth-from-last suture at a whorl height of 28 mm; *C*, hypotype USNM 427929, fourth-from-last suture at a diameter of 60 mm; *D*, hypotype USNM 427927, fourth-from-last suture at a diameter of 70 mm. *E*, *M. swallowi* (Shumard), hypotype USNM 427942, sixth-from-last suture at a diameter of 51 mm, from the Templeton Member of the Woodbine Formation at

USGS Mesozoic locality 14546 in the bed of Red River about 13 km east of Arthur City, Lamar County, Texas. *F*, *M. bergquisti* Cobban, hypotype USNM 427946, most of external suture at a whorl height of about 53 mm, from the Coleraine Formation at USGS Mesozoic locality 13060 at the Arcturus mine, Marble, Itasca County, Minnesota. *G*, *M. mosbyense* Cobban, hypotype USNM 220382, fifth-from-last suture at a diameter of 61 mm, from the Mosby Sandstone Member of the Belle Fourche Shale at USGS Mesozoic locality 21486 about 1.6 km southwest of Yellow Water Reservoir in the NE¼ sec. 14, T. 13 N., R. 25 E., Petroleum County, Montana. *H*, *M. geslinianum* (d'Orbigny), hypotype USNM 427950, seventh-from-last suture at a diameter of 83.5 mm, from the Britton Formation 2.5 km southeast of Britton, Ellis County, Texas.

D5947 on the western flank of the Black Hills uplift in the NW¼ sec. 14, T. 47 N., R. 65 W., Weston County, Wyoming. This species, which we are referring to as *M. sp. A*, is probably from low in the zone of *Dunveganoceras pondi*. Whorls are fairly stout, like those of similar-sized specimens of *M. latoventer*, but the ornament on the outer whorls as well as on the innermost ones is quite different and more like that of *M. praecox*. The smallest specimen (USNM 923751) has a diameter of 12.0 mm, a breadth of

7.7 mm (ratio of 0.64), a height of 6.4 mm (0.53), a whorl breadth to whorl height ratio of 1.2, and an umbilicus of 10.3 mm (0.86). At the smallest end of the outer whorl, ornament consists only of low rectiradiate ribs that end in conspicuous nodate inner ventrolateral tubercles that are spaced at eight per whorl. By the end of the first quarter of a whorl, at a diameter of about 6.7 mm, weak nodate outer ventrolateral tubercles appear, as do weak secondary ribs that support faint inner and outer ventrolateral tubercles.



Low, rounded siphonal tubercles arise at the end of the first half of the outer whorl at a diameter of about 7.3 mm. As the whorl enlarges, the ribs become stronger, and the primaries arise from umbilical bullae. At the position of the inner ventrolateral tubercle, each rib bends forward and terminates in the outer ventrolateral tubercle. Primary and secondary ribs alternate, and each bears inner and outer ventrolateral tubercles. The outer ventrolateral tubercles strengthen, but the inner ones weaken, and, at the larger end of the whorl, the inner ones disappear. Outer ventrolateral tubercles are strong and nodate at the end of the whorl. Each of these tubercles is matched by a weak clavate siphonal tubercle. Another inner whorl (USNM 423752) from locality D5947 verifies this sequence of ornament. The earliest whorls have only weak primary ribs and conical inner ventrolateral tubercles that weaken and disappear by a diameter of 9.8 mm. As these tubercles weaken, outer ventrolateral tubercles arise, and, by a diameter of 10 mm, the outer ones become conspicuous and somewhat clavate.

Small specimens (pl. 5, figs. 4–11) from another locality on the western flank of the Black Hills show a similar early development of ornament. This collection

consists of four well-preserved specimens from a limestone concretion from the lower part of the Greenhorn Formation at USGS Mesozoic locality D4462 in the NE¼ sec. 24, T. 47 N., R. 65 W., Weston County, Wyoming. These specimens, herein referred to as *M. aff. praecox*, have inner ventrolateral tubercles that persist to large diameters. These tubercles are absent on even the smallest topotypes of *M. praecox* from locality 21850, and the ribs are narrower and sharper. The smallest specimen (USNM 423755) from locality D4462 has a diameter of 9.2 mm and an umbilicus of only 0.8 mm (ratio to diameter of 0.09). The outer whorl has a somewhat squarish section that is a little broader than it is high and exhibits flattened flanks and a broadly rounded to slightly flattened venter. Ornament at the small end of the outer whorl consists only of nodate inner ventrolateral tubercles. Nodate outer ventrolateral tubercles arise at about the end of the first half of the whorl at a diameter of about 6 mm. Prorsiradiate ribs arise slightly farther out, and the first umbilical bulla appears at the end of the whorl. Faint siphonal clavi are present also by the end of the whorl. On the complete outer whorl, 12 inner ventrolateral tubercles are present; they are nodate and strong on most of the whorl, but, near the larger end, they weaken and become bullate. Another small specimen (pl. 5, figs. 4–6), 10 mm in diameter, shows this same development of ornament except that the inner ventrolateral tubercles are still strong and nodate at the larger end. On a third specimen (pl. 5, figs. 9–11), the inner ventrolateral tubercles disappear at the base of the body chamber at a diameter of about 12.5 mm. Ornament on this small body chamber consists of umbilical bullae; narrow, prorsiradiate primary and secondary ribs that curve forward and rise into conspicuous outer ventrolateral clavi; and weak siphonal clavi located on broad, transverse swellings. A fourth small specimen (pl. 5, figs. 7, 8) is part of a body chamber ornamented like the third specimen. Whether these specimens represent a very small species of *Metoicoceras* or whether they represent juvenile *M. praecox* cannot be determined from the small collection at hand.

Typical *M. praecox*, such as those from locality 28150, occur with *Dunveganoceras pondi* and *Calycoceras canitaurinum* (Haas). All three species occur in the basal bed of the Greenhorn Formation in the Black Hills area of northeastern Wyoming, southeastern Montana, and western South Dakota.

In the Frontier Formation in north-central Wyoming, a zone of ammonites of early late Cenomanian age can be recognized between the zones of *D. pondi* and *Metoicoceras mosbyense* (Cobban, 1988, p. 14, 15). Ammonites in this zone include *Calycoceras aff. C. canitaurinum* (Haas) and the new species *D. problematicum*, *M. frontierense* (pl. 6, figs. 11–15), and *M. aff. frontierense* (pl. 6, figs. 16–18). The latter species was foreshadowed by fairly smooth variants of *M. praecox* that have rejuvenated ribbing at the aperture. As we pointed out earlier, *M. frontierense* differs

◀ **Figure 3.** Costal whorl sections (natural size) of various species of *Metoicoceras*. A, *M. geslinianum* (d'Orbigny), hypotype USNM 425303 at a diameter of 39 mm, from the Colorado Formation at USGS Mesozoic locality D11529 in the NW¼NE¼ sec. 11, T. 18 S., R. 18 W., Grant County, New Mexico. B, *M. mosbyense* Cobban, hypotype USNM 427947 at a diameter of 48 mm, from the Mosby Sandstone Member of the Belle Fourche Shale at USGS Mesozoic locality 21485 in the SW¼ sec. 1, T. 13 N., R. 25 E., Petroleum County, Montana (pl. 5, figs. 1–3). C, *M. praecox* Haas, hypotype USNM 427908 at a diameter of 44.5 mm, from the basal part of the Cody Shale at USGS Mesozoic locality 21850 about 16 km northeast of Greybull, Big Horn County, Wyoming (pl. 2, figs. 6, 7). D, *M. bergquisti* Cobban, holotype UMIP 9004, at a whorl height of 34.5 mm, from the Coleraine Formation at the Arcturus mine, Marble, Itasca County, Minnesota. E, *M. praecox* Haas, hypotype USNM 427914 at a diameter of 66 mm, from the same locality as C (pl. 2, figs. 10–12). F, *M. mosbyense* Cobban, hypotype USNM 220382 at a diameter of 87 mm, from the same locality as B (pl. 5, figs. 15–17). G, *M. swallowi* (Shumard), hypotype USNM 105991 at a diameter of 113 mm, from the Templeton Member of the Woodbine Formation at USGS Mesozoic locality 13797 about 13 km east of Arthur City, Lamar County, Texas. H, *M. latoventer* Stephenson, hypotype USNM 427945 at a whorl height of 38 mm, from the Templeton Member of the Woodbine Formation at USGS Mesozoic locality 17183 about 4.5 km southeast of the center of Whitesboro, Grayson County, Texas (pl. 5, figs. 18, 19). I, *M. mosbyense* Cobban, hypotype USNM 427949 at a diameter of 118 mm, from the same locality as B and F. J, *M. geslinianum* (d'Orbigny), hypotype USNM 411503 at a diameter of 216 mm, from the Britton Formation 4 km south of Britton, Ellis County, Texas.

from its ancestor in that inner ventrolateral tubercles persist well out on most or all of the phragmocone whorls. In addition, the venter of *M. frontierense* tends to be smooth on adult body chambers, whereas it is undulose in *M. praecox*. This smooth-ventered body chamber stage seems to ally *M. frontierense* to *M. bergquisti* Cobban (1983, p. 14; pl. 8, figs. 1–4; pl. 12, figs. 1–5; pl. 13; pl. 14, figs. 1–5, 10–15), a species described from Minnesota. *Metoicoceras bergquisti* is a stouter species that attains a much larger size and has a flatter but smooth adult venter. This species is probably younger than *M. frontierense*, inasmuch as an associated ammonite, *D. hagei* Warren and Stelck (1955, p. 69, pl. 5, fig. 1), is more closely related to *D. albertense* (Warren, 1930, p. 21; pl. 1, figs. 1, 2) and *D. conditum* Haas (1951, p. 5, figs. 2–9) than it is to *D. pondi*. Both *D. albertense* and *D. conditum* are found in the zone of *M. mosbyense*. *Metoicoceras bergquisti* has both inner and outer ventrolateral tubercles on most or all of the phragmocone, although the inner tubercles weaken and disappear on early whorls of the more slender and smoother variants. The earliest whorls of this species have not been seen. A body chamber of the species was recently found in the Woodbridge Member of the Raritan Formation in the clay pit of the Fisher Brick Company at Sayreville, Middlesex County, New Jersey (USGS Mesozoic locality 29584), the first occurrence of the genus on the Atlantic coast of the United States.

Metoicoceras mosbyense, which characterizes the next zone above *M. frontierense*, is abundant and widely distributed from north-central Montana to southwestern New Mexico. The species differs from all older forms in that ribs become flattened on the outer part of the flank near the end of the phragmocone and on the adjacent part of the body chamber, where they cross the venter transversely as broad, flat-topped swellings. Dimorphism is now recognized in this species. The holotype (Cobban, 1953, p. 48, pl. 7) is an adult microconch, whereas the holotype of *M. muelleri* Cobban (1953, p. 49, pl. 8, fig. 7; pl. 9) is an adult macroconch. Adult microconchs, which are as small as 125 mm in diameter, are moderately stout and rather strongly ornamented. Inner ventrolateral tubercles may persist to a diameter of 25 mm, whereas the outer ventrolateral tubercles are present to the end of the phragmocone. Umbilical bullae may be present on all the phragmocone whorls. Adult macroconchs may attain diameters of 260 to 285 mm, or they may be as small as 180 mm (pl. 4, figs. 7, 8). Macroconchs are more slender and more weakly ornamented than microconchs, and umbilical bullae may be absent (pl. 5, fig. 17). Adult body chambers usually have a pronounced change in ribbing from broad, flat ribs on the older part to more closely spaced, narrow ones on the younger part (pl. 4, figs. 7, 8). Inner ventrolateral tubercles disappear at some diameter between 7 and 11 mm.

The innermost whorls of both the macroconch and the microconch have been described in detail by Cobban (1953,

p. 48–52, pl. 6, figs. 1–6). Ornament of these innermost whorls is much like that of the innermost whorls of older species in that strong, nodate inner ventrolateral tubercles arise before any of the other ornament. A change occurs, however, in the early development of the outer ventrolateral tubercles. These tubercles occur in pairs along the ventrolateral shoulder, separated by smooth spaces, and each of the pairs is set forward a little from the larger inner ventrolateral tubercle, like the one shown by Hyatt (1903, pl. 11, fig. 14).

Metoicoceras geslinianum (d'Orbigny, 1850, p. 146) (pl. 6, figs. 1–10), the youngest species of the genus in the Western Interior, occurs in the zone of *Sciponoceras gracile* near the top of the Cenomanian. *Metoicoceras geslinianum* descended from *M. mosbyense*, from which it differs mainly in that inner ventrolateral tubercles persist out onto the adult body chamber. Ribs flatten on the outer part of the flank near the end of the phragmocone and the adjacent part of the body chamber, just as they do on *M. mosbyense*. The earliest whorls, however, show a change not observed in the *M. mosbyense* whorls. Outer ventrolateral tubercles occur in pairs, as they do in *M. mosbyense*, but a constriction that arises on the ventrolateral shoulder and arches across the venter separates each tubercle of a pair. These pairs and constrictions disappear at a diameter of about 8 or 9 mm, and, at larger diameters, ventrolateral tubercles are regularly spaced.

Dimorphism is conspicuous in *M. geslinianum* and closely parallels that of *M. mosbyense*. Microconchs are fairly evolute, robust, and coarsely ornamented. Adults range in diameter from 135 to 210 mm. Macroconchs are more involute and compressed and have weaker ornament. Adults attain diameters ranging from 195 to 245 mm. The dimorphism has been well described and illustrated by Wright and Kennedy (1981) and Kennedy (1988).

Metoicoceras geslinianum is abundant in the basal part of the Bridge Creek Member of the Greenhorn Limestone in the central Great Plains and in the equivalent rocks farther west and southwest in southern Utah, northeastern Arizona, southwestern Colorado, and much of New Mexico. From this large endemic center, the species migrated southward into Trans-Pecos Texas and Chihuahua, Mexico, and eastward across Texas. Ecologic conditions at this time must have been perfect for widespread migration, because the species has been found in Brazil, Africa, western Europe, Israel, Iran, and the U.S.S.R.

Following this great migration, *Metoicoceras* seems to have disappeared. The genus is believed to have given rise to *Spathites* Kummel and Decker, 1954, of latest Cenomanian through middle Turonian age (Kennedy and others, 1980).

ORIGIN OF METOICOCERAS

Wright (1956) suggested that *Utaturiceras* Wright, 1956 was the direct ancestor of *Metoicoceras*. The type

species of *Utaturiceras*, *Ammonites vicinalis* Stoliczka (1864, p. 84, pl. 44, figs. 1, 4, 5, 7, 8, non figs. 2, 3, 6), has been well described by Matsumoto and Sarkar (1966), who designated as lectotype the adult specimen figured by Stoliczka (1864, pl. 44, fig. 8). This specimen is a compressed, fairly involute form that has high whorls and a narrow umbilical shoulder, slightly inflated flanks, and a narrow, flattened venter bordered by ventrolateral clavi. Ribs are numerous, prorsiradiate, and slightly flexuous on the body chamber and mostly of equal lengths, whereas the ribs are primary and secondary on the inner whorls. Inner and outer ventrolateral tubercles are present on the whorls out to the body chamber, where the inner ones weaken to slight swellings on the ribs. On the innermost whorls of a paratype (Matsumoto and Sarkar, 1966, pl. 33, fig. 1a–c), inner ventrolateral tubercles form first, and outer ones form later. The lectotype shows some resemblance to the splendid adult specimen of *M. swallowi* illustrated by Stephenson (1953, pl. 52, figs. 2–5), but their sutures are totally different. *Metoicoceras swallowi* has a simple pseudoceratitic suture marked by short lobes, whereas *U. vicinale* has a complex suture characterized by long lobes. *Utaturiceras* is a lower Cenomanian member of the Mantelliceratinae and is closely allied to *Mantelliceras* and *Graysonites*. Resemblance to *Metoicoceras* is mere homeomorphy.

C.W. Wright and W.J. Kennedy (Juignet and others, 1973, p. 25) proposed the upper Cenomanian genus *Thomelites* and suggested that it might be ancestral to *Metoicoceras*. *Thomelites* (type species *Jeanrogericeras sornayi* Thomel, 1966, p. 431, pl. 11, figs. 1–3) has rather massive umbilical tubercles from which arise one to three ribs, each bearing inner and outer clavate ventrolateral tubercles that are matched on the venter by conspicuous siphonal clavi. These siphonal clavi persist out to the outer whorl. In their treatment on *Spathites*, Kennedy and others (1980, p. 822) continued to show *Thomelites* as ancestral to *Metoicoceras*, but, a little later, Kennedy and others (1981, p. 54) pointed out differences between *Thomelites* and *Metoicoceras* and noted that these genera “coexisted in time but not in space.” In fact, *Metoicoceras* is known to appear in the middle Cenomanian, before *Thomelites*, which is known only from the upper Cenomanian.

All three Gulf Coast species of *Metoicoceras* came from the middle Cenomanian Templeton Member of the Woodbine Formation in northern Texas. All are rare: *M. swallowi*, the type species of the genus, is represented in the USGS collections by seven specimens in addition to the five figured by Stephenson (1953); *M. latoventer* is represented by three specimens in addition to the four figured by Stephenson; and *M. crassicostrae* is known from the holotype and one other specimen. No other ammonites are known to have been associated with *M. swallowi* at its type locality, and the holotype has been lost. This species has been found at several other localities in northern Texas, but the only other ammonite with it is *Metengonoceras dumbli*

(Cragin), a species that seems to be of late middle Cenomanian age (Cobban, 1987b), suggestive of an age older than that of the Western Interior *M. praecox*.

Early whorls of *M. swallowi* were examined from a phragmocone that was collected at the type locality of the species at USGS Mesozoic locality 14546 from the bed of Red River near old Slate Shoals 12.9 km east of Arthur City, Lamar County, Texas (Stephenson, 1953, p. 42, loc. 201). The smallest whorl examined (USNM 427941) has a diameter of 10 mm, but the umbilicus is not preserved. Flanks and venter are well rounded and smooth at the small end, whereas flanks are flattened and the venter is broadly rounded at the larger end. Faint rectiradiate primary ribs and nodate inner and outer ventrolateral tubercles arise together on the older part of the whorl at a diameter of about 5.5 mm. This ornament is well defined on the younger half of the whorl, where every other inner ventrolateral tubercle lies on a primary rib. A rib bends forward from each inner tubercle and terminates in an equal-sized outer ventrolateral tubercle. All inner tubercles are nodate; the outer ones are nodate at first but become clavate by the end of the whorl. Faint siphonal tubercles also arise on the last half of the whorl; each matches an outer ventrolateral tubercle. Inner ventrolateral tubercles number 9 or 10 on the last half of this whorl. The ornament contrasts greatly with the ornament on similar-sized whorls of *M. praecox*, where these tubercles are absent.

Metoicoceras latoventer has not been found with *M. swallowi*, although both species are said to occur in the Templeton Member of the Woodbine Formation. Ammonites found with *M. latoventer* are *Metengonoceras dumbli* (Cragin) and “*Acanthoceras*” *cuspidum* Stephenson (1953). The latter species has been found in both the *Plesiakanthoceras wyomingense* and *Dunveganoceras pondi* zones in the Black Hills area of the Western Interior. The first zone has been considered as latest middle Cenomanian and the other as earliest late Cenomanian (Cobban, 1984). The presence of *Metengonoceras dumbli* favors a late middle Cenomanian age near that of *Metoicoceras swallowi*.

The small inner whorls of *M. latoventer* are like those of *M. swallowi*. A paratype (USNM 105999) figured by Stephenson (1953, pl. 53, figs. 5–7) has equal-sized umbilical and inner and outer ventrolateral tubercles on a whorl about 11 mm in diameter. Inner ventrolateral tubercles are nodate, and every other one is connected to a nodate umbilical tubercle by a low, prorsiradiate primary rib. Clavate outer ventrolateral tubercles are set forward a little from the inner ones, and each is matched by a weaker siphonal clavus. The last half whorl has four umbilical tubercles and seven ventrolateral tubercles. Sutures of *M. latoventer* (text fig. 2A) are like those of *M. swallowi* (text fig. 2E) in that the saddles are little divided or undivided.

The holotype of *M. crassicostrae* is a complete adult from USGS Mesozoic locality 20314 about 4.3 km north of Bells, Grayson County, Texas. The specimen has more

rounded whorls and fewer ribs than *M. latoventer* does, and the umbilical tubercles are stronger and conical. Sutures, however, are similar. Ammonites from the type locality of *M. crassicostrae* are *Metengonoceras dumbli* and the species described by Stephenson (1953) as *Mammites? bellsanusi*. The latter species is better assigned to *Plesiacanthoceras* Haas, 1964, as Cobban (1987a, p. 18) has already suggested. The presence of *Plesiacanthoceras* and *Metengonoceras dumbli* again suggests a middle Cenomanian age for the Templeton Member of the Woodbine Formation and a correlation with the *P. wyomingense* zone of the Western Interior.

Although *Metioceras swallovi*, *M. crassicostrae*, and *M. latoventer* share several common features and are regarded as a closely related group, we cannot put them in stratigraphic sequence. Their origin probably lies in some contemporary member of the Acanthoceratinae, and Stephenson included in his type series of *P. bellsanusi* a paratype specimen (USNM 105986) that is actually a *M. crassicostrae*. The ornament of this specimen is close to that of the holotype of *P. bellsanusi* (Stephenson, 1953, pl. 51, figs. 8–11), but it is more compressed and has much simpler sutures. This evidence suggests that the origin of the early Gulf Coast *Metioceras* lay in *Plesiacanthoceras*, which evolved sutural simplification and profound modification of adult ornament.

The oldest *Metioceras* from the Western Interior come from the lower part of the upper Cenomanian and are thus younger than the Gulf Coast species. *Metioceras* sp. A has several features in common with *M. latoventer* on its inner whorls but shows early loss of inner ventrolateral tubercles combined with a stout whorl section. *Metioceras* aff. *praecox* has a more compressed section than *M. sp. A* does but has distinct inner ventrolateral tubercles, which separate it from the topotype series of *M. praecox*, where these tubercles are incipient only in some specimens. There is thus a series of early stages that might be linked as *M. latoventer* giving rise to *M. sp. A* giving rise to *M. aff. praecox* and then to *M. praecox* itself, although we do not have adults of the middle two to be certain. Furthermore, the suture lines of *M. crassicostrae* are much simpler than those of *M. praecox*. *M. praecox* stands apart from all other species in its lack of inner ventrolateral tubercles and may be an offshoot of the main *Metioceras* lineage that gave rise to *M. bergquisti*, *M. frontierense*, *M. mosbyense*, and *M. geslinianum*, all of which may have arisen from the poorly known species of the *Dunveganoceras pondi* zone (*M. aff. praecox*, *M. sp. A*), in which inner ventrolateral tubercles are present in juveniles and adults, and in the progressive increase in the degree of incision of the lobes and saddles (text fig. 2).

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PLATES 1–6

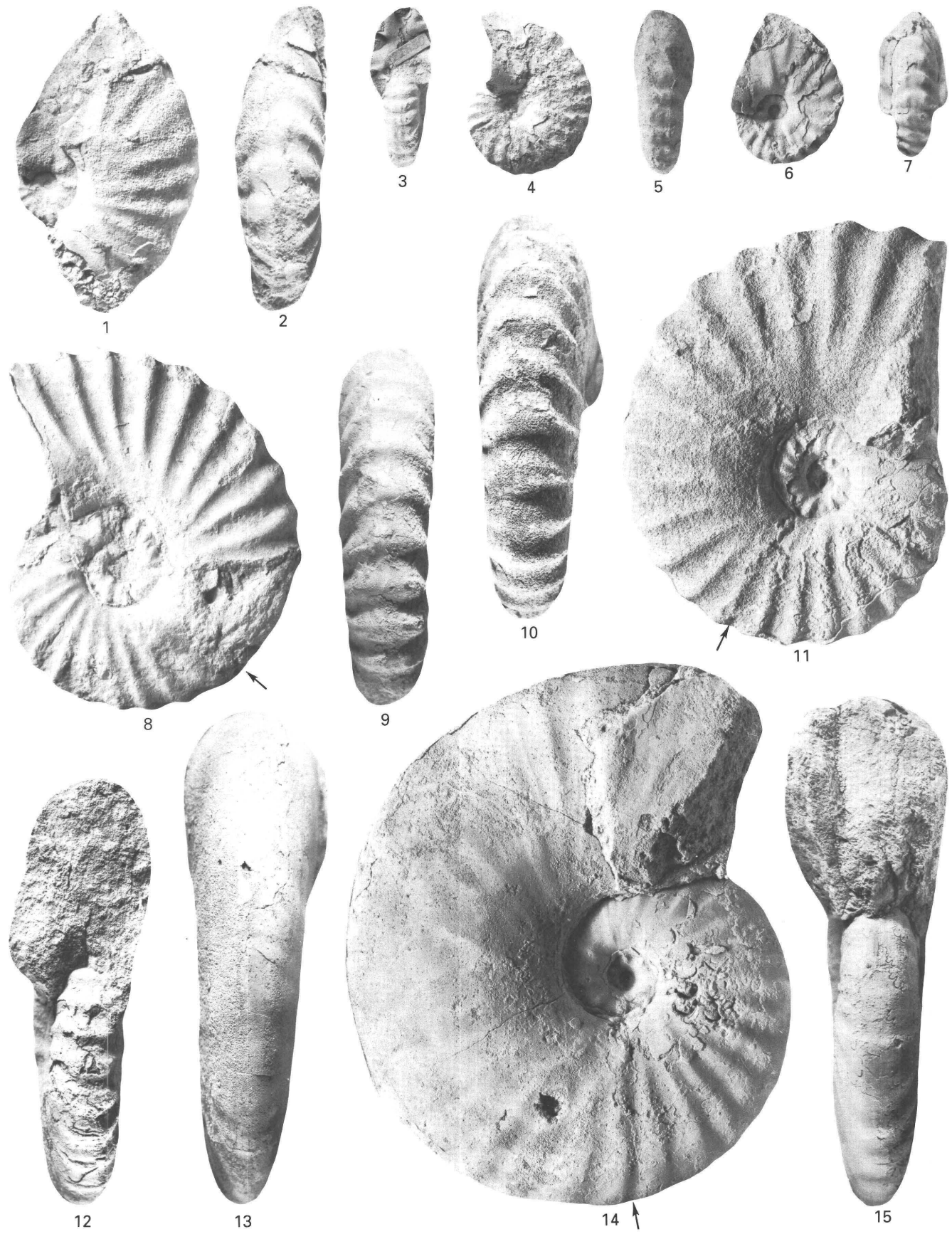
Contact photographs of the plates in this report are available, at cost, from the
U.S. Geological Survey Photographic Library, Federal Center, Denver, CO 80225.

PLATE 1

Metoicoceras praecox Haas (p. B2)

[All figures natural size. Arrows point to base of body chambers]

- Figures 1–15. From the basal part of the Cody Shale at U.S. Geological Survey Mesozoic locality 21850 in the SE¼ sec. 9, T. 53 N., R. 92 W., Big Horn County, Wyoming.
- 1, 2. Hypotype USNM 427938.
 - 3–5. Hypotype USNM 427906.
 - 6, 7. Hypotype USNM 427905.
 - 8, 9. Hypotype USNM 427916.
 - 10–12. Hypotype USNM 427920.
 - 13–15. Hypotype USNM 427928.



METOICOCERAS PRAECOX

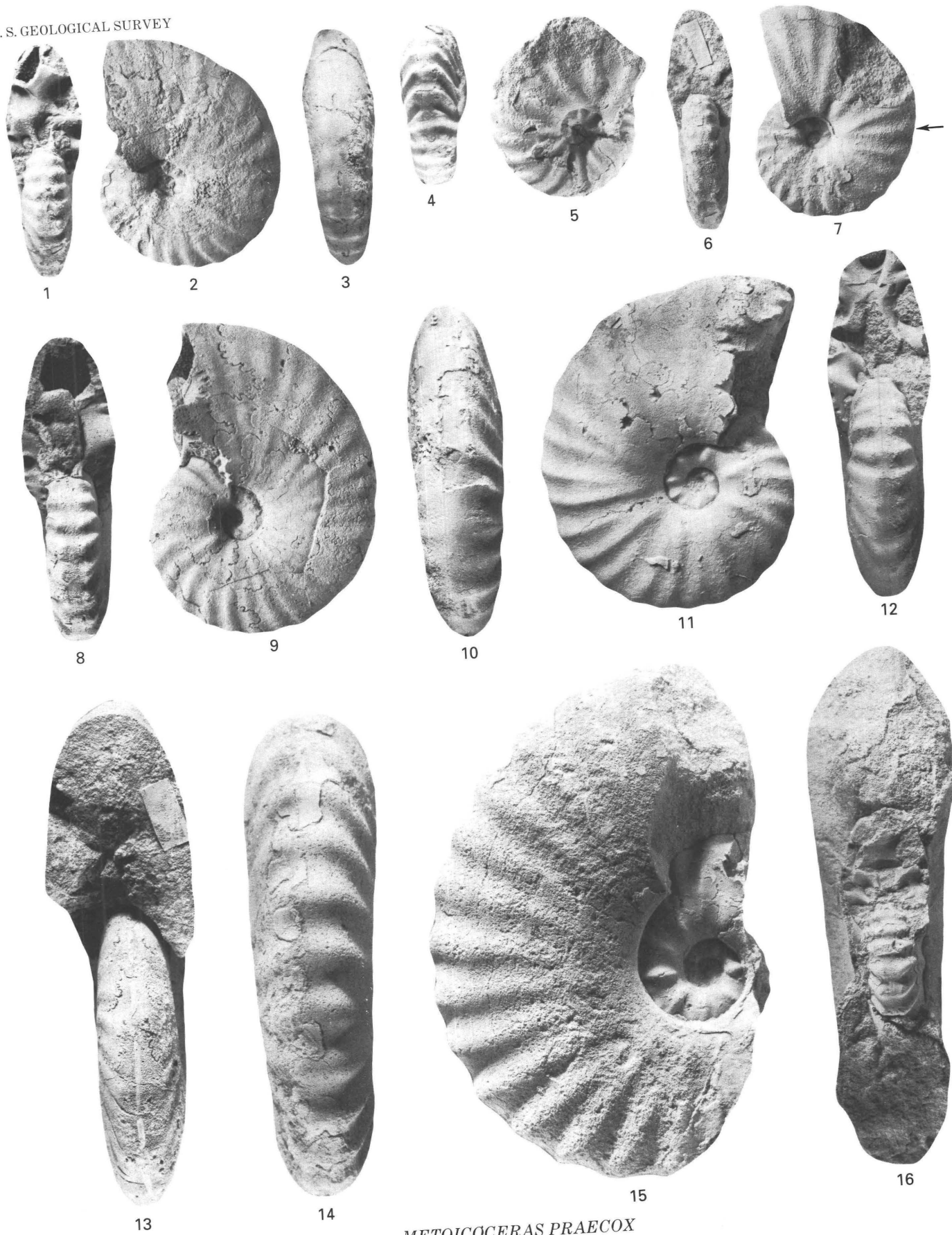
PLATE 2

Metoicoceras praecox Haas (p. B2)

[All figures natural size. Arrow points to base of body chamber]

Figures 1–16. From the basal part of the Cody Shale at U.S. Geological Survey Mesozoic locality 21850 in the SE $\frac{1}{4}$ sec. 9, T. 53 N., R. 92 W., Big Horn County, Wyoming.

- 1–3. Hypotype USNM 427909.
- 4, 5. Hypotype USNM 427907.
- 6, 7. Hypotype USNM 427908.
- 8, 9. Hypotype USNM 427912.
- 10–12. Hypotype USNM 427914.
- 13. Hypotype USNM 427929.
- 14–16. Hypotype USNM 427940.



METOICOCERAS PRAECOX

PLATE 3

***Metoicoceras praecox* Haas (p. B2)**

[All figures natural size. Arrows point to base of body chambers]

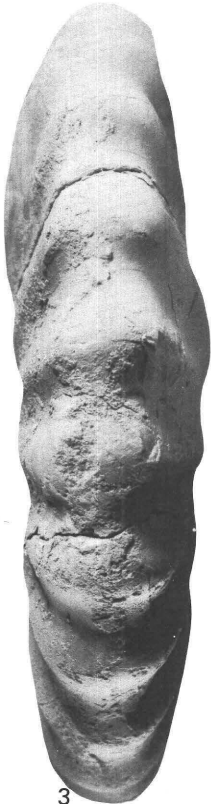
- Figures 1–6. From the basal part of the Cody Shale at U.S. Geological Survey Mesozoic locality 21850 in the SE $\frac{1}{4}$ sec. 9, T. 53 N., R. 92 W., Big Horn County, Wyoming.
- 1–3. Hypotype USNM 427926.
 - 4–6. Hypotype USNM 427936.



1



2



3



4



5



6

METOICOCERAS PRAECOX

PLATE 4

Metoicoceras sp. A and *Metoicoceras mosbyense* Cobban

[All figures natural size. Arrow points to base of body chamber]

- Figures 1–6. *Metoicoceras* sp. A (p. B4). From the Belle Fourche Shale at U.S. Geological Survey Mesozoic locality D5947 about 4.8 km south of Upton in the NW¼ sec. 14, T. 47 N., R. 65 W., Weston County, Wyoming.
- 1, 2. Figured specimen USNM 423750.
 - 3, 4. Figured specimen USNM 423748.
 - 5, 6. Figured specimen USNM 423749.
- 7, 8. *Metoicoceras mosbyense* Cobban (p. B8). Hypotype 427948, from the Mosby Sandstone Member of the Belle Fourche Shale at U.S. Geological Survey Mesozoic locality 21486 about 1.6 km southwest of Yellow Water Reservoir in the NE¼ sec. 14, T. 13 N., R. 25 E., Petroleum County, Montana.



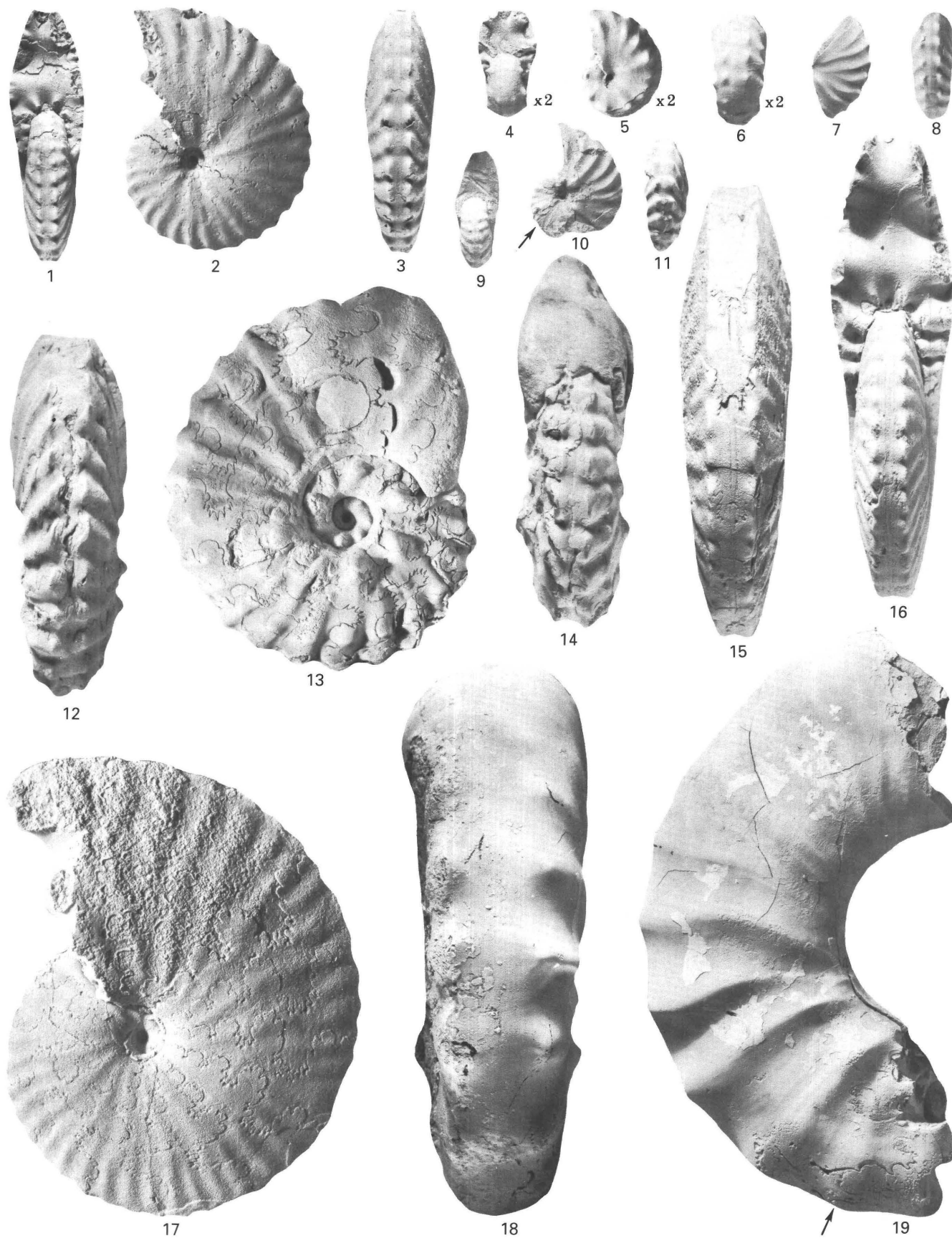
METOICOCERAS SP. AND *METOICOCERAS* MOSBYENSE

PLATE 5

Metoicoceras mosbyense Cobban, *Metoicoceras* aff. *praecox* Haas, *Metoicoceras swallowi* (Shumard), and *Metoicoceras latoventer* Stephenson

[All figures natural size except as indicated. Arrows point to base of body chambers]

- Figures 1–3, 15–17. *Metoicoceras mosbyense* Cobban (p. B8). From the Mosby Sandstone Member of the Belle Fourche Shale at U.S. Geological Survey Mesozoic locality 21485 at Yellow Water Reservoir in the SW¼ sec. 1, T. 13 N., R. 25 E., Petroleum County, Montana.
1–3. Hypotype USNM 427947.
15–17. Hypotype USNM 220382.
- 4–11. *Metoicoceras* aff. *praecox* Haas (p. B7). From the Greenhorn Formation at U.S. Geological Survey Mesozoic locality D4462 about 5.7 km south-southeast of Upton in the NE¼ sec. 24, T. 47 N., R. 65 W., Weston County, Wyoming.
4–6. Figured specimen USNM 423756, ×2.
7, 8. Figured specimen USNM 423753.
9–11. Figured specimen USNM 423754.
- 12–14. *Metoicoceras swallowi* (Shumard) (p. B9). Hypotype USNM 427943, from the Templeton Member of the Woodbine Formation at U.S. Geological Survey Mesozoic locality 14546 about 13 km east of Arthur City, Lamar County, Texas.
- 18, 19. *Metoicoceras latoventer* Stephenson (p. B9). Hypotype USNM 427945, from the Templeton Member of the Woodbine Formation at U.S. Geological Survey Mesozoic locality 17183 about 4.5 km southeast of the center of Whitesboro, Grayson County, Texas.



METOICOCERAS MOSBYENSE, *METOICOCERAS* AFF. *PRAECOX*,
METOICOCERAS SWALLOVI, AND *METOICOCERAS LATOVENTER*

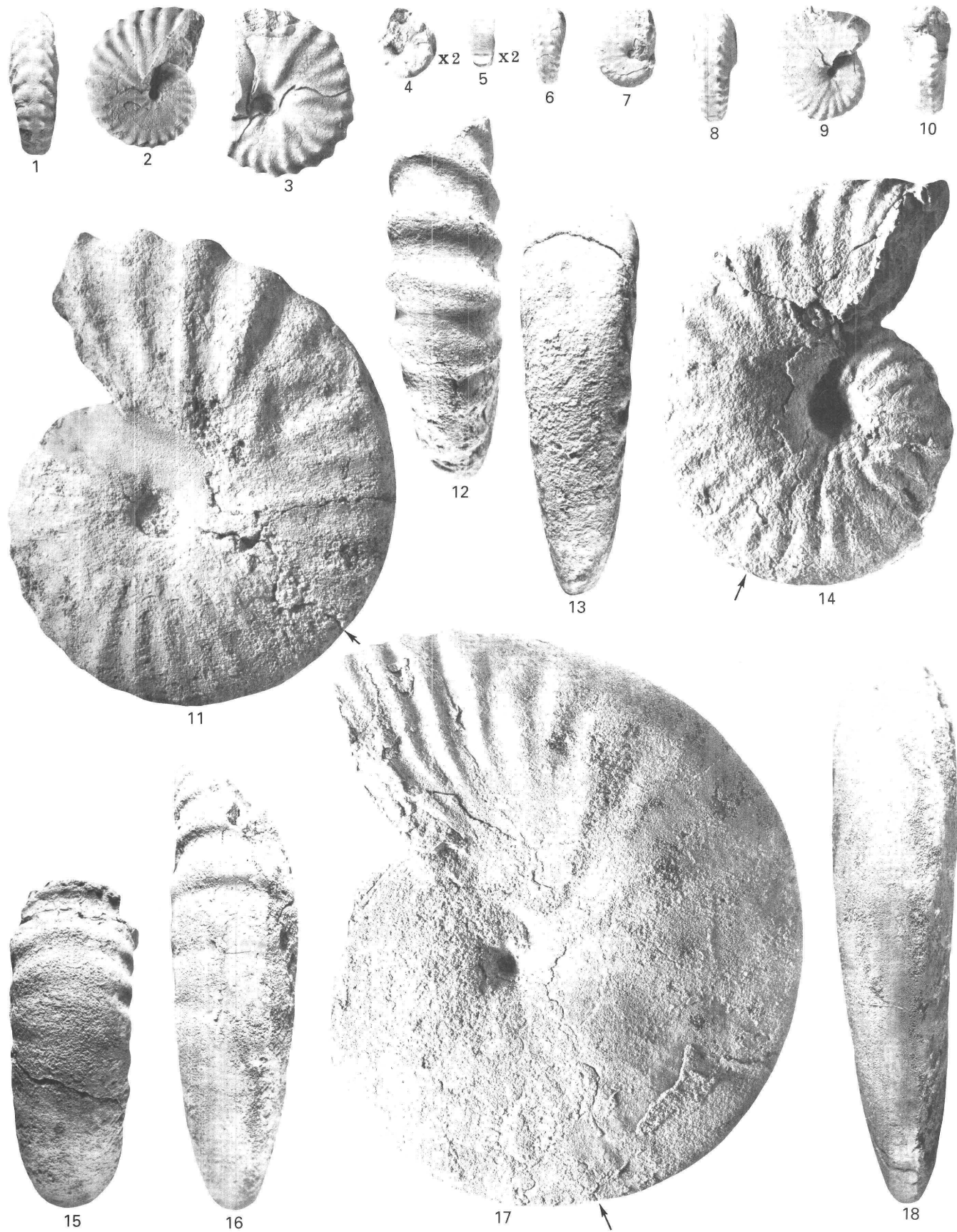
PLATE 6

Metoicoceras geslinianum (d'Orbigny), *Metoicoceras frontierense* Cobban, and *Metoicoceras* aff. *frontierense* Cobban

[All figures natural size except as indicated. Arrows point to base of body chambers]

Figures 1–10. *Metoicoceras geslinianum* (d'Orbigny) (p. B8).

- 1, 2. Hypotype USNM 425301, from the Bridge Creek Limestone Member of the Colorado Formation in the Cookes Range at U.S. Geological Survey Mesozoic locality D6842 in the N $\frac{1}{2}$ N $\frac{1}{2}$ sec. 30, T. 20 S., R. 8 W., Luna County, New Mexico.
3. Hypotype USNM 425302, from the Colorado Formation in the Big Burro Mountains at U.S. Geological Survey Mesozoic locality D11529 in the NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 11, T. 18 S., R. 18 W., Grant County, New Mexico.
- 4, 5. Hypotype USNM 425295 ($\times 2$.) from the same locality as figure 3.
- 6, 7. Hypotype USNM 425298, from the same locality as figure 3.
- 8–10. Hypotype USNM 425299, from the same locality as figure 3.
- 11–15. *Metoicoceras frontierense* Cobban (p. B7). From the Frontier Formation at U.S. Geological Survey Mesozoic locality 23154 in the NE $\frac{1}{4}$ sec. 1, T. 43 N., R. 83 W., Johnson County, Wyoming.
- 11, 12. Paratype USNM 376930.
- 13–15. Holotype USNM 376927.
- 16–18. *Metoicoceras* aff. *frontierense* Cobban (p. B7). Figured specimen USNM 422701, from the Twowells Tongue of the Dakota Sandstone at U.S. Geological Survey Mesozoic locality D6173 in the NE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 3, T. 10 N., R. 31 E., Apache County, Arizona.



METOICOCERAS GESLINIANUM, *METOICOCERAS FRONTIERENSE*,
AND *METOICOCERAS* AFF. *FRONTIERENSE*

Chapter C

Baculites thomi Reeside, 1927, an
Upper Cretaceous Ammonite in the
Western Interior of the United States

By WILLIAM A. COBBAN and W. JAMES KENNEDY

Description and illustrations of a distinctive marker species
from rocks at the Santonian-Campanian boundary

U.S. GEOLOGICAL SURVEY BULLETIN 1934

SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

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<i>Baculites thomi</i> Reeside	C5
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PLATES

[Plates follow references cited]

- 1, 2. *Baculites thomi* Reeside

FIGURES

1. Map of part of the Western Interior of the United States showing localities of *Baculites thomi* Reeside described in table 1 C2
2. Drawing showing sutures and whorl sections of *Baculites thomi* Reeside C6

TABLES

1. Localities at which *Baculites thomi* fossils were collected C3
2. Average angle of taper and average number of flank and ventral ribs per height of *Baculites thomi* Reeside C7

Baculites thomi Reeside, 1927, an Upper Cretaceous Ammonite in the Western Interior of the United States

By William A. Cobban¹ and W. James Kennedy²

Abstract

The heteromorphic ammonite *Baculites* is an important marker fossil for much of the marine Upper Cretaceous of the Western Interior of the United States. *Baculites thomi* Reeside, 1927, is a previously poorly known species that is herein redescribed from well-preserved material from the top of the Kevin Member of the Marias River Shale in northwestern Montana. The species ranges from the upper Santonian into the lower Campanian.

INTRODUCTION

Baculites thomi Reeside (1927a, p. 13, pl. 12, figs. 9–14) was based on two specimens, the holotype and a paratype from the Telegraph Creek Formation in south-central Montana. Since the publication of Reeside's work, *B. thomi* has been recorded in a few papers and illustrated in only two. The species has a distinctive ornament, a fairly brief time span, and a wide geographic distribution; accordingly, *B. thomi* can serve as a good index fossil.

Baculites thomi originally was described briefly and illustrated by three retouched views of the holotype and by the suture of the paratype. We herein redescribe the species on the basis of abundant well-preserved material from one locality (U.S. Geological Survey (USGS) Mesozoic locality 21419) in Toole County in northwestern Montana. The specimens include nearly all growth stages, and some adults have complete apertures. The present study reveals that *B. thomi* descended from *B. codyensis* Reeside of late Coniacian-early Santonian age and ranged through rocks of late Santonian-early Campanian age.

All specimens illustrated in this report are kept in the U.S. National Museum of Natural History (USNM), Washington, D.C., where they have USNM catalog numbers.

R.E. Burkholder (retired from the USGS) took the photographs. Kennedy acknowledges the financial support of the Natural Environment Research Council (U.K.) and the technical assistance of the staff of the Geological Collections, Oxford University Museum, and the Department of Earth Sciences, Oxford, U.K.

LOCALITIES OF COLLECTIONS

Localities at which *Baculites thomi* has been collected in the Western Interior are shown in text figure 1 and are numbered from north to south. The USGS Mesozoic locality number, the collector(s), the year of collection, the locality, and the stratigraphic assignment are given in table 1.

PUBLISHED RECORDS OF *BACULITES THOMI* REESIDE

Montana

The types of *Baculites thomi* came from the Elk Basin Sandstone Member of the Telegraph Creek Formation in the type area of that formation west of Hardin in Big Horn County in south-central Montana, where the species was associated with *Desmoscaphites bassleri* Reeside (Reeside, 1927a, p. 14, unnumbered table) (text fig. 1, loc. 19).

Cobban (1950, p. 1900) also noted the presence of *B. thomi* with *D. bassleri* in the type area of the Telegraph Creek Formation and listed the following additional fossils from the formation (some names have been updated herein): *Scaphites leei* Reeside (form II of Cobban, 1969, p. 15), *Haresiceras mancosense* (Reeside), *B. haresi* Reeside, *B. aquilaensis* Reeside, and *Inoceramus* (*Sphenoceramus*) *lundbreckensis* McLearn.

East of Hardin (text fig. 1), the Eagle Sandstone, which overlies the Telegraph Creek Formation, grades into siltstone and mudstone that contains beds of ferruginous and calcareous concretions. This time equivalent of the Eagle

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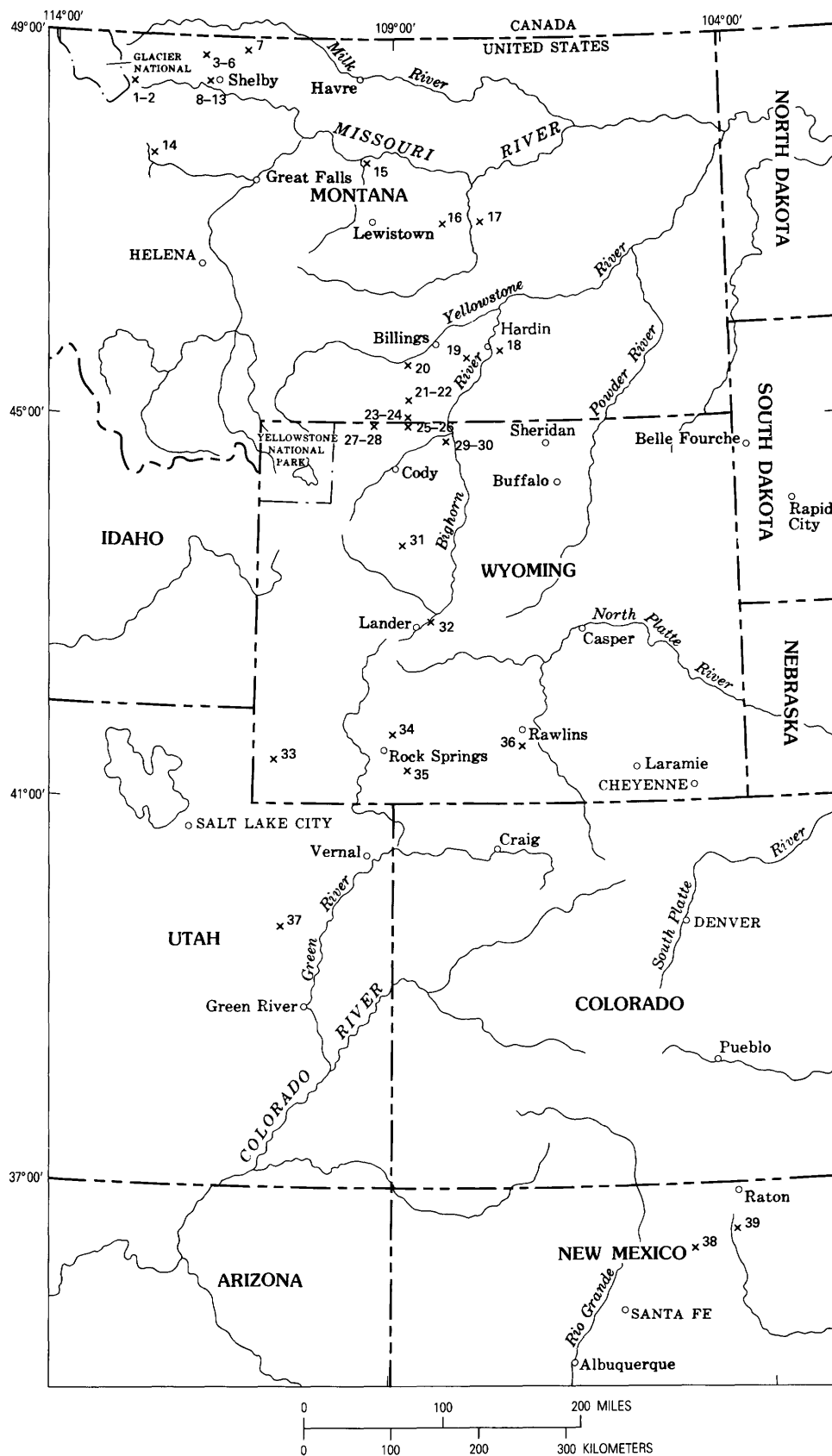


Figure 1. Part of the Western Interior of the United States showing localities of *Baculites thomi* Reeside described in table 1.

Table 1. Localities at which *Baculites thomi* fossils were collected

Locality on text figure 1	USGS Mesozoic locality ¹	Collector(s) and year of collection, description of locality, and stratigraphic assignment
1.....	24738	C.E. Erdmann, 1953. NW $\frac{1}{2}$ NW $\frac{1}{2}$ sec. 8, T. 32 N., R. 12 W., Glacier County, Montana. Telegraph Creek Formation.
2.....	24739	C.E. Erdmann, 1953. NW $\frac{1}{2}$ SE $\frac{1}{2}$ sec. 4, T. 32 N., R. 12 W., Glacier County, Montana. Telegraph Creek Formation.
3.....	11995	A.J. Collier and R.G. Lusk, 1923. Sec. 17, T. 35 N., R. 3 W., Toole County, Montana. Marias River Shale, from 6 m below top.
4.....	20695	C.E. Erdmann, 1944. NE $\frac{1}{2}$ NW $\frac{1}{2}$ sec. 24, T. 35 N., R. 4 W., Toole County, Montana. Marias River Shale, from 7 m below top of Kevin Member.
5.....	D1237	C.E. Erdmann, R.W. Lemke, E.K. Maughan, and W.A. Cobban, 1956. NE $\frac{1}{2}$ NW $\frac{1}{2}$ sec. 24, T. 35 N., R. 4 W., Toole County, Montana. Marias River Shale, from a thin bed of sandstone about 30 m below top of Kevin Member.
6.....	D5514	C.E. Erdmann, 1963. NE $\frac{1}{2}$ NW $\frac{1}{2}$ sec. 24, T. 35 N., R. 4 W., Toole County, Montana. Marias River Shale, from 8 m below top.
7.....	D9151	D.D. Rice, 1974. East of East Butte in the SW $\frac{1}{2}$ NW $\frac{1}{2}$ sec. 13, T. 36 N., R. 5 E., Liberty County, Montana. Telegraph Creek Formation, from upper part.
8.....	21419	W.A. Cobban, 1948. About 12.9 km west of Shelby in the NE $\frac{1}{2}$ sec. 31, T. 32 N., R. 3 W., Toole County, Montana. Marias River Shale, from limestone concretions 3 m below top of Kevin Member.
9.....	21420	W.A. Cobban, 1948. Same locality as 21419. Telegraph Creek Formation, from 7.3 to 10.7 m above base.
10.....	D692	W.L. Rohrer, 1955. SW $\frac{1}{2}$ NW $\frac{1}{2}$ sec. 31, T. 32 N., R. 3 W., Toole County, Montana. Marias River Shale, from 9.1 m below top.
11.....	D693	W.L. Rohrer, 1955. Same locality as D692. Marias River Shale, from 4.3 m below top.
12.....	D694	W.L. Rohrer, 1955. Same locality as D692. Marias River Shale, from 2.9 m below top.
13.....	D696	W.L. Rohrer, 1955. Same locality as D692. Telegraph Creek Formation, from 45 m above base.
14.....	D3803	D.L. Snow and M.R. Mudge, 1962. North Fork of Sun River, 0.5 mi north of Circle Creek, Teton County, Montana. Lower part of Telegraph Creek Formation.
15.....	21568	J.B. Reeside, Jr., C.T. Moore, and W.A. Cobban, 1949; J.R. Gill and L.G. Schultz, 1961. NW $\frac{1}{2}$ NW $\frac{1}{2}$ sec. 13, T. 22 N., R. 17 E., Fergus County, Montana. Telegraph Creek Formation, from 12.2 m below top.
16.....	D4912	W.A. Cobban, 1965. Bank of McDonald Creek 1.6 km east of Winnett near center of east line of sec. 6, T. 14 N., R. 27 E., Petroleum County, Montana. Telegraph Creek Formation, from limestone concretions 46 m below base of cliff-forming Eagle Sandstone.
17.....	23896	W.A. Cobban, 1952. Stream cut 5.5 km east of Mosby Post Office, in the SE $\frac{1}{2}$ sec. 5, T. 14 N., R. 31 E., Garfield County, Montana. Colorado Shale, from 15 m below top of Niobrara Shale Member.
18.....	21206	W.A. Cobban, 1947. Eleven kilometers east of Hardin, near the center of the north line of sec. 13, T. 1 S., R. 34 E., Big Horn County, Montana. Cody Shale, from silty limestone concretions in Gammon Ferruginous Member.
19.....	10902	W.T. Thom, Jr., 1921. Sec. 27, T. 1 S., R. 30 E., Big Horn County, Montana. Telegraph Creek Formation, from Elk Basin Sandstone Member.
20.....	D3302	J.R. Gill, 1961. SW $\frac{1}{2}$ NW $\frac{1}{2}$ sec. 6, T. 3 S., R. 23 E., Carbon County, Montana. Cody Shale, from Niobrara Member.
21.....	D4223	J.R. Gill, 1962. SW $\frac{1}{2}$ NE $\frac{1}{2}$ sec. 26, T. 7 S., R. 23 E., Carbon County, Montana. Telegraph Creek Formation, from top of Elk Basin Sandstone Member.
22.....	D4637	J.R. Gill and C.R. Givens, 1964. NW $\frac{1}{2}$ SE $\frac{1}{2}$ sec. 21, T. 8 S., R. 24 E., Carbon County, Montana. Telegraph Creek Formation, from middle of 24-m-thick sandy unit 62 m below Elk Basin Sandstone Member.
23.....	D1445	W.A. Cobban, 1957. Northern side of Elk Basin in the NW $\frac{1}{2}$ sec. 35, T. 9 S., R. 23 E., Carbon County, Montana. Telegraph Creek Formation, from Elk Basin Sandstone Member.
24.....	D1446	W.A. Cobban, 1957. J.R. Gill and R.K. Maynard, 1965. Butte in the NW $\frac{1}{2}$ SW $\frac{1}{2}$ sec. 35, T. 9 S., R. 23 E., Carbon County, Montana. Telegraph Creek Formation, from Elk Basin Sandstone Member.

Table 1. Localities at which *Baculites thomi* fossils were collected—Continued

Locality on text figure 1	USGS Mesozoic locality ¹	Collector(s) and year of collection, description of locality, and stratigraphic assignment
25.....	D3295	J.R. Gill and L.G. Schultz, 1961. SE $\frac{1}{2}$ sec. 19, T. 58 N., R. 99 W., Park County, Wyoming. Telegraph Creek Formation, from 4.6 m below top of Elk Basin Sandstone Member.
26.....	D3296	J.R. Gill and L.G. Schultz, 1961. Same locality as D3295. Telegraph Creek Formation, from top of Elk Basin Sandstone Member.
27.....	D4632	J.R. Gill and W.A. Cobban, 1964. SW $\frac{1}{2}$ SE $\frac{1}{2}$ sec. 26, T. 58 N., R. 103 W., Park County, Wyoming. Cody Shale, from fine-grained sandstone about 407 m above base.
28.....	D4635	J.R. Gill and W.A. Cobban, 1964. SW $\frac{1}{2}$ SE $\frac{1}{2}$ sec. 26, T. 58 N., R. 103 W., Park County, Wyoming. Telegraph Creek Formation, from near top of Elk Basin Member.
29.....	D4198	R.E. Burkholder and W.A. Cobban, 1963. NW $\frac{1}{2}$ SE $\frac{1}{2}$ sec. 29, T. 55 N., R. 95 W., Big Horn County, Wyoming. Cody Shale, from unit of large, brown, calcareous sandstone concretions.
30.....	D4199	R.E. Burkholder and W.A. Cobban, 1963. SW $\frac{1}{2}$ sec. 20, T. 55 N., R. 95 W., Big Horn County, Wyoming. Cody Shale, same stratigraphic unit as D4198.
31.....	21752	J.B. Reeside, Jr., J.D. Love, M.L. Troyer, and W.R. Keefer, 1949. NE $\frac{1}{2}$ SW $\frac{1}{2}$ sec. 22, T. 6 N., R. 1 W., Fremont County, Wyoming. Cody Shale, from a sandstone unit 870 m above base.
32.....	1550	J.B. Reeside, Jr., J.D. Love, R.M. Thompson, and M.L. Troyer, 1949. NW $\frac{1}{2}$ SW $\frac{1}{2}$ sec. 4, T. 33 N., R. 98 W., Fremont County, Wyoming. Cody Shale, from 281 m below top.
33.....	D3114	J.H. Smith, 1961. NE $\frac{1}{2}$ sec. 21, T. 17 N., R. 117 W., Uinta County, Wyoming. Hilliard Shale, from a bed of sandstone 336 m below base of Lazeart Sandstone Member of Adaville Formation.
34.....	D2221	J.H. Smith, 1959. SE $\frac{1}{2}$ SE $\frac{1}{2}$ sec. 5, T. 20 N., R. 104 W., Sweetwater County, Wyoming. Blair Formation, from sandstone 30 to 38 m below top.
35.....	D6406	J.R. Gill, 1967. Center of sec. 33, T. 17 N., R. 102 W., Sweetwater County, Wyoming. Rock Springs Formation, from top of Chimney Rock Tongue.
36.....	D3051	J.H. Smith, 1961. SE $\frac{1}{2}$ SW $\frac{1}{2}$ sec. 23, T. 19 N., R. 88 W., Carbon County, Wyoming. Steele Shale, from 55 m above base.
37.....	D2126	A.D. Zapp, 1959. NW $\frac{1}{2}$ NE $\frac{1}{2}$ sec. 22, T. 13 S., R. 10 E., Carbon County, Utah. Mancos Shale, from about 60 m below base of Panther Tongue of Star Point Sandstone.
38.....	D11425	G.R. Scott, 1980; E.A. Merewether, R.E. Burkholder, and W.A. Cobban, 1984. Urraca Mesa in the SE $\frac{1}{2}$ SW $\frac{1}{2}$ sec. 7, T. 25 N., R. 19 E., Colfax County, New Mexico. Niobrara Formation, from upper shale unit of the Smoky Hill Shale Member.
39.....	D11597	G.R. Scott, 1981. Southern bank of Tinaja Creek in the SW $\frac{1}{2}$ NE $\frac{1}{2}$ sec. 26, T. 28 N., R. 23 E., Colfax County, New Mexico. Niobrara Formation, from upper shale unit of Smoky Hill Shale Member.

¹D indicates Denver Mesozoic invertebrate locality numbers; all others are Washington, D.C., Mesozoic invertebrate locality numbers.

Sandstone is known as the Gammon Ferruginous Member of the Cody Shale (Cobban, 1964, p. 8). A sandy unit in the Gammon Member contains *B. thomi* along with a large and varied molluscan fauna that includes a late form of *S. hippocrepsis* (Cobban, 1969, form III), *B. haresi*, *B. aquilaensis*, and *Inoceramus* (*Endocostea*) cf. *barabini* Morton (names updated) (Richards, 1955, p. 60; Knechtel and Patterson, 1956, p. 33). Farther north, in central Montana, *B. thomi* has been recorded from 15 m below the top of the Colorado Shale, where it is associated with an early form of *S. leei* Reeside (Cobban, 1969, form I), *Desmoscaphites* sp., and *I. (Sphenoceramus)* sp. (Cobban, 1964, p. 6).

Baculites thomi was reported from several localities on the Sweetgrass arch and the adjoining part of the Disturbed belt in northwestern Montana. The oldest and largest collections (text fig. 1, locs. 8, 10–12) have come

from a small area 12.4 to 13.6 km west of Shelby (Cobban, 1950, p. 1900; 1951a, p. 2195; 1951b, p. 39; 1964, p. 5; 1969, p. 14), where excellent specimens of *B. thomi* were found near the top of the Kevin Member of the Marias River Shale, which underlies sandy beds assigned to the Telegraph Creek Formation. Important fossils associated with *B. thomi* include the following (names updated): *S. leei* (Cobban, 1969, form I), *D. erdmanni* Cobban, *Clioscaphites novimexicanus* (Reeside), and *I. (S.) lundbreckensis*. One of these specimens of *B. thomi* was illustrated (Cobban, 1955b, pl. 2, fig. 4). *B. thomi* was also reported from this part of the Marias River Shale farther north (Collier, 1929, p. 72; Cobban and others, 1976, p. 55, 56) (text fig. 1, locs. 3–6). The lower part of the Telegraph Creek Formation also contains *B. thomi* at the first locality (Cobban, 1950, p. 1900; 1955a, p. 114; 1964, p. 5) (text

fig. 1, locs. 9, 13) as well as farther west in the Disturbed belt (Mudge, 1972, p. 72) (text fig. 1, loc. 14). The following molluscan fossils were found with *B. thomi* (names updated): *S. leei* (Cobban, 1969, form II), *Haresiceras* (*Mancosiceras*) *mancosense* (Reeside), *D. bassleri* Reeside, *B. haresi*, and *I. (S.) lundbreckensis*.

Wyoming

Baculites thomi has been recorded from Wyoming in only four reports. The species was noted in the upper or sandy member of the Cody Shale on the northern side of the Wind River Basin (text fig. 1, loc. 31) by Yenne and Pippingos (1954) and by Keefer and Troyer (1956, 1964), where it was associated with *Desmoscaphtes bassleri*. *Baculites thomi* was also reported by Yenne and Pippingos from the sandy member of the Cody Shale on the southern side of the Wind River Basin, where it was found with *Scaphites hippocrepsis* (Cobban, 1969, form I), *Haresiceras montanaense* (Reeside), and *B. haresi* (names updated). Smith (1965, p. 20) reported *B. thomi* farther south on the Rock Springs uplift (text fig. 1, loc. 34), where the species was found in a sandstone unit about 30 to 38 m below the top of the Blair Formation. Associated fossils include *S. hippocrepsis* (Cobban, 1969, form III) and *B. haresi*.

New Mexico

The only report of *Baculites thomi* in New Mexico is from Scott and others (1986, p. 9, 17, 32, text figs. 14g, 15f) in the Raton basin (text fig. 1, locs. 38, 39). The species was found in a limestone bed in the Niobrara Formation that contains *Scaphites leei* I, *Desmoscaphtes erdmanni*, *Clioscaphtes choteauensis* Cobban, *Texasites omeraensis* (Reeside), *Reginaites leei* (Reeside), *Inoceramus* (*Sphenoceramus*) *lundbreckensis*, *I. (Endocostea) balticus* Böhm, and *I. (Cordiceramus) muelleri* Petrascheck).

AGE OF BACULITES THOMI REESIDE

Baculites thomi has been found with *Desmoscaphtes erdmanni*, *D. bassleri*, and the late form of *Scaphites hippocrepsis* (III). Each of the last three species is a guide to an ammonite zone in the Western Interior (Cobban, 1964, table 2; 1969, p. 6). Rocks that contain *Desmoscaphtes* have been long assigned to the Santonian (Cobban and Reeside, 1952, unnumbered chart). These rocks contain the free-swimming crinoids *Marsupites* and *Uintacrinus*, which are considered as guides to the upper Santonian (for example, Ernst, 1963, p. 102, 105–108; 1966, p. 136, 139; 1973, p. 82, 83; Ernst and Schulz, 1974, p. 14, 24, fig. 6; Ernst and Schmid, 1975, p. 121; Klikushin, 1983, p. 103, 104; Birkelund and others, 1984, p. 15; Bailey and others, 1984, p. 37). Although *Marsupites* and *Uintacrinus* are

present with either *D. erdmanni* or *D. bassleri* in several of the USGS collections, these crinoids have been recorded with *D. bassleri* in only two reports (Thom and others, 1935, p. 54, 55; Keefer and Troyer, 1964, p. 88).

Although *B. thomi* is most abundant in the upper Santonian, it ranges into rocks as young as the zone of *S. hippocrepsis* III, where it is scarce (Richards, 1955, p. 60; Knechtel and Patterson, 1956, p. 33). This late form of *S. hippocrepsis* occurs in the upper part of the lower Campanian in Europe (Schmid and Ernst, 1975, p. 325, 326, fig. 2). The range of *B. thomi* is thus upper Santonian into lower Campanian, its peak development being in the Santonian.

SYSTEMATIC PALEONTOLOGY

Family BACULITIDAE Gill, 1871

Genus BACULITES Lamarck, 1799

Type species.—*Baculites vertebralis* Lamarck, 1801, p. 103, by subsequent designation by Meek, 1876, p. 391.

Baculites thomi Reeside

Plates 1, 2; text figure 2

1927a. *Baculites thomi* Reeside, p. 13, pl. 12, figs. 9–14.

1927a. *Baculites asper* Morton. Reeside, p. 13 (*pars*), pl. 10, figs. 9–12 only.

1955b. *Baculites thomi* Reeside. Cobban, p. 204, pl. 2, fig. 4.

1986. *Baculites thomi* Reeside. Scott, Cobban, and Merewether, p. 17, figs. 14g, 15f.

Types.—The holotype by original designation is USNM 73315, from the Elk Basin Sandstone Member of the Telegraph Creek Formation at USGS Mesozoic locality 10902 in sec. 27, T. 1 S., R. 30 E., Big Horn County, Montana (text fig. 1, loc. 19). Hypotypes USNM 433905–433907 and 440808–440816 are from limestone concretions 3 m below the top of the Kevin Member of the Marias River Shale at USGS Mesozoic locality 21419 in the NE1/4 sec. 31, T. 32 N., R. 3 W., Toole County, Montana (text fig. 1, loc. 8).

Diagnosis.—A baculite of moderate size characterized by a fairly stout ovate section, a small angle of taper, and conspicuous ornament of strong flank and ventral ribs. Flank ribs may be closely spaced and crescentic or more distantly spaced and nodelike. The suture is of moderate complexity for the genus.

Material.—About 300 specimens are present in the collection from locality 21419 (text fig. 1, loc. 8). These specimens range in whorl height from 3.5 mm to 30 mm.

Description.—Nearly all specimens from locality 21419 are straight, although an occasional juvenile may show slight curvature (pl. 1, fig. 4). The expansion rate (taper angle) is very small for adults and slightly more for juveniles. Table 2 summarizes the expansion rates of 259

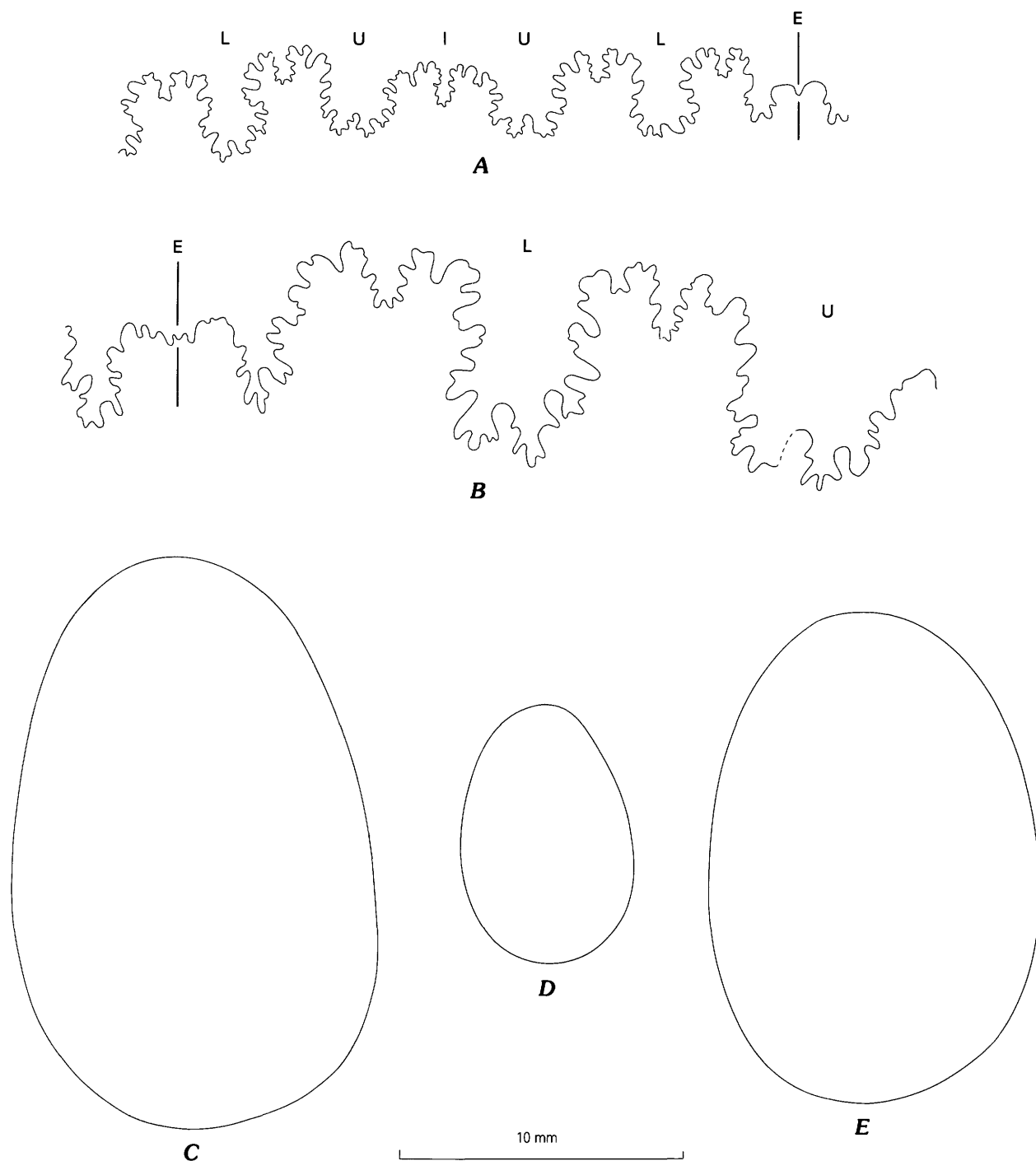


Figure 2. Sutures and whorl sections of *Baculites thomi* Reeside. **A**, Hypotype USNM 440808 at a whorl height of 9 mm (pl. 1, figs. 1–3). **B**, Hypotype USNM 440816 at a whorl height of 20 mm (pl. 2, figs. 7–9). **C**, Hypotype USNM 440814 at a whorl height of 19.3 mm

(pl. 2, figs. 1–3). **D**, Hypotype USNM 440808 at a whorl height of 19.8 mm (pl. 1, figs. 1–3). **E**, Hypotype USNM 433905 at a whorl height of 20 mm (pl. 1, figs. 13–15). **E** is external lobe, **L** is lateral lobe, **U** is umbilical lobe, and **I** is internal lobe.

specimens that have whorl heights ranging from 5 to 21.9 mm; measurements of larger specimens are too few to be meaningful.

The whorl section is a somewhat compressed oval, the venter being only slightly narrower than the dorsum (text figs. 2C–E). Flanks are very broadly rounded.

Table 2. Average angle of taper and average number of flank and ventral ribs per height of *Baculites thomi* Reeside

[Number of specimens is in parentheses]

Whorl height (mm)	Taper (degrees)	Number of flank ribs	Number of ventral ribs
5.0–5.9	4.5 (11)	0.0 (0)	0.0 (0)
6.0–7.9	4.7 (28)	.0 (0)	4.2 (5)
8.0–9.9	4.5 (42)	2.0 (1)	3.8 (13)
10.0–11.9	4.0 (38)	2.1 (16)	3.1 (18)
12.0–13.9	3.0 (46)	2.2 (24)	3.2 (27)
14.0–15.9	1.6 (39)	2.0 (31)	3.2 (28)
16.0–17.9	1.5 (32)	2.0 (26)	2.9 (28)
18.0–19.9	1.4 (17)	2.1 (14)	2.7 (14)
20.0–21.9	1.3 (6)	2.4 (6)	2.9 (4)

Ornament is lacking on juveniles that have whorl heights of less than 5 mm. Ventral ribs may appear at a whorl height of 5 mm, and flank ribs may arise at a height of 6 mm, but ornament is usually missing on most specimens of less than 8 mm in whorl height. Ribs are weak, irregular in strength, and closely spaced at first (pl. 1, figs. 1–6), but they become stronger, regular, and a little more widely spaced in the later juvenile and early and middle adult growth stages (pl. 1, figs. 11–21). Ribs are crescentic (concave side forward) and cross the dorsal two-thirds of the flank. They are slightly asymmetric, much narrower than the interspaces, and spaced at two or three in a distance equal to the whorl height. The ribs project forward on the outer third of the flank and weaken on the dorsolateral shoulder; they become greatly weakened on crossing the dorsum in a broad convexity and may bear delicate growth lines and striae. Ribs strengthen markedly over the ventrolateral shoulder and venter, which they cross in a broad convexity. Occasional intercalated ribs are present, so that there may be as many as six ribs in a distance equal to the whorl height (pl. 2, fig. 3). Interspaces between ribs may bear delicate growth lines and sometimes feeble riblets; these riblets may be especially well developed on the dorsolateral and dorsal parts of the shell, and some venters develop primary plus secondary ribbing patterns (pl. 1, fig. 19; pl. 2, fig. 7). Co-occurring with this typical form are weakly ornamented individuals that we take to be no more than variants of the species. An occasional individual may have nearly smooth or smooth flanks and a strongly corrugated venter (pl. 1, figs. 16–18). Other specimens may have unusually strong ornament (pl. 1, figs. 11–15) on which the flank ribs are more nodelike and more distantly spaced than those on normal specimens (pl. 1, figs. 19–21). Flank ribs on the older adults weaken, but ventral ribs tend to remain strong (pl. 2, figs. 4–6). Apertures are preserved on a few adults (pl. 1, figs. 7–10). The aperture, which is concave on the flank, has a short linguoid dorsal rostrum and a long ventral rostrum that is flexed dorsally into a shallow cowl. The ventral rostrum tapers gradually and has

a rounded termination; the rostrum is ornamented by five to seven low, broad, blunt ventral ribs that decline just before its rounded tip.

The suture is moderately incised (text figs. 2A, B). The external lobe (E) is broad, and the lateral (L) and umbilical (U) lobes are symmetrically bifid and about equal in size, but they are narrower than E. The internal lobe (I) is very small. First and second lateral saddles (E/L and L/U) are symmetrically bifid and a little wider than L.

The species is dimorphic. Several specimens that have the last few septa approximated at whorl heights of 12 to 19 mm are interpreted as microconchs, as are the two small adults having long curved ventral rostrums, shown on plate 1. The large adult that has the last two septa approximated, shown on plate 2 (figs. 4–6), is interpreted as a macroconch; its whorl height at the end of the phragmocone is 28.5 mm.

Discussion.—*Baculites thomi* evolved from *B. codyensis* Reeside (1927b, p. 4, pl. 2, figs. 6–19) of middle Coniacian to early Santonian age. Both species have strong flank ribbing, but *B. codyensis* is a smaller species that lacks the conspicuously corrugated venter of *B. thomi*.

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PLATES 1, 2

Contact photographs of the plates in this report are available, at cost, from the U.S. Geological Survey Photographic Library, Federal Center, Denver, CO 80225.

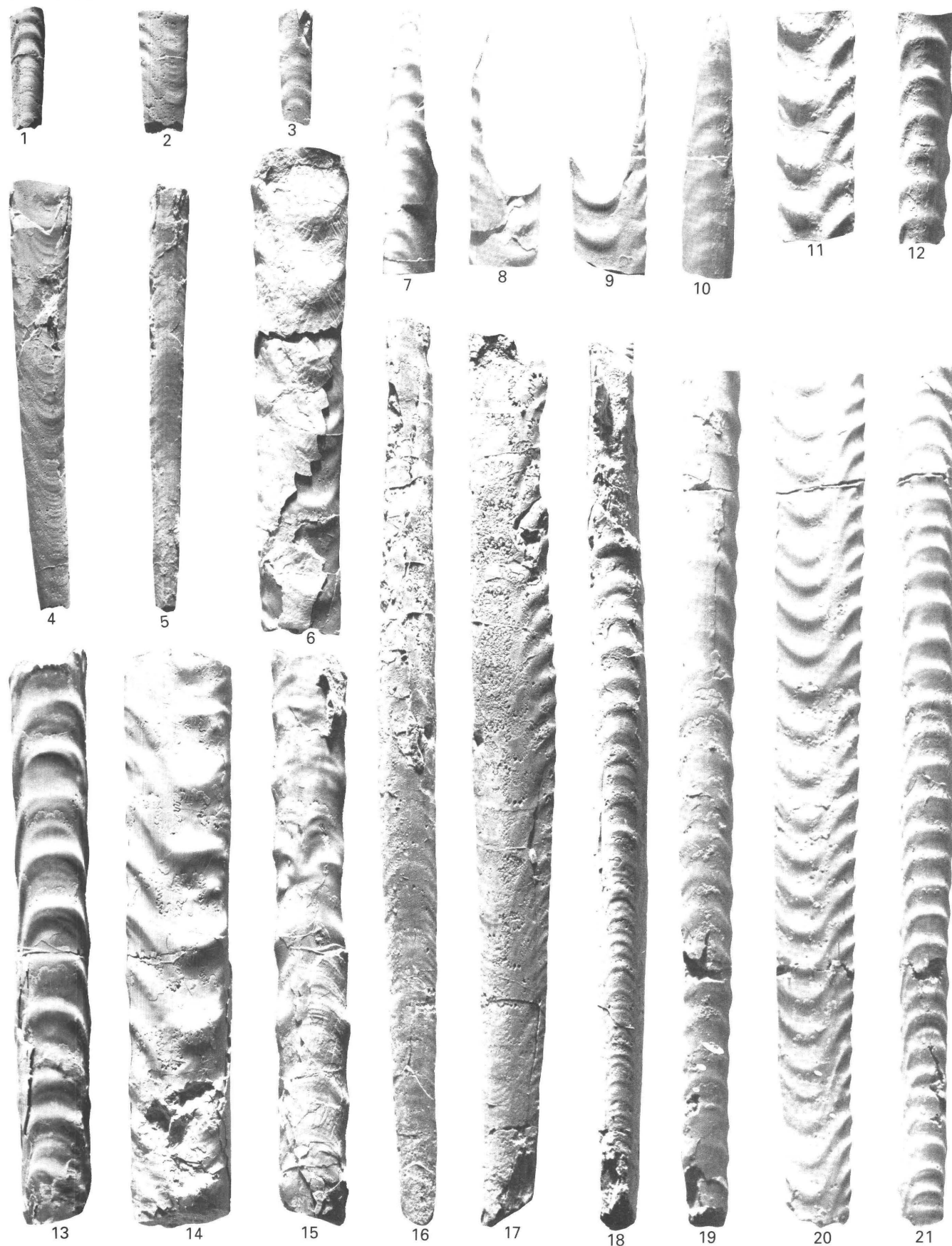
PLATE 1

Baculites thomi Reeside (p. C5)

[All figures natural size]

Figures 1–21. From the upper part of the Kevin Member of the Marias River Shale at U.S. Geological Survey Mesozoic locality 21419, 12.9 km west of Shelby in the NE¼ sec. 31, T. 32 N., R. 3 W., Toole County, Montana (fig. 1, loc. 8).

- 1–3. Hypotype USNM 440808.
- 4, 5. Hypotype USNM 440809.
- 6. Hypotype USNM 440810.
- 7, 8. Hypotype USNM 440811.
- 9, 10. Hypotype USNM 440812.
- 11, 12. Hypotype USNM 433906.
- 13–15. Hypotype USNM 433905.
- 16–18. Hypotype USNM 440813.
- 19–21. Hypotype USNM 433907.



BACULITES THOMI

PLATE 2

Baculites thomi Reeside (p. C5)

[All figures natural size]

Figures 1–9. From the upper part of the Kevin Member of the Marias River Shale at U.S. Geological Survey Mesozoic locality 21419, 12.9 km west of Shelby in the NE¼ sec. 31, T. 32 N., R. 3 W., Toole County, Montana (fig. 1, loc. 8).

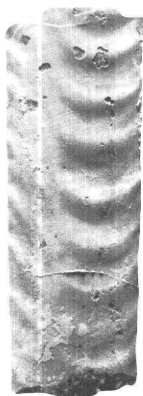
1–3. Hypotype USNM 440814.

4–6. Hypotype USNM 440815.

7–9. Hypotype USNM 440816.



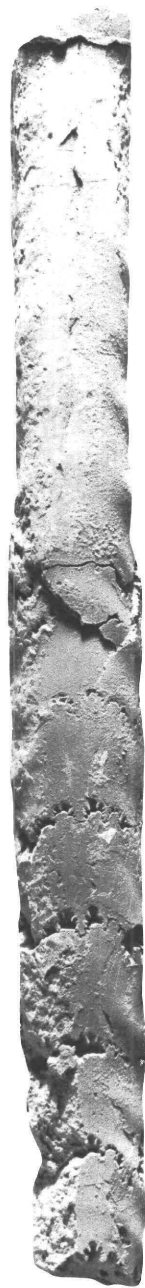
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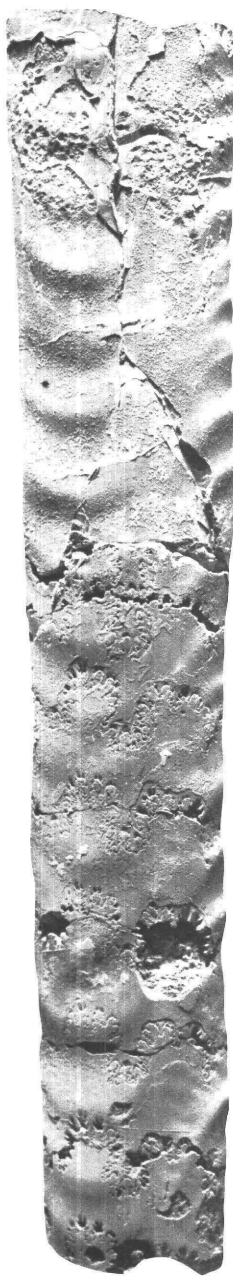
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BACULITES THOMI

Chapter D

Discovery of Early Ordovician Fossils in Bucks County, Pennsylvania

By JOHN E. REPETSKI and AVERY ALA DRAKE, JR.

U.S. GEOLOGICAL SURVEY BULLETIN 1934

SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

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The Conodonts	D4
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PLATE

[Plate follows references cited]

1. Early Ordovician conodonts from Buckingham Valley, Bucks County, Pennsylvania

FIGURES

- 1, 2. Maps showing:
 1. Buckingham Valley, Pennsylvania **D2**
 2. Geology of the Buckingham Valley, Bucks County, Pennsylvania, showing conodont localities **D3**

Discovery of Early Ordovician Fossils in Bucks County, Pennsylvania

By John E. Repetski and Avery Ala Drake, Jr.

Abstract

Conodonts from dolomites in the Buckingham Valley carbonate rock sequence of Bucks County, Pennsylvania, are the first identifiable Early Ordovician fossils recovered from that area. They confirm previous lithostratigraphic correlation of those rocks with the Rickenbach Dolomite of the Beekmantown Group of the Great Valley sequence in eastern Pennsylvania and northern New Jersey. The fauna is assignable to the Lower Ordovician *Rossodus manitouensis* Zone, and the species and lithology indicate warm, shallow marine carbonate platform paleoenvironments.

INTRODUCTION

The current geologic map of Pennsylvania (Berg and others, 1980) shows an isolated area of Ordovician carbonate rocks in the Buckingham Valley of Bucks County. This sequence of poorly exposed dolomites historically has been identified as or correlated with lithologically similar Lower Ordovician units of the Beekmantown Group of the Great Valley sequence to the north and west. Previously, however, the age of these carbonate rocks had not been confirmed because no fossils had ever been reported from them. During our investigations of the stratigraphy and tectonic history of Lower Ordovician rocks in eastern Pennsylvania and northern New Jersey, we have sampled several outcrops of carbonate rocks in Bucks County (fig. 1). Conodonts recovered from some of these samples are the first Early Ordovician fossils reported from the Buckingham Valley and at last confirm the previous lithologic correlations of some of these rocks with the Rickenbach Dolomite of the Beekmantown Group.

Acknowledgments

We acknowledge and thank R.C. and A.L. Orndorff and D.J. Weary (U.S. Geological Survey) for their technical assistance in preparing the conodont samples and the illustrations for this project.

PREVIOUS WORK

Rocks now called Beekmantown in eastern Pennsylvania were originally named Coplay by Wherry (1909), although he did no geologic mapping. Miller (1934) and Miller and others (1939, 1941) substituted the name Beekmantown for these rocks because they recognized their similarity to the Beekmantown of New York. Subsequently, most workers have used Beekmantown, although Willard (1958) pointed out, correctly, that the uppermost beds of the unit were of Chazyan (now late Whiterockian) age and that the name Coplay should be reinstated. The name Beekmantown, however, has become so entrenched that no workers have accepted Willard's suggestion. The Beekmantown was promoted to group status and divided into (in ascending order) the Stonehenge Limestone, the Rickenbach Dolomite, the Epler Formation (interbedded limestone and dolomite), and the Ontelaunee Formation (mostly dolomite) in eastern Pennsylvania (Hobson, 1957). Drake (1965) recognized two mappable units in the Delaware Valley that he correlated with Hobson's Rickenbach Dolomite and Epler Formation. More recently, Drake and Lyttle (1985) and Drake and others (1985) have recognized limestone near the base of the Beekmantown Group in New Jersey, and conodont studies by J.E. Repetski show that these rocks correlate with the Stonehenge Limestone of east-central Pennsylvania. These data led to a restudy of the Rickenbach Dolomite in the Delaware Valley, which showed that its lower part, although dolomite, can be mapped separately as Stonehenge Formation.

In the Buckingham Valley, the entire carbonate rock package was originally termed Auroral Limestone by Rogers (1858) and later Shenandoah Limestone (Bascom and others, 1909). G.W. Stose (in Bascom and others, 1931) was the first to suggest that some of the rocks were Beekmantown on the basis of their similarity to the Beekmantown Formation in the Lancaster Valley. Willard and others (1950) made the same correlation on the basis of the similarity to the Beekmantown Formation of the Lehigh Valley. Lyttle and Epstein (1987) recognized the similarity of the rocks earlier mapped as Beekmantown to the Rickenbach Dolomite as then mapped in eastern Pennsylvania

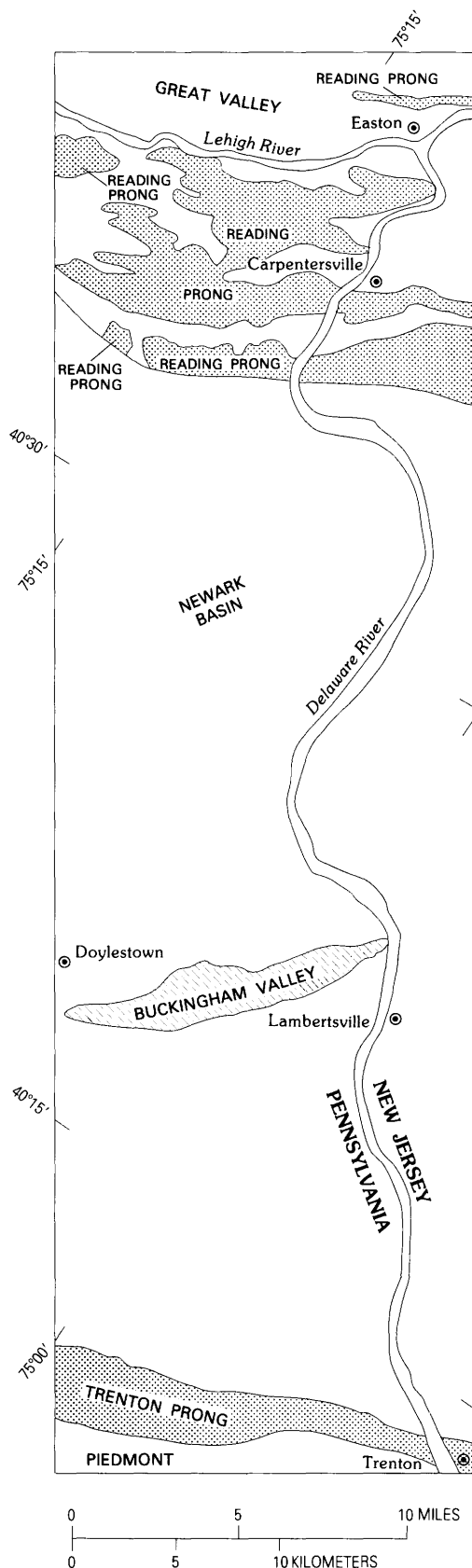


Figure 1. Buckingham Valley, Pennsylvania. Shading indicates crystalline rocks of the Reading Prong and the Trenton Prong.

and New Jersey. The work reported on herein confirms the presence of the Rickenbach Dolomite in the Buckingham Valley.

GEOLOGY OF THE BUCKINGHAM VALLEY

The Buckingham Valley is an upthrown fault block within the Newark Mesozoic basin (fig. 2). It is important in that it exposes a part of the Laurentian shelf between the rocks of the Great Appalachian Valley to the north and the shelf-edge and slope deposits in the Piedmont to the south. Laurentian basement rocks may or may not crop out in Buckingham Mountain. Bascom and others (1931) showed a small area of gabbro on the southwestern crest of Buckingham Mountain, as did Gray and others (1960); Willard and others (1959) could find no outcrops and did not show crystalline rocks on their map (Willard and others, 1950). Berg and others (1980) showed a small area of gneiss where previous workers showed gabbro, whereas Lyttle and Epstein (1987) showed quartz diorite in this place. During our work, we found only a few pieces of nondescript crystalline rock float in a sandstone pit; therefore, we do not show Laurentian basement in figure 2. That such basement is just below the surface is shown clearly on the aeromagnetic map of the Buckingham quadrangle (Bromery and others, 1959) by typical Reading Prong magnetic signatures. Buckingham and Little Buckingham Mountains are underlain by arkosic conglomerate, arkose, and orthoquartzite. Arkosic conglomerate occurs at the base of the unit and passes up into arkose and, finally, white orthoquartzite. Abundant conglomerate horizons suggest the presence of numerous intraformational unconformities. *Olenellus* fragments have been collected from the uppermost white quartzite beds. The rift-drift facies transition is difficult to pick but presumably is at the change from arkose to orthoquartzite. Only the highest beds, however, are proven to be marine. Bascom and others (1931) called these rocks Hardyston Quartzite, whereas Willard and others (1959) and Gray and others (1960) called them Chickies Quartzite. Berg and others (1980) and Lyttle and Epstein (1987) reverted to Hardyston Quartzite. Lithologically, the unit most closely resembles the Hardyston, the basal siliciclastic unit in the Reading Prong, although the 900-ft thickness here is far greater than the 60 ft measured in the Riegelsville quadrangle to the north (Drake, 1969). The Chickies Quartzite in the Trenton West quadrangle to the south consists of about equal parts of (1) white quartzite and a few pebble conglomerate beds and (2) quartz-muscovite schist (A.A. Drake, Jr., unpublished data, 1984). We think that the unit here best correlates with the Hardyston and that at least the upper part is of Early Cambrian age.

The Hardyston is overlain by a carbonate unit called the Elbrook Formation by Bascom and others (1931). This name seemed inappropriate to Howell and others (1950) and

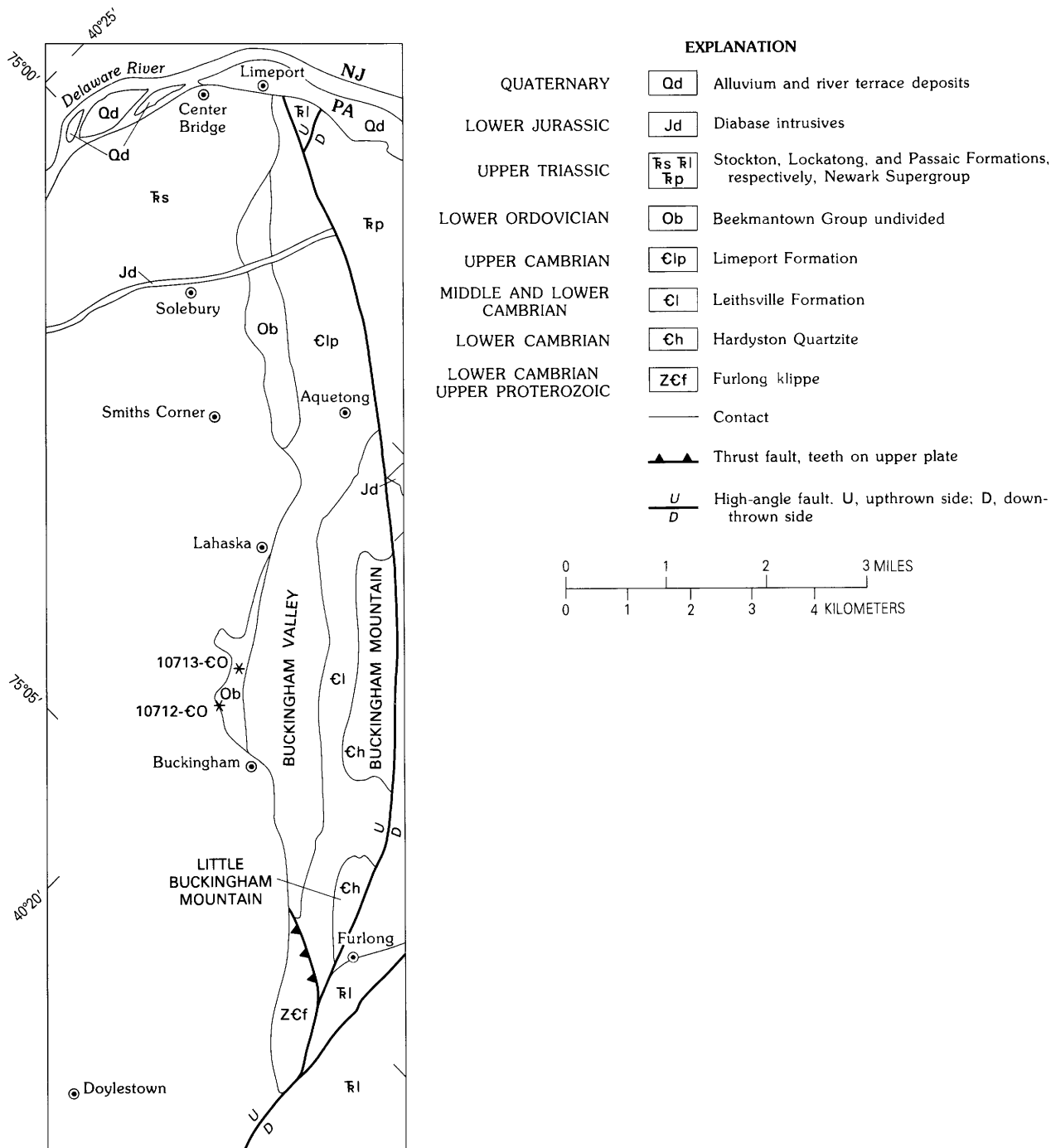


Figure 2. Geology of the Buckingham Valley, Bucks County, Pennsylvania (modified from Willard and others, 1950), showing conodont localities (10712-CO and 10713-CO).

Willard and others (1959) on the basis of both lithology and age—the Elbrook Formation is Middle and Late Cambrian. They therefore correlated this unit with the Leithsville Formation of the Lehigh Valley. This usage was followed by Berg and others (1980) and Lytle and Epstein (1987). Our examination showed that the unit has all the features of the Leithsville of eastern Pennsylvania and New Jersey.

The Leithsville is succeeded upward by a cyclic, shallowing-upward sequence of flat-pebble dolomite, dololite, dolarenite, oolitic dolarenite, dolorudite, algal stromatolite, and dolomicrite. This cycle was determined by direct observation in the field and was later confirmed by a Markov process study done by Aaron (1979). These rocks were mapped as Conococheague Limestone by Bascom and

others (1931). Howell and others (1950) named the unit Limeport Limestone. This 400- to 500-ft sequence is essentially identical to about the lower half of the Allentown Dolomite of the Great Valley to the north, and Howell and others (1950) separated the Allentown into a lower Limeport Limestone and an upper Allentown (restricted) Limestone. The typical Allentown cycles become less common in the upper Allentown, and intertidal deposits are sparse in higher beds.

The Limeport in the Buckingham Valley contains an early Late Cambrian (Dresbachian) fauna (Bascom and others, 1931; Howell, 1957), as do similar rocks in the lower Allentown at Carpentersville and Peapack, N.J., to the north (Howell, 1945). Late Cambrian (Trempealeuan) fossils were collected at Newton, Andover, and Blairstown, N.J., and Portland, Pa., in the Great Valley (Howell, 1945; Howell and others, 1950). These data led Howell and others (1950) to postulate an unconformity within the Allentown—their Limeport and Allentown Limestones—representing middle Late Cambrian (Franconian) time, as no fossils of that age have been found. No direct evidence for such an unconformity has been found in geologic mapping at a scale of 1:24,000 between the Schuylkill River in Pennsylvania and Orange County, New York. The lack of middle Late Cambrian fossils in these largely intertidal deposits is perhaps not surprising.

Berg and others (1980) and Lyttle and Epstein (1987) abandoned the name Limeport for the Upper Cambrian rocks in the Buckingham Valley and called them Allentown. We do not agree with this designation because (1) the Buckingham Valley is 20 mi across strike from the Allentown outcrop belt, (2) the Limeport Formation is 400 to 500 ft thick as opposed to the 1,700 ft of Allentown measured at Carpentersville, N.J. (Drake, 1969), and (3) the Limeport lacks the rocks typical of the upper half of the Allentown in the Great Valley. We therefore accept the name Limeport Formation for the Upper Cambrian rocks in the Buckingham Valley for use by the U.S. Geological Survey (USGS).

The lower part of the Beekmantown in the Buckingham Valley is very finely to finely crystalline, dark-medium- to medium-gray, earthy, laminated dolomite, like the dolomite mapped as Stonehenge Formation in New Jersey and eastern Pennsylvania. Higher beds, which constitute most of the Beekmantown in the area, consist of medium-gray to dark-medium-gray, fine- to medium-grained, granular dolomite that appears to be massive. Weathered surfaces, however, show that most sedimentation units, marked by sandy lenses or partings, are of medium thickness. The dolomite contains abundant gray, somewhat translucent chert in lenses and partial beds as well as blocky to subrounded forms. Most exposures contain some solution collapse breccia. At some places, the solution collapse breccia is abundant. This rock is typical of the Rickenbach Dolomite as mapped in New Jersey and eastern Pennsylvania (Drake and Lyttle, 1985;

Drake and others, 1985; A.A. Drake, Jr., unpublished data, 1968–89). Paleontologic data reported herein support this correlation.

The physically highest rocks in the Buckingham Valley constitute the Furlong klippe (Drake and others, 1989), which lies across the contact between the Leithsville and the Limeport Formations at a high angle (fig. 2). These rocks were correlated with the Cocalico Shale of the Piedmont in Lancaster County, Pennsylvania, by Bascom and others (1931) and Willard and others (1950). The Cocalico Shale constitutes the Cocalico klippe of Drake and others (1989). The rocks of the Furlong klippe consist of green and purple variegated phyllite; purple phyllite; dark-gray phyllite; light-green, siliceous, blocky phyllite; hard, coarse feldspathic sandstone; grayish-green quartzite; and polymictic quartzose conglomerate containing purple quartz clasts. These rocks resemble some of the older units of the Taconic klippe of New York and western New England (Drake and others, 1989). The hard green quartzite and polymict conglomerate closely resemble the Rensselaer Graywacke, whereas the other rocks resemble the Nassau Formation. The phyllites could equally be interbeds within the Rensselaer. If this correlation is correct, the Furlong klippe contains Iapetan rift-facies rocks of Late Proterozoic to Early Cambrian age, and the Buckingham Valley occurrence is the only one known south of the Rensselaer Plateau in New York.

THE CONODONTS

The conodonts found in the Buckingham Valley dolomites establish the age of these rocks as Early Ordovician. Although the faunules recovered are sparse, they contain index species that allow confident assignment to the *Rossodus manitouensis* Zone. The *R. manitouensis* Zone replaces North American Midcontinent Province conodont “Fauna C,” the third of five sequential faunas recognizable in cratonic and shelf facies in North America (Ethington and Clark, 1971). The biozone consists of an association of species that range through the lower (but not basal) part of the Ibexian Series (*sensu* Ross and others, 1982). Work subsequent to 1971 (for example, Ethington and Clark, 1981; Landing, 1981; Repetski, 1982) has demonstrated that the ranges of some species of “Fauna C” extend into lower and (or) higher strata than the range of that faunal interval as originally defined, but this work generally has confirmed and clarified the biostratigraphic concept of “Fauna C.” In addition, this subsequent work has shown that some of the species indeed are limited to the range of “Fauna C.” Landing and others (1986) formally defined and named the *R. manitouensis* Zone, incorporating the recent data, and their concept is applied herein.

Two samples from the several scattered outcrops and small abandoned quarries near the village of Buckingham

(locations shown in fig. 2) contained conodonts. A total of 5.5 kg of rock was processed for conodonts by means of standard techniques using formic acid and a 200-mesh bottom screen. One sample (USGS fossil locality 10712-CO, fig. 2) (2 kg processed) produced a single specimen assignable only to *Cordylodus* cf. *C. proavus* Müller (pl. 1O) as well as one indeterminate coniform element. The other sample (USGS fossil locality 10713-CO, fig. 2) (3.5 kg processed) yielded the following:

- 1 *Clavohamulus densus* Furnish (pl. 1C)
- 2 *C. spp.*; possibly juvenile elements of *C. densus* (pl. 1D)
- 2 *Juanognathus?* n.sp. (pl. 1L-N)
- 4 *Loxodus bransoni* Furnish (pl. 1A, B)
- 1 *Rossodus manitouensis* Repetski and Ethington (pl. 1H)
- 4 *Scolopodus? sulcatus* Furnish (pl. 1E-G)
- 6 *Variabiloconus bassleri* (Furnish) (pl. 1I-K)
- 2 indeterminate coniform elements

The color alteration index (CAI) of these conodont elements is 5½, which is consistent with the regional pattern in the Lower Ordovician of the Great Valley nearby (Karklins and Repetski, 1989).

The conodonts of the *R. manitouensis* Zone, including all of the diagnostic species found in the Buckingham Valley samples, are known from other Beekmantown Group exposures in the Great Valley, although most of these data are as yet unpublished in detail. Tipnis (1975) recovered species of the *R. manitouensis* Zone from the middle and upper parts of the Stonehenge Limestone near Reading in Berks County, Pennsylvania, and Repetski (1979; unpublished data, 1977) found that diagnostic *R. manitouensis* Zone species continue upward through the lower and middle parts of the overlying Rickenbach Dolomite in its type region, also in Berks County. This same stratigraphic range for the fauna—from approximately middle Stonehenge through middle Rickenbach—has been confirmed at numerous other localities and sections along strike in the Great Valley from the Reading vicinity eastward to the Delaware River and across northern New Jersey into Orange County, New York (J.E. Repetski and A.A. Drake, Jr., unpublished USGS collections, 1976–89; J.E. Repetski, cited by Ross and others, 1982; Savoy and others, 1981). Thus, the faunal data confirm the age equivalence and support the lithic correlation of the upper fossiliferous dolomites of the Buckingham Valley with the Rickenbach Dolomite in the Great Valley.

The presence of the species *Clavohamulus densus* and *Loxodus bransoni*, with or without *Juanognathus?* n.sp., indicates a warm, shallow marine environment having normal to slightly elevated salinity. The distribution of these species is consistently in rocks representing these types of environments. In the Eastern United States beyond the study region, this species association occurs in the shallow-water dolomites and limestones of the Great Mead-

ows Formation (of Flower, 1964) in the Champlain Valley of New York (Repetski, 1977); in the middle to upper Stonehenge and lower Rockdale Run Formations in western Maryland (J.E. Repetski, USGS unpublished collections, 1976); in middle and upper Stonehenge Limestone in south-central Pennsylvania to western Virginia (Tipnis and Goodwin, 1972; Orndorff, 1988); and in middle to upper Chepultepec Dolomite in eastern Tennessee (Repetski, 1985). Both the conodont fauna and the lithology indicate that the Buckingham Valley carbonate sequence was part of this broad, shallow-water facies belt.

CONCLUSIONS

Our work shows that the rocks in the Buckingham Valley of Pennsylvania, previously inferred to belong to the Beekmantown Group, are Beekmantown. The carbonate sequence within the Buckingham Valley is similar to the shelf deposits of the Great Valley to the north; the transition to shelf edge and slope deposits lies farther south and is covered by rocks of the Newark Basin.

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PLATE 1

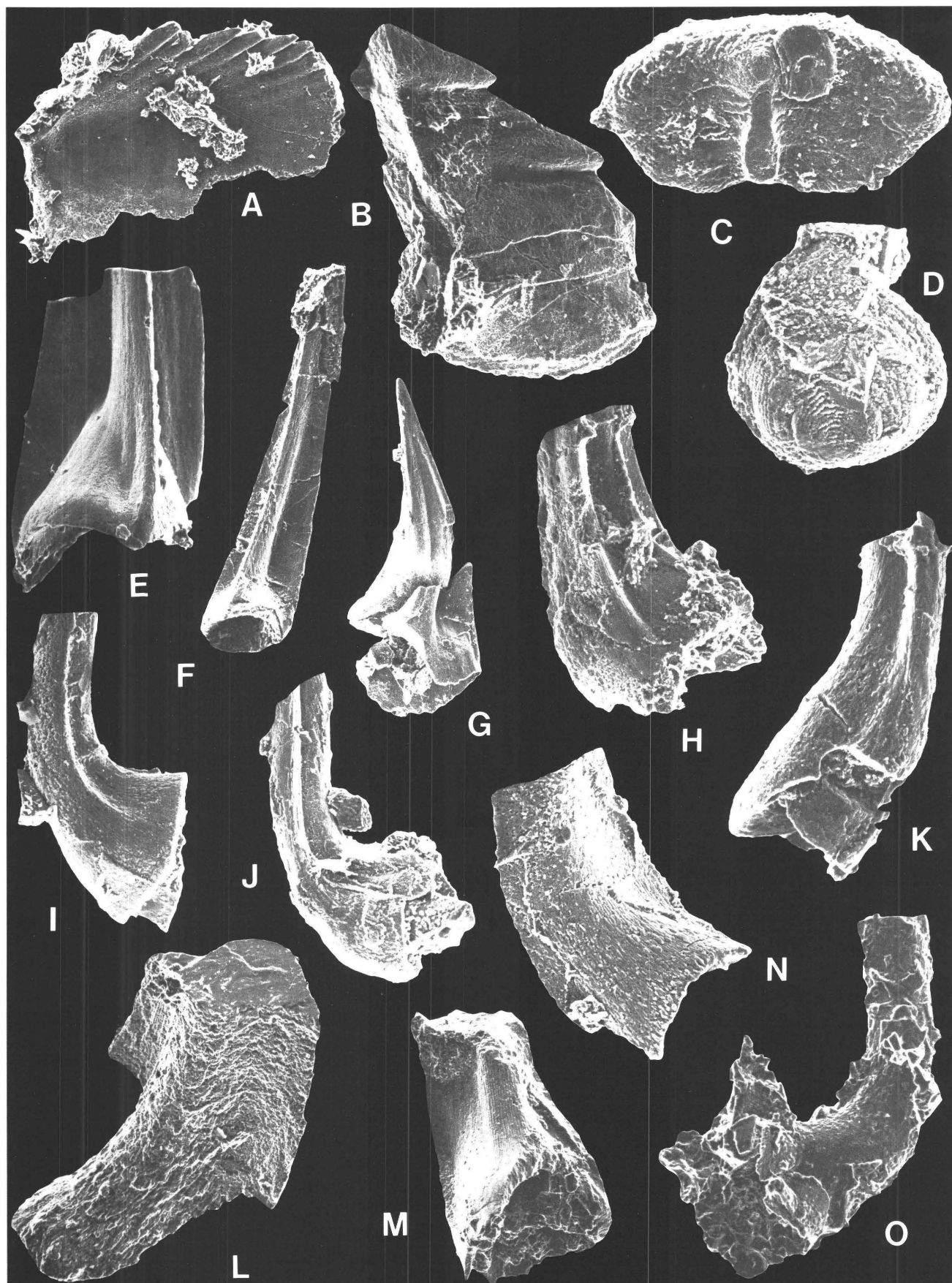
Contact photographs of the plate in this report are available, at cost, from the U.S. Geological Survey Photographic Library, Federal Center, Denver, CO 80225.

PLATE 1

Early Ordovician conodonts from the Buckingham Valley, Bucks County, Pennsylvania

[All specimens are from USGS fossil locality 10713-CO, except *O*, which is from USGS fossil locality 10712-CO. Specimens are coated only with carbon for scanning electron microscope photography and are repositied in the type collections of the Paleobiology Department, U.S. National Museum of Natural History, Washington, DC 20560.]

- A, B.* *Loxodus bransoni* Furnish. Inner lateral views of posterior portions of two specimens: USNM 442680 ($\times 100$) and USNM 442681 ($\times 240$).
- C.* *Clavohamulus densus* Furnish. Posterior view; USNM 442682 ($\times 165$).
- D.* *Clavohamulus* sp. Basal posterior view of small specimen, possibly a juvenile of *C. densus*; USNM 442683 ($\times 225$).
- E–G.* *Scolopodus? sulcatus* Furnish. Posterolateral views of asymmetrical specimens (*E, F*), USNM 442684 ($\times 175$) and USNM 442685 ($\times 95$); posterior view of broken symmetrical element (*G*), USNM 442686 ($\times 135$).
- H.* *Rossodus manitouensis* Repetski and Ethington. Posterolateral view of coniform element, USNM 442687 ($\times 225$).
- I–K.* *Variabiloconus bassleri* (Furnish). Outer (*I*) and inner (*J, K*) lateral views: USNM 442688 ($\times 190$), USNM 442689 ($\times 180$), and USNM 442690 ($\times 225$).
- L–N.* *Juanognathus?* n.sp. Upper oblique (*L*) and posterolateral (*M, N*) views of three specimens: USNM 442691 ($\times 250$), USNM 442692 ($\times 180$), and USNM 442693 ($\times 180$).
- O.* *Cordylodus* cf. *C. proavus* Müller. Posterolateral view of inner side of juvenile or primitive cordylodan morphotype; USNM 442694 ($\times 355$).



EARLY ORDOVICIAN CONODONTS FROM BUCKS COUNTY, PENNSYLVANIA

Chapter E

An Unusual Late Cretaceous Fauna from an Oyster-Rich Interval in the Santa Cruz Mountains of California

By WILLIAM P. ELDER

U.S. GEOLOGICAL SURVEY BULLETIN 1934

SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

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An Unusual Late Cretaceous Fauna from an Oyster-Rich Interval in the Santa Cruz Mountains of California

By William P. Elder

Abstract

Deformed fossiliferous strata resembling the Great Valley sequence are present in a fault wedge near Loma Prieta in the Santa Cruz Mountains of California. Macrofaunal analysis of these strata indicates a late Campanian to early Maastrichtian age for the upper part of this sequence. Numerous unusual species are present in this interval of turbidite deposits, the least common of which are found near the base of the Upper Cretaceous strata in a zone containing abundant *Amphidonte* exogyrid oysters and *Calcispongea*. Among the fossils discussed and illustrated from this zone in this paper, the following are either extremely rare or previously unreported in strata of this age in California: the bivalves *Isognomon* sp., *Barbatia* sp., *Acesta* n.sp., *Lima* n.sp., and *Inoceramus* (*Endocostea*?) sp. aff. *I. (E.?) cymbaeformis* Pergament; an *Astrangiidae*? coral species; and a species of *Calcispongea*. In addition to the unusual macrofossils present in this interval, dissolution of shell material in some beds has produced exquisite casts of shell borings, which also are briefly discussed and illustrated.

Composition of the oyster-rich assemblage indicates a relatively high energy, near-shore habitat consisting of mixed sand and rock or shell-bed substrates. These sediments were subsequently transported downslope by turbidity currents. Fossils found in the overlying Upper Cretaceous strata are indicative of a more offshore shelf habitat, which suggests a seaward shift in sediment source area or transgression through time. Component taxa in the oyster beds include North Pacific species whose tectonically transported distributions range from Baja California to Vancouver Island, British Columbia. Some of these species have been previously reported only to the north and some only to the south of Loma Prieta. Thus, the unusual faunal composition of the oyster beds appears to be caused by the preservation of a very near shore assemblage, which is rare in strata of this age in California, rather than by biogeographic constraints. The apparent absence of rudists in this very near shore assemblage, where they would be expected if present, suggests signif-

icant displacement of the Upper Cretaceous rudist-bearing rocks west of the San Andreas fault relative to those near Loma Prieta.

INTRODUCTION

Upper Cretaceous rocks east of the San Andreas fault in California's Santa Cruz Mountains have been poorly dated, and the macrofossils have received little study. Yet important clues about post-Late Cretaceous displacement along fault systems to the east of and on the San Andreas fault in the San Francisco Bay area are provided by this isolated patch of moderately fossiliferous, deformed rocks that are structurally and lithologically similar to portions of the Great Valley sequence. Although determination of the relationship between these rocks and age-equivalent rocks deposited in the Central Valley of California and to the south is still in the formative stage, an important step to understanding the degree and history of displacement along the California margin is the documentation of complete macrofossil assemblages present during different time slices. This paper documents some late Campanian to early Maastrichtian fossil assemblages present near Loma Prieta in the Santa Cruz Mountains and discusses in particular an unusual assemblage of turbidite transported near-shore fossils associated with an oyster coquina.

Many of the fossils found in and adjacent to this oyster-rich interval are rare taxa that are poorly illustrated in the literature or have not been previously known or described. Thus, in addition to documenting the age and composition of these assemblages, the fossils and molds associated with the oyster-rich zone, although typically poorly preserved, offer the opportunity to illustrate several of these rare and undescribed taxa. Also, zones of complete shell dissolution have yielded exquisite casts of shell borings, which will be illustrated and briefly discussed.

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STRATIGRAPHIC AND GEOLOGIC SETTING

The fossils reported on in this study come from an unnamed fault-bounded stratigraphic unit that has been informally referred to as Upper Cretaceous "sedimentary rocks in the Sierra Azul" by Bailey and Everhart (1964) and Upper Cretaceous "sandstone, shale, and conglomerate of Sierra Azul" by McLaughlin and others (1988a). Faults at low angles to bedding (interpreted as normal detachment faults) apparently separate the Upper Cretaceous rocks from the underlying Upper Jurassic to Lower Cretaceous and the overlying Eocene strata (McLaughlin and others, 1988a). The Upper Cretaceous unit lies in an extremely folded and faulted region, but its outcrop belt forms a roughly elongate wedge truncated by numerous faults—namely, the San Andreas, Lomita, and Sargent fault zones to the southwest and the Hooker, Soda Springs, and Berrocal faults to the northeast (text fig. 1) (Dibblee and Brabb, 1978; McLaughlin and others, 1988a). Some of these faults are presently active (San Andreas, Lomita, Sargent) or are suspected to be active (Berrocal).

The amount of post-Late Cretaceous displacement of this Upper Cretaceous fault wedge is unknown. Faunal assemblages and lithostratigraphic distributions in these rocks and in those of similar age to the east along the margins of the Diablo Range are too poorly understood at present to form any conclusive correlations.

The Upper Cretaceous rocks of the Sierra Azul consist of a basal conglomeratic unit containing pebble to boulder clasts, primarily of volcanic and plutonic rock types (Simoni, 1974; McLaughlin and others, 1988a). This conglomerate forms an areally extensive, massive bed up to approximately 1,000 m thick in the northern part of the outcrop belt but is present as thinner lenses in some areas, particularly in the southern part of its distribution (McLaughlin and others, 1988a; R.J. McLaughlin, oral commun., 1989). The interval of oyster beds discussed in this paper is associated with the uppermost part of this conglomeratic interval and is found in a zone of interbedded fine- to medium-grained lithic wacke, pebble to cobble conglomerate, oyster-rich coquinite, and vuggy wacke

resulting from the dissolution of bioclasts (text fig. 2). McLaughlin and others (1988a) have interpreted this basal conglomeratic unit to be bounded by low-angle normal faults at most places, although it is locally depositionally overlain by sandstone and argillite.

Overlying the conglomeratic unit are strata primarily composed of rhythmically interbedded sandstone and argillite exhibiting thinning-upward bedding cycles, load features, plane laminations at tops of beds and, rarely, graded bedding; conglomeratic lenses are locally present (McLaughlin and others, 1988a). No fossils have been found in this flyschlike unit, the thickness of which is difficult to ascertain because of structural complications. The upper part of the Upper Cretaceous section is largely massive, sandy to silty argillite and wacke containing some fossiliferous carbonate concretions. The uppermost part of this argillaceous interval contains an upward-thickening sequence of sandstone and shale beds. No fossils have been found in the uppermost part of the unit, which is interpreted as being in fault contact with an overlying conglomeratic unit of early Eocene age (McLaughlin and others, 1988a). The entire Upper Cretaceous sequence probably consists of 400 to 1,100 m of section, depending on location and possible complications caused by faulting.

DEPOSITIONAL SETTING

The lithologies and bed forms in the Upper Cretaceous rocks of the Sierra Azul are indicative of a deep-sea fan deposit (for example, Normark, 1978; Walker, 1978, 1984; Nilsen, 1980). Deep-sea fan deposits are widely developed in strata of equivalent age in the San Joaquin Valley of California (Ingersoll, 1979), as well as in southern California and northern Baja California (Bottjer and Link, 1984). As noted earlier, the overall facies pattern in the Sierra Azul rocks is from unsorted and poorly sorted conglomerate, to finely interbedded sandstone and shale displaying upward-thinning sequences, to massive sandstone and argillite, and finally to an upward-thickening sequence of interbedded sandstone and shale. This pattern suggests transition from an inner to midfan channel setting at the base of the sequence (massive conglomerate), to a distal midfan or possibly back-levée environment (flyschlike deposits) in the middle part of the sequence, and, finally, to a midfan channel progradational setting (massive to interbedded argillite and wacke) near the top of the section (compare with Walker, 1978; Ingersoll, 1978).

The oyster coquina beds were apparently deposited near the time that the basal conglomerate-filled channel began to be filled in with finer grained sediments. Bedding in this oyster-rich interval suggests two upward-thinning sequences (text fig. 2). Exposures of the oyster beds are poor and widely spaced, but the beds have been traced intermittently for over 6 km along strike (text fig. 1, locs.

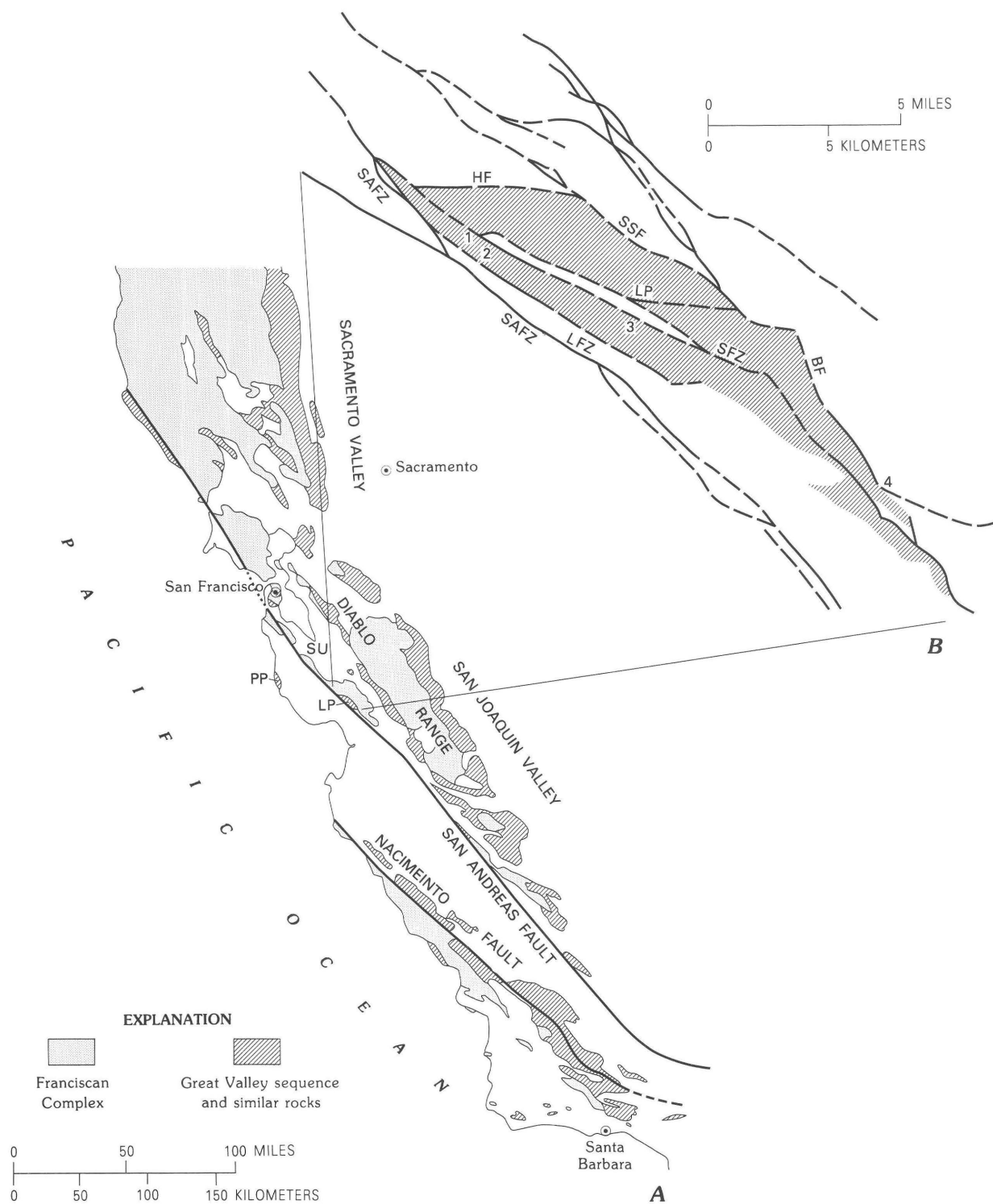


Figure 1. Locations and settings of rocks similar to the Great Valley sequence near Loma Prieta (LP), Calif. A, Position of Loma Prieta relative to major fault systems and Mesozoic outcrop belts in west-central California and to well-dated Late Cretaceous outcrops of similar age at Stanford University (SU) and Pigeon Point (PP). B, Enlarged map showing the fault-bounded wedge of deformed Great Valley-like rocks and the four localities where the oyster bed or a similar faunal assemblage has

been found. Locality 1, M8575; locality 2, M8576; locality 3, M8525; locality 4, M6781 (see appendix for exact location information). Abbreviations are as follows: HF, Hooker fault; SSF, Soda Springs fault; BF, Berrocal fault; SAFZ, San Andreas fault zone; LFZ, Lomita fault zone; SFZ, Sargent fault zone. Faults are dashed where inferred. Modified from Bailey and others (1964), Rogers (1966), Dibblee and Brabb (1978), and McLaughlin and others (1988a).

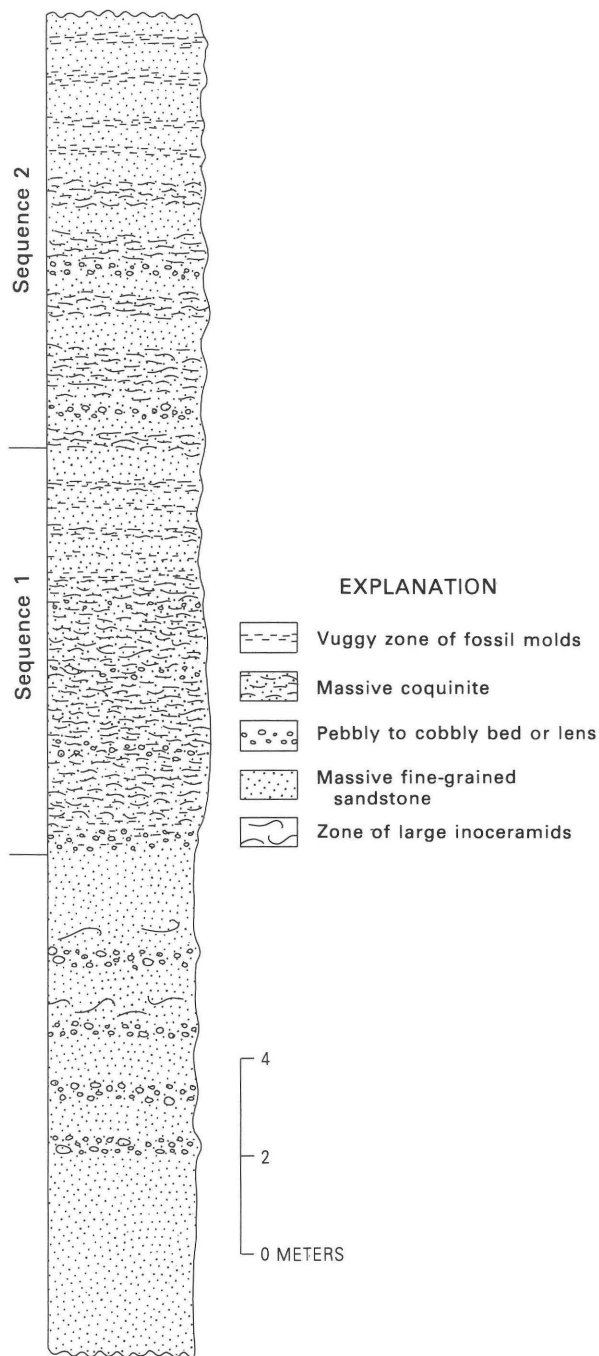


Figure 2. Oyster-rich zone at locality M8525 (text fig. 1, loc. 3)

1–3) and may extend for at least another 6 km to the south, on the basis of the occurrence of several fossils near Sveadal (text fig. 1, loc. 4) that are associated with this bed at the other localities. At the one locality where the base of the oyster-rich interval is exposed, albeit poorly (text fig. 1, loc. 3), the basal part of the interval is a massive oyster coquinite containing pebbly to cobbly zones (text figs. 3, 4) and is overlain by interbedded lenses of sandstone, pebbly



Figure 3. Cross-sectional view typical of the oyster-rich interval. Knife is 9 cm long.

sandstone containing rare cobble clasts, and coquinite or vuggy sandstone resulting from the dissolution of the shell material (text figs. 2, 5).

The repeated sandstone, pebbly sandstone, and faunally similar shell layers found through the interval shown in text figure 2 suggest that numerous turbidity flows deposited this unique oyster-rich zone, although it is possible that a single flow of fluctuating intensity also could have produced this depositional fabric. The fairly uniform assemblage in the oyster-rich zone is very different from the assemblages found in the overlying massive sandstone and argillite (although several species do occur in both of these facies) (see table 1) and thus reflects a change in source area, transport distance, or biofacies distribution between the facies. The mixing of abundant shell material into pebbly sandstone lenses in and above the generally massive oyster bed suggests that the shell material was not cemented at the time of transport. Although the disarticulation of all identifiable bivalve shells suggests that they were dead at the time of transport, the fact that many of the large thin-shelled *Lima*, *Lyrioclamys*, and “*Mytilus*” are unbroken implies minimal reworking before transport and little interaction between clasts entrained in the density flow.

AGE AND CORRELATION

Because the Upper Cretaceous rocks of the Sierra Azul have yielded no microfossils, macrofossils are the only source of age control presently available. Molluscan fossils associated with the oyster bed near the bottom of the Upper Cretaceous interval and the concretions present near the top of the sequence all indicate a late Campanian to early Maastrichtian age. The preponderance of molluscan fossils suggests a late Campanian age.



Figure 4. Print made from an acetate peel of the oyster coquina showing the fabric of the bed. Dark areas are shell material (mostly *Amphidonte* shells). White areas are Calcispongia. Rounded, oblong, dark-gray area at right center is a Cyclostome bryozoan. The original upright orientation is unknown but probably was from the lower left to the upper right. Print is natural size.

Age information provided by fossils found in the oyster-rich interval is poorly constrained but is indicative of a late Campanian age. The component taxa *Amphidonte* (*Amphidonte*) *parasitica* (Gabb), *Lyrioichlamys traskii* (Gabb), *Hipponix dichotomus* (Gabb), and poorly preserved *Crassatella* probably assignable to *Crassatella conradiana* (Gabb) all have their type locality at Texas Flat near Folsom, west of Sacramento, Calif. Matsumoto (1960) stated that the fossiliferous beds at this locality probably belong to the upper Campanian on the basis of the occurrence of *Baculites inornatus* Meek and *B. occidentalis* Meek in the Folsom area. *Baculites inornatus* also is found in concretions overlying the oyster-rich zone at Loma Prieta. *Spondylus subnodosus* (Packard) is a common element in the oyster beds and has its type locality in Packard's (1922) "*Tellina*" *ooides* zone of California's Santa Ana



Figure 5. Pebbly to cobbly conglomeratic zone in the shell-bed interval. Knife is 9 cm long.

Mountains. This zone lies in the upper Campanian *Metaplocenticeras pacificum* ammonite zone (Popenoe, 1942; Matsumoto, 1960; Muller and Jeletzky, 1970).

A late Campanian age is suggested by other mollusks found both above and below the oyster beds. *Inoceramus* (*Endocostea*?) sp. aff. *I. (E.?) cymbaeformis* (Pergament) is found in sandstone immediately underlying the oyster-rich zone. Pergament (1974, 1978, fig. 11) showed *I. (E.?) cymbaeformis* as occurring in the basal *I. (E.) balticus* zone in strata that probably lie in the uppermost Campanian of the eastern Soviet Union. In addition, the overlying massive sandstone unit contains *Biplica obliqua* (Gabb), *Glycymeris* (*Glycymerita*) *anae* Smith, and *Clioscolus* sp. cf. *C. cordatus* Whiteaves, all of which are characteristic of Campanian rocks (Popenoe, 1942, 1957; Smith, 1945; Bannon and others, 1989). Concretions in the overlying massive argillite unit contain *Baculites rex* Anderson, which is usually found in Maastrichtian strata but may range into the upper Campanian (Matsumoto, 1959). *Inoceramus* sp. aff. *I. (E.) goldfussi* (d'Orbigny) also is present in these concretions and is likewise indicative of a late Campanian to early Maastrichtian age. *Baculites rex* is found in some concretions of this interval with *B. inornatus* Meek and *Baculites* sp. aff. *B. anceps* Lamark, which are definitively known only from the upper Campanian in California (Matsumoto, 1959). Thus, the majority of biostratigraphic data indicates a late Campanian age for the Upper Cretaceous rocks at Loma Prieta. The 400 to 1,100 m of these rocks preserved in this region therefore appear to have been deposited in less than the approximately 7-m.y. late Campanian interval (Obradovich, 1988). On the basis of average sedimentation rates calculated for California Cretaceous deep-sea fan deposits by Ingersoll (1979), these strata may well have been deposited within a time interval of 2 to 4 m.y.

Table 1. Checklist of macrofossils from the upper Campanian to lower Maastrichtian rocks near Loma Prieta, Calif.
[X, present; —, not present; *cf.*, comparable to; *aff.*, affinities with; ?, questionable identification]

Locality ¹	USGS Mesozoic locality	Quadrangle ²	Age ³	<i>Acesta</i> n.sp. A	<i>Acila</i> (<i>Truncacila</i>) <i>demessa</i> Finlay	<i>Acila</i> (<i>Truncacila</i>) sp.	<i>Amphidonte</i> (<i>Amphidonte</i>) <i>parasitica</i> (Gabb)	<i>Barbatia</i> sp.	<i>Calva</i> sp.	<i>Cliscolus cordatus</i> Whiteaves	<i>Crassatella conradiana</i> (Gabb)	<i>Crassatella</i> sp.	<i>Cymbophora popenoei</i> Saul	<i>Cymbophora</i> sp.	<i>Etea?</i> sp.	<i>Glycymeris</i> (<i>Glycymerita</i>) <i>anae</i> Smith	<i>Glycymeris</i> sp.	Heterodont bivalve indet.	<i>Indogrammatodon?</i> <i>vancouverensis</i> (Meek)	<i>Indogrammatodon?</i> sp.	Inoceramid indeterminate	<i>Inoceramus</i> (<i>Endocostea</i>) <i>goldfussi</i> d'Orbigny	<i>Inoceramus</i> (<i>Endocostea?</i>) <i>cymbaeformis</i> Pergament	<i>Isognomon</i> sp.	<i>Lima</i> n.sp. A	<i>Lyriochlamys traskii</i> (Gabb)	<i>Mytilus quadratus</i> Gabb	<i>Ostrea</i> sp.
1	M8575	LG	C-M	X	—	—	X	—	—	—	—	X	—	X	—	—	X	X	—	—	—	—	—	—	—	—	—	—
2	M8576	L	C-M	X	—	—	X	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	—	X	X	<i>cf.</i>	—
3	M8525	LP	C-M	X	—	—	X	X	—	—	<i>aff.</i>	X	<i>aff.</i>	—	—	X	—	—	—	X	—	<i>aff.</i>	<i>aff.</i>	X	X	X	—	X
4	M6781	LP	C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	<i>aff.</i>	—	—	—	—	—	—
	M8529	LP	C-M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—	—	X
	M8539	LP	C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	M8535	LP	C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
	M8554	LP	C-M	—	—	X	—	—	—	<i>cf.</i>	—	—	—	—	—	—	—	—	X	—	<i>cf.</i>	—	—	—	—	—	—	X
	M8568	LP	C-M	—	X	—	—	—	X	—	—	—	—	—	—	X	—	—	<i>cf.</i>	—	—	—	—	—	—	—	—	—
	M8524	LP	C-M	—	<i>cf.</i>	—	—	—	X	—	—	—	—	—	?	X	—	—	<i>cf.</i>	—	—	—	—	—	—	X	—	—
	M8590	LP	C	—	—	—	—	—	—	<i>cf.</i>	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
	M8540	LP	C	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	<i>aff.</i>	—	—	—	—	—	—	—	—	—

¹Numbered localities are oyster-bed localities shown on text figure 1. Unnumbered localities are from the overlying sandy to argillaceous interval. All locality data are listed in the appendix.

²LG, Los Gatos 7 1/2-min quadrangle; L, Laurel 7 1/2-min quadrangle; LP, Loma Prieta 7 1/2-min quadrangle.

³C-M, Campanian to Maastrichtian; C, Campanian.

The nearest well-dated outcrops of rocks equivalent in age to the Upper Cretaceous rocks of the Sierra Azul are on the Stanford University campus and across the San Andreas fault at Pigeon Point (text fig. 1). A claystone cropping out near the Stanford campus contains foraminifers and macrofossils, including *Baculites inornatus*, of late Campanian age (Graham and Church, 1963). However, *B. inornatus* is apparently the only species to co-occur in the Stanford and Loma Prieta localities (Graham and Church (1963) have listed the Stanford macrofossils). Additionally, the claystone at Stanford contains much less sand and silt than the argillite at Loma Prieta does and is a light gray to gray green in color rather than the dark olive gray to olive black of the Loma Prieta rocks. These discrepancies imply different sediment source areas and depositional environments for the two localities and may be explained either by local changes in fan facies and feeder channel systems or by significant displacement on faults between these localities.

The age range of the Pigeon Point Formation is unclear (Saul, 1978, p. 50–52), but at least part of the formation is of late Campanian to early Maastrichtian age

(Hall and others, 1959; Saul, 1978, 1983). Although the lithologies of the Pigeon Point Formation and the Upper Cretaceous rocks of the Sierra Azul are similar, both largely reflecting a turbidite origin, the Pigeon Point Formation is much thicker (Howell and Joyce (1981) estimated a thickness of 3,300 m) and displays a regressive sequence ending in slope and, finally, shallow shelf deposits at the top of the preserved section (Howell and Joyce, 1981). This regressive sequence contrasts with the apparent transgression or shoreline retreat evident through the section near Loma Prieta. Macrofossils are typically rare in the Pigeon Point Formation but are locally abundant in the shelf facies. Of the approximately 66 species known from the Pigeon Point Formation and the 50 species known from the Upper Cretaceous rocks near Loma Prieta, only 8 to 10 species are common to both areas (Elder and Miller, 1989). Only one species is present at both areas but not known from elsewhere—the crab *Archaeopus antennatus* Rathbun, 1908.

The total amount of northward displacement of the Upper Cretaceous rocks of the Sierra Azul is uncertain, as

Pecten undetermined	<i>Plicatula</i> sp.	<i>Pterotrigonia evansana</i> (Meek)	<i>Spondylus subnodosus</i> (Packard)	<i>Tellina</i> sp.	<i>Yaadia robusta</i> Saul	<i>Yaadia</i> sp.	<i>Yoldia</i> sp.	<i>Baculites anceps</i> Lamark	<i>Baculites inornatus</i> Meek	<i>Baculites rex</i> Anderson	<i>Caudyceras tenuiliratum</i> Yabe	<i>Aporrhais</i> sp.	<i>Biplica obliqua</i> (Gabb)	<i>Depanochilus</i> sp.	Gastropod indeterminate	<i>Gyrodes</i> sp.	<i>Hipponix dichotomus</i> (Gabb)	<i>Opalia</i> (<i>Confusiscala</i>) sp.	Patellacean gastropod	<i>Peristys</i> sp.	<i>Dentalium cooperi</i> Gabb	<i>Dentalium</i> sp.	Astrangidae?	Echinoid fragment	<i>Isocrinus</i> sp.	Acrothoracean barnacle boring	<i>Archaeopus antennatus</i> Rathbun	<i>Callianassa</i> ? sp.	Fish scales	Calcispongea	Clionid boring	Cheilostome bryozoa	Cyclostome bryozoa	
X	?	X	X	X	?	X	?	aff.	X	X	?	X	X	X	X	X	X	X	X	X	?	X	?	?	X	X	X	X	X	X	X	X	X	X
X	—	—	—	—	—	—	—	—	—	X	—	—	—	X	—	X	—	—	—	—	aff.	—	—	—	—	—	—	X	—	X	—	—	—	—
—	—	—	—	—	—	—	?	X	X	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	X	—	—	—	X	—	—	?	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	—	—	—	—	—	—	—	X	—	X	cf.	X	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—
—	—	X	—	?	—	—	—	—	—	—	—	—	cf.	—	—	—	—	X	—	—	—	X	X	—	—	X	—	—	—	—	—	—	—	—
—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	?	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—

is the relative displacement between these strata and those to the west of the San Andreas fault in the Pigeon Point Formation. Paleomagnetic data for the Pigeon Point Formation imply 1,500 km or more of northward displacement before the suturing of the Salinian terrane to cratonal North America in the early Tertiary (Champion and others, 1984). McLaughlin and others (1988b) suggested more than 320 km of northward displacement for the Sierra Azul outlier between 60 and 52 Ma. In addition to these apparent Cretaceous to early Tertiary displacements, subsequent movement on the San Andreas and subsidiary faults has transported both the Pigeon Point Formation and the Upper Cretaceous rocks of the Sierra Azul northward relative to the North American craton. Graham and others (1989) have proposed between 300 and 330 km of post-Oligocene right-lateral displacement along the San Andreas fault in central California. In the San Francisco Bay area, this displacement has been distributed between the San Andreas fault and other faults to the west of Loma Prieta and subsidiary faults to the east, particularly the Calaveras and Hayward faults. Thus, it is difficult to determine not only the total displacement of the Upper Cretaceous rocks of the Sierra Azul but also the displacement of these strata relative to those of the Pigeon Point Formation to the west of the San Andreas fault.

One line of macrofaunal evidence suggests considerable displacement across the San Andreas fault, which lies between Loma Prieta and Pigeon Point. No specimens of the marginal Tethyan rudist, *Coralliochama*, have been found at Loma Prieta. This rudist is characteristic of upper Campanian to lower Maastrichtian strata to the west of the San Andreas fault from Punta Banda in northern Baja California to Gualala, near Point Arena, Calif., and has never been found to the east of the fault (Saul, 1986). Although the absence of *Coralliochama* at Loma Prieta is negative evidence and should not be relied upon too heavily, as the apparent absence of this rudist at Pigeon Point illustrates, this evidence nevertheless suggests considerable right-lateral displacement across the San Andreas fault to the west of Loma Prieta.

In addition, if significant right-lateral displacement has occurred to the east of Loma Prieta in the San Francisco Bay area, then the Upper Cretaceous rocks of the studied area should have been offset from those of the south-central to southern Diablo Range or points further south if there was significant pre-Eocene displacement along a pre-San Andreas transform. Rocks of late Campanian to early Maastrichtian age are widely distributed on the eastern side of the Diablo Range (Popenoe and others, 1960) and are locally present but poorly known on the western side of the

range. Documentation of macrofossil assemblages from rocks of this age in the Diablo Range is outdated and sketchy, but the apparent lack of very near shore assemblages, like those present near Loma Prieta, in the turbidite facies flanking the Diablo Range suggests extensive transport of the Sierra Azul rocks from points further south, given the tectonic regime.

The assemblages at Loma Prieta do have a number of elements in common with those found in rocks of late Campanian to early Maastrichtian age from southern California (table 2). Strata of this age in the Simi Hills, the Santa Monica Mountains, and the Santa Ana Mountains share many common elements with the Loma Prieta molluscan fauna (Packard, 1916, 1922; Popenoe, 1937, 1942; Saul and Alderson, 1981), as does the basal part of the Point Loma Formation near San Diego (Sundberg, 1984; Sundberg and Riney, 1984; Bannon and others, 1989). However, a number of the species found at Loma Prieta also have been found in the Sacramento Valley and as far north as the Vancouver Island area in the upper Campanian to lower Maastrichtian Nanaimo Group (table 2) (Meek, 1876; Whiteaves, 1876–1903; White, 1889); this latter area also may have experienced some northward tectonic displacement (for example, McLaughlin and others, 1988b).

The most important influence on the oyster-bed assemblage near Loma Prieta appears to have been its near-shore proximity rather than its paleogeographic position on the Pacific coast. This influence is illustrated by a striking similarity between the Loma Prieta assemblage and one found near Folsom on the eastern side of the Sacramento Valley, as the co-occurring species mentioned earlier and several other probable co-occurring species indicate. The strata near Folsom consist of approximately 100 m of medium-grained sandstone deposited directly on granite (Popenoe and others, 1960) and apparently represent very near shore deposits. This near-shore depositional environment is supported by the reported presence of land snails mixed with the marine taxa (Anderson, 1958).

CHARACTERISTIC MOLLUSCAN FOSSILS

The oyster-rich assemblage is comprised of many bivalve taxa that are rare or previously unknown in California. The uncommon or unnamed bivalves include *Isognomon* sp., *Lyrioclamys traskii* (Gabb), *Spondylus subnodosus* (Packard), *Acesta* n.sp. A, *Lima* n.sp. A, *Barbatia* sp., and *Inoceramus* (*Endocostea*?) sp. aff. *I. (E.?) cymbaeformis* Pergament. The taxonomies, occurrences, and ecologies of these and other molluscan taxa characteristic of this assemblage are discussed below.

Barbatia sp.

Plate 1, figures 2, 7, 9

At least one species of *Barbatia* is found in the oyster-rich interval. It is represented by four partial internal molds showing most of the hinge area but little of the cardinal area and three partial external molds showing ornamentation on the posterior half of shell. *Barbatia* sp. is a moderately large (the largest valve is about 75 mm long, 45 mm wide, and 17 mm thick), elongate, subquadrate form on which the beak is situated three-quarters of the way toward the anterior and on which the ventral margin is slightly to moderately incurved at midlength of the shell. The hingeline is slightly arcuate and has approximately 20 posterior and 8 anterior teeth that become moderately divergent at the distal ends. The external ornamentation consists of fine, slightly sinuous, radiating striae (every fifth to seventh being more deeply incised) and fine concentric growth lamellae; the intersection of these two features produces a reticulate, punctate appearance. The overall valve shape and orientation of the hinge teeth suggest that this species belongs to the subgenus *Barbatia*.

No *Barbatia* have been reported in rocks of this age on the Pacific slope or in Japan. Thus, this occurrence is probably a new species quite similar to *Barbatia cochlearis* Wade, 1926 and *Barbatia fractura* Wade, 1926, which are found in rocks of similar age on the gulf coast of the United States. The Loma Prieta species differs from these two species in having finer, less distinct radial ornamentation, primary and secondary radial striae, and a more broadly rounded anterior margin.

Barbatia species are byssate epifaunal nestlers that live in near-shore shallow-water environments (see Sundberg, 1980, fig. 21), where they may occupy exposed shallow depressions on firm substrates or attach to plants or rocks (Kauffman, 1969). The moderately concave ventral margin of the above species indicates a fairly large byssal gape and a strong byssal attachment, both of which imply adaptation to a relatively high energy environment.

Mytilus sp. cf. *M. quadratus* Gabb, 1869

Plate 1, figure 3

Mytilus sp. cf. *M. quadratus* is a moderately rare element in the oyster-rich interval. It is represented by one nearly complete internal mold and three incomplete external molds. Although several specimens of this species from Loma Prieta are considerably larger than the ones illustrated by Gabb (1869, pl. 31, fig. 87) and Stewart (1930, pl. 1, fig. 9), the Loma Prieta species is identical in shape and ornamentation to *Mytilus quadratus* (see Gabb (1869, p. 191) for description).

Although it is quite possible that several species have been attributed to *Mytilus quadratus* in the past, this species has been noted from Point Loma, near San Diego (Cooper, 1894), northward to the northern end of the Sacramento Valley near Horsetown (Diller, 1893) and throughout much

Table 2. Geographic distribution of some selected taxa in the oyster beds near Loma Prieta, Calif.

[X, taxon present]

Taxon ¹	Vancouver Island area	Oregon	Sacramento Valley	San Joaquin Valley	Santa Ana Mountains	San Diego area
<i>Mytilus quadratus</i>			X	X		X
<i>Isognomon</i>	X		X			
<i>Lyrioichlamys traskii</i>	X		X			
<i>Spondylus subnodosus</i>				X	X	X
<i>Amphidonte parasitica</i>	X	X	X			

¹The following taxa are known only from the oyster-rich interval near Loma Prieta: *Barbatia* sp., *Acesta* n.sp. A, *Lima* n.sp. A, *Inoceramus* (*Endocostea*?) sp. aff. *I. (E.?) cymbaeformis*, and *Astrangiidae*? sp.

of the Diablo Range. *Mytilus quadratus* is most often associated with fossils of Campanian to Maastrichtian age but has been reported with fossils suggesting an age as old as Albian to Cenomanian (Diller, 1893).

Mytilus is an epifaunal, byssally attached bivalve. The broad, quadrate morphology and the orientation of the posterior adductor muscle on *Mytilus* sp. cf. *M. quadratus* is indicative of this epifaunal lifestyle (Stanley, 1970). Byssate, closely attached bivalves such as *Mytilus* and *Modiolus* most often inhabit the shallow sublittoral to littoral zones (see Sundberg, 1980, fig. 20) in areas of strong wave and current action (Kauffman, 1969).

Isognomon sp.

Plate 1, figures 1, 5

Isognomon sp. is a moderately rare element in the oyster-rich interval. It is represented by two nearly complete internal molds and one nearly complete external mold, as well as four other partial molds. This species is similar to *I. excavata* (White, 1889) in size and excavation of the anterior margin but appears to be less erect than the latter. It is unfortunate that neither growth lines nor the posteroventral margin is preserved on any of the Loma Prieta specimens; thus, detection of the posteroventral angulation and the flattening of the ventral margin noted by White (1889) on *I. excavata* is prevented. Specimens from Loma Prieta have long, straight hinges characterized by about 10 nearly equally spaced ligament pits about half as wide as the interspaces. The exterior of the valves was apparently nearly smooth.

Isognomon is a rare taxon in the Upper Cretaceous of the North American Pacific coast. It is represented by *I. excavata* on Vancouver Island (White, 1889) and from near Folsom, Calif. (Popenoe and others, 1960).

Isognomon is a byssate epifaunal bivalve that inhabits a range of shallow-water habitats, from exposed hard surfaces, such as plants or corals, to depressions or fissures in hard substrates (Kauffman, 1969; Stanley, 1970). More rounded or quadrate forms, like the species from Loma Prieta, tend to be fissure dwellers (Kauffman, 1969).

Inoceramus (*Endocostea*?) sp. aff. *I. (E.?) cymbaeformis* Pergament, 1974

Plate 1, figure 10; plate 2, figures 6, 7, 11

Inoceramus (*Endocostea*?) sp. aff. *I. (E.?) cymbaeformis* is apparently a moderately common species in the sandstone and pebbly conglomerate interval developed immediately below the oyster-rich zone. Several partial to nearly whole molds of this species have been found at localities M8525 and M6781 (text fig. 1, appendix), and several specimens were illustrated by Bailey and Everhart (1964, fig. 49) from the southern branch of Almaden Canyon at an altitude of 700 m. This species is characterized by the following: large size (exceeding 150 mm in height and 180 mm in width); a broad, enrolled umbo projecting 20 mm or more above the hinge of adult specimens; a long posterior wing having a broad flexure of the posterior margin and separated from the disc by a broad, shallow sulcus; surface ornament of subregular rugae near the umbo and irregular rugae and growth lamellae on the disc; and adult forms that are subquadrate in outline and that have nearly flat anterior and posteriodorsal margins separated from a very broadly convex to nearly straight ventral margin by moderate angulations. The inner rib characteristic of *Endocostea* has not been observed on any specimens.

These features are very distinctive and unlike those found on other inoceramids in the U.S. Geological Survey (USGS) collections at Menlo Park, Calif., or described for the Pacific Northwest, with the exception of *Inoceramus*? illustrated by Meek (1876) from Vancouver Island. The Loma Prieta species has close affinities to *Inoceramus cymbaeformis* (see Pergament, 1974, pl. 45, figs. 9a, 9b) from the upper Campanian of the Bering Sea coastal region of the Soviet Union. It differs, however, in having neither as abrupt a change in growth direction nor the development of a pronounced pedestal at the change from early to late developmental stages and in having a flexure of the posterior margin that was not noted by Pergament (1974). The latter characteristic is similar to a characteristic of *I. (Endocostea) cymba* Böhm 1909, from the lower Campanian of northwestern Germany and the Black Hills of the

United States (see Seitz, 1967), with which Pergament (1974) questioned the synonymy of his species. Thus, the species at Loma Prieta displays morphologic characteristics somewhat intermediate between these two taxa, suggestive of close taxonomic relations to both.

Inoceramids were byssally attached or free-living, epifaunal to semi-infaunal reclining bivalves that lived in a wide variety of environments (Kauffman, 1967; Stanley, 1970). The large lunule developed on the Loma Prieta specimens suggests that this species was byssally attached and rested on its anterior face, the commissure being in a nearly vertical position.

***Lyriochlamys traskii* (Gabb), 1864**

Plate 1, figures 4, 6, 8; plate 2, figures 5, 8–10

Lyriochlamys traskii is a moderately common component of the oyster-rich interval and also has been found at one locality in the massive sandstone facies. It is represented by numerous partial internal and external molds. This moderately large pectinid (up to 90 mm in height and 70 mm in width) is characterized by numerous radiating squamous ribs and occasional interribs extending to the margins of the disc and onto the auricles and by *Camptonectes*-like divaricate striae between the ribs. Growth lamellae may be prominent on large specimens, forming squamae at their intersections with the radial ribs. The degree of ornamentation and the roundness of the disc are quite variable (see Gabb (1864, 1869) for additional description).

This species has been listed from as far south as San Diego (Cooper, 1894) and the Santa Ana Mountains (Sundberg, 1980) to as far north as the Vancouver Island area (Whiteaves, 1903), as well as at several localities in the Sacramento Valley (Gabb, 1864; Stanton, 1893). It generally is associated with faunas indicative of Campanian to early Maastrichtian age but may be present in mid-Cretaceous strata of the Hornbrook Formation of northern California (Anderson, 1902). *Lyriochlamys traskii* is typically a rare faunal element where it has been found.

The deep byssal notch developed on the right valve of this species indicates strong byssal attachment, probably to a hard substrate. The squamose ribs suggest that it has adapted to a fissure-dwelling lifestyle, as many bivalves having a *Chlamys*-like morphology have done (Kauffman, 1969), although the generally undeformed morphology of the specimens suggests growth in an unconfined habitat.

***Spondylus subnodosus* (Packard), 1922**

Plate 2, figures 1–4; plate 3, figures 8, 13

Spondylus subnodosus is a common faunal element in the oyster-rich beds. It is represented by numerous shells and molds. This species is characterized by large, inequivalve shells (specimens up to 100 mm high and 70 mm wide) having numerous radiating, flat-topped ribs. On some

specimens, every fifth to seventh rib is more strongly developed and has small nodes. The radials are evident on the internal surfaces of small- to medium-sized specimens, becoming visible only on the peripheral regions of large shells. Broad rugae are present on the one right valve collected at Loma Prieta, and narrow, sharp rugae are present on the periphery of large left valves. Packard (1922) described this species as both *Spondylus striatus* Packard, 1922 and *Lima subnodosa* Packard, 1922 (see Packard (1922) for further description). Hanna (1924) pointed out that *S. striatus* Packard is a junior homonym but apparently failed to recognize *L. subnodosa* as a synonym for the above and replaced *S. striatus* Packard with *S. fucatus* Hanna, 1924. In accord with the International Code of Zoological Nomenclature (1985, article 60b), the name *S. subnodosus* is adopted for this species, and *S. fucatus* Hanna, 1924 becomes a junior synonym.

In addition to the Santa Ana Mountains where the type locality of *Spondylus subnodosus* is found, it has been recorded from near San Diego (Sundberg, 1984; Sundberg and Riney, 1984). *Spondylus* probably attributable to this species also have been found in rocks of the lower Maastrichtian Rosario Formation in Baja California (Anderson and Hanna, 1935; Anderson, 1958). *Spondylus* fragments are rare elements in several Menlo Park USGS collections from Campanian rocks of the San Joaquin Valley.

Spondylus are cementing epifaunal bivalves that attach to hard substrates by their larger right valves. Cretaceous as well as modern *Spondylus* typify high-energy wave- or current-dominated environments, as their occurrence in the Cretaceous on the upper surfaces of boulders on a rocky coast and on reef tops illustrates (Surlyk and Christensen, 1974). The much greater number of left valves relative to right valves found at Loma Prieta suggests that the more robust right valves tended to remain cemented to near-shore rocks after death, whereas the left valves became detached after breakdown of the ligaments and were transported offshore and downslope by turbidity currents.

***Acesta* n.sp. A**

Plate 3, figures 1–4, 7, 11, 12

Acesta n.sp. A is a common component of the oyster-rich interval and is represented by numerous specimens. This species is characterized by the following: a large (to over 120 mm high and 60 mm wide), thin, elongate, inequivalve shell that is smooth for the first 10 to 20 mm and then has numerous slightly wavy, radiating ribs (typically 45 to 55) and concentric growth lamellae that form a squamose texture at their intersections; a nearly straight anterior face extending down three-quarters or more of the anterior margin and separated from the disc by a strong umbonal angulation and from a narrow, long, anterior auricle by a moderately sharp sulcus; a broad posterior auricle not distinctly separated from the disc; a moderately oblique resilifer immediately posterior to the beak; and

growth lamellae but no radials visible on the internal surface of the shell. The broad, oblique ligamental pit and inequilateral shape of this species strongly suggest that it should be placed in the limiid genus *Acesta*. However, the ornament is unlike that characteristic of any subgenus of *Acesta* (see Moore, 1969; Vokes, 1963; Kauffman, 1964) and thus indicates the need for a new subgenus to be erected for this species. *Acesta* n.sp. A is similar in many respects to *A. longa* (Römer) 1841 from the Lower Cretaceous of Europe (Woods, 1904–13), as well as to "*Lima*" *multiradiata* Gabb, 1869 from the Paleocene of Lake County, California (Stewart, 1930). The Loma Prieta species apparently differs from "*L.*" *multiradiata* in having fewer ribs and in developing a squamose texture at an earlier stage than the specimen illustrated by Stewart (1930, fig. 2) and is more elongate and erect than the specimens illustrated by Dickerson (1914, pl. 8, fig. 1) or Stanton (1896, pl. 43, figs. 7, 8).

The Limidae are byssally attached, epifaunal bivalves that are typically nestlers or fissure dwellers, but many also have the ability to swim for short periods (Kauffman, 1969; Stanley, 1970). Most *Acesta* in modern oceans are found in cool, deep-water environments, and little is known of their life habits (Vokes, 1963; Kauffman, 1964). However, Kauffman (1964) described three species of *Acesta* (*Cos-tellacesta*) from Maastrichtian deposits of the Atlantic and gulf coasts of North America that contain a temperate shallow-water fauna, suggesting that at least some of this group may have had different habitat preferences in the past.

Lima n.sp. A

Plate 3, figures 5, 9

Lima n.sp. A is a moderately rare component of the oyster-rich beds and has been found only at locality M8576, where four specimens were collected. This species is characterized by a moderately small (to 27 mm high and 16 mm wide), trigonal, inequilateral shell having very fine, subsquamose radiating ribs extending to the beak and occasionally becoming dichotomous at distances greater than 10 mm from the beak on some specimens; this latter characteristic appears quite variable. A small anterior auricle is suggested on one specimen, and the posterior auricle apparently is not differentiated from the disc. However, the auricular region is poorly preserved on all specimens. This species is similar to *Lima* n.sp. illustrated by Sundberg (1984, pl. 1, fig. 2) from the Point Loma Formation but is apparently somewhat narrower and smaller and shows no indication of growth constrictions, as the latter specimen does. As noted above, this small *Lima* may have had a nestling or fissure-dwelling lifestyle.

Amphidonte (*Amphidonte*) *parasitica* (Gabb), 1864

Plate 3, figures 6, 10; plate 4, figures 9, 17–23

Amphidonte (*A.*) *parasitica* comprises the bulk of the fossils found in the oyster-rich interval, where it may

represent over 90 percent of the bioclasts and forms a coquinite at places. Although this species is exceedingly abundant, very few decent specimens have been collected owing to characteristic fracturing and exfoliation of shell material. Good internal molds are reasonably common, but a good external mold has yet to be found. This species is characterized by a large (to 100 mm high, 70 mm wide, and 10 mm thick), elongate, moderately inflated left valve having a low, strongly opisthocline beak, a large attachment area, a prominent spiral keel, and a lamellar surface. The right valve is nearly flat and displays concentric lamellae to squamulae on the outer surface; one specimen shows faint radial striae on the posteroventral surface. Numerous chomata are developed along the entire anterior to ventral margin of both valves. Gabb (1864) and Stewart (1930) have provided further description.

This exogyne bivalve is extremely variable in shape at Loma Prieta, as is characteristic of many oysters. This ecophenotypic variability of the oysters makes earlier reports of *Amphidonte* (*A.*) *parasitica* somewhat suspect. However, it has been cited as occurring at several localities in the Sacramento Valley and northward to the Vancouver Island area (see Anderson, 1958), most often in strata of late Campanian age.

Most cementing bivalves are found in shallow-water environments having depths of less than 35 m (Kauffman, 1969). The low profile and the robust shell and large attachment surface of *Amphidonte* (*A.*) *parasitica* imply that it was adapted to relatively shallow water, high-energy environments.

Crassatella spp.

Crassatella is a moderately rare element in the oyster-rich zone, where it is represented by eight specimens of at least two and probably three species. The specimens are all very poorly preserved molds that do not allow identification to the species level. The broad, protruding anterior margin and the broad, rounded posterior margin, as well as the hinge of some specimens (pl. 4, fig. 10), suggest that they belong to the *C. conradiana* group of Saul and Alderson (1981). However, the crenulated margin characteristic of this group is not evident on any of these specimens. In addition to the above species, a slightly inflated, elongate form having a crenulated margin is present.

The ecologic implications of these *Crassatella* are unclear. The elongate, slightly inflated form indicates adaptation for deeper and more rapid burrowing than the form of the *C. conradiana* group (see Kauffman, 1969, fig. 90) and thus suggests a more shallow water habitat for the former relative to the latter species. This interpretation is consistent with Saul and Alderson's (1981) observations that the slightly inflated, elongate *C. saulae* group is typically associated with a more shallow water fauna than the more inflated *C. conradiana* group, although the two

may be found together. On the whole, *Crassatella* apparently suggests a source area of slightly greater water depth than do most of the other faunal elements present in the oyster beds; Saul (1982) suggested that this genus is an indicator of moderate shelf depth in late Campanian molluscan assemblages of the Santa Ana Mountains.

OTHER FAUNAL COMPONENTS

In addition to the bivalve species noted above, several gastropod species are present, although all are represented by only one or two specimens. This rarity of gastropods seems unusual for the near-shore aspect of the fauna and may reflect only the extremely poor preservation of aragonitic shell material. In addition to a poorly preserved specimen resembling *Margarites ornatissimus* (Gabb), 1864, the presence of two moderately well preserved patelliform gastropod species is worthy of note. One species appears to be referable to the Mesogastropoda species *Hipponix dichotomus* (Gabb), 1864, (pl. 4, figs. 7, 8). The other species probably belongs to the Archeogastropoda superfamily Patellacea (pl. 4, figs. 4, 5). As with many of the bivalve taxa, the type locality for *H. dichotomus* is Texas Flat. This species also has been reported from the Point Loma Formation near San Diego (Cooper, 1894). The presence of Patellacea suggests a rocky, near-shore habitat within the photic zone, because modern patelliform Archeogastropoda feed on seaweeds on rocky surfaces (Kanie, 1975).

The oyster-rich assemblage also contains several unusual nonmolluscan components. One important member of this assemblage is a ramus sponge (pl. 4, figs. 11–15) probably belonging to the Calcispongea (J. Keith Rigby, oral commun., 1989), given the presence on some specimens of acrothoracian barnacle borings (pl. 4, fig. 13), which are known only from carbonate substrates (Seilacher, 1969). This sponge may account for up to 30 percent of the bioclasts in some portions of the oyster-rich zone. Calcispongea are associated with shallow-water beds and reefy beds throughout the fossil record but are particularly characteristic of greensand facies in the Cretaceous; they are also common in chalky rocks of this age (Finks, 1983). These sponges are indicative of clear water, full oceanic salinity, and depths of probably less than 100 m and more likely less than 30 m; modern species are most common at depths of less than 10 m (deLaubenfels, 1957a, b). Growth of this fairly delicate ramus sponge probably could not have occurred in highly turbulent conditions, and occasional flabellate morphology (pl. 4, fig. 15) suggests uniform current conditions (Bidder, 1923).

In addition to the Calcispongea, one or more species of boring clionid sponge are indicated in the oyster beds by the abundant occurrence of several species of the ichnogenus *Entobia* (pl. 5, figs. 13, 14, 18; also probably fig. 6).

These sponge borings were most common in the *Amphidonte* and *Spondylus* shells, which were thicker than other shells present in these beds.

Another unusual component in these beds is an encrusting colonial coral, probably referable to the Astrangiidae. Three specimens of this species have been found (pl. 5, figs. 1, 2). This coral has not been previously described or illustrated in California. The Astrangiidae are ahermatypic corals that are widely distributed in littoral to neritic zones in temperate to tropical seas (Vaughn and Wells, 1943). Also, an encrusting Cheilostome bryozoan is commonly found on shells in these beds, particularly on the inside of *Amphidonte* shells (pl. 4, fig. 16), and several specimens of a Cyclostome bryozoan have been found. The presence of these typically stenohaline, encrusting organisms is indicative of full marine salinity and sedimentation rates low enough for their establishment and survival before burial and (or) downslope transport.

Another stenohaline group, the Echinodermata, is represented in the oyster-rich interval by rare occurrences of poorly preserved *Isocrinus* columnal plates and by fragments of several echinoid taxa. One of the latter species belongs to a cidaroid genus, as its large, stout spines indicate (pl. 4, figs. 1–3).

The Crustacea are represented in the oyster-rich zone by acrothoracian barnacle borings, mostly assignable to the ichnogenus *Rogerella* (pl. 5, figs. 15, 17). These borings are common and may be found on almost every bivalve species present, as well as on some calcisponge specimens. One fragmentary crustacean manus, probably assignable to *Callianassa*, also has been found in this zone (pl. 4, fig. 6). The shape and ornamentation of this manus are very similar to those shown for *C. stimpsonii* Gabb, 1864, (Gabb, 1864, pl. 9, fig. 1).

In addition to the groups noted above, the molds of several small, coiled tubes attached to the surface of shells for nearly their entire length apparently reflect the presence of a *Spirorbis*-like serpulid worm (pl. 5, figs. 7, 11). The Annelida also may be represented by boring polychaete worms. Their presence is reflected by rare meandering and U-shaped borings running parallel to shell surfaces and resembling *Maeandropolydora* (pl. 5, figs. 10, 12, 16).

Several other borings and traces of unknown affinities are found in voids created by the dissolution of shells in the oyster beds. Long, deep sac-shaped or arcuate borings that penetrate the entire thickness of *Spondylus*? or possibly wood molds and that have oblique constrictions may be the result of boring bivalves (*Gastrochaenolites*?) (pl. 5, figs. 5, 8, 9). One possible example of algal microboring (pl. 5, fig. 3) indicates, if correct, that the shell fragment was in the photic zone at the time of boring. Also, a rasplike trace of possible isopod or gastropod origin was found on the internal surface of a *Spondylus* shell (pl. 5, fig. 4), and an unusual dendritic pattern developed on the surface of a shell mold (pl. 5, fig. 11) may reflect another type of bryozoan.

PALEOECOLOGIC AND PALEOBIOGEOGRAPHIC CONCLUSIONS

The degree of community mixing within the oyster-rich assemblage is unknown, but it is not unreasonable to assume that most or all of the component taxa lived in close proximity to one another. This assemblage is characterized by molluscan taxa that are indicative of near-shore, relatively high energy environments. Many of the components suggest a rocky near-shore setting inhabited by cementing bivalves and nestling to fissure-dwelling byssate bivalves. Taxa indicative of this environment include *Spondylus*, *Mytilus*, *Barbatia*, *Lima*, *Lyrioclamys*, *Isognomon*, and the patelliform gastropods. Other elements suggest a relatively near shore habitat having a sandy to gravelly substrate. Taxa in this group include *Amphidonte*, *Yaadia*, *Crassatella*, and *Glycymeris*. The presence of the delicate ramus sponges, which grew on hard objects on the substrate, suggests a sublittoral environment having moderate wave or current energy. It is possible that *Amphidonte* "oyster reefs" were developed on a relatively fine grained substrate and thereby facilitated habitation of the many component taxa that required hard substrates for attachment. Alternatively, the assemblage may reflect a broad source area of mixed rocky and sandy coastal habitats having water depths below the breaker line but probably near or above wave base. Either of the above hypotheses implies extensive offshore transport by density currents to the probable continental rise setting characteristic of turbidite deposition.

The absence of many of the near-shore taxa noted above, plus the common to abundant occurrence of *Baculites* and other rare ammonites, *Acila*, *Indogrammatodon*?, and *Inoceramus* in the massive sandstone and argillite facies overlying the oyster beds (table 1), suggests a more offshore source environment for those facies than for the oyster-rich zone. Saul and Alderson (1981) have noted that the above assemblage is characteristic of fine-grained sediments throughout California and is thus probably indicative of low-energy, relatively offshore environments. These taxa, with the exception of *Acila*, also form the core of Russell and others' (1986) assemblage characteristic of Upper Cretaceous outer shelf to slope deposits in California.

Unfortunately, the full paleoecologic and paleobiogeographic implications of the taxa present in the oyster-rich beds at Loma Prieta are difficult to ascertain because of their transported nature and their scattered distribution and rare occurrences elsewhere (table 2 lists the west coast distributions of some taxa). Many of the species present have ranges from southern California, through the Central Valley, and extending to the Vancouver Island area of British Columbia; species in the latter area may have experienced some northward tectonic transport since the late Campanian (for example, McLaughlin and others, 1988b). Exceptions are *Spondylus subnodosus*, which has

been reported only in southern California, and *Amphidonte parasitica*, which has been noted only from northern California to British Columbia.

On the whole, the taxa present in the Upper Cretaceous rocks of the Sierra Azul imply temperate to warm-temperate oceanic conditions. Species indicative of a Tethyan influence, such as the rudists that are found in rocks of this age west of the San Andreas fault, are yet to be found at Loma Prieta. Given the strong near-shore aspect of the oyster-rich assemblage, rudist fragments would be a likely component if they were living commonly at the paleolatitude of the source area. Their absence suggests the aforementioned extensive northward transport of the rocks west of the San Andreas fault relative to Loma Prieta but does not negate considerable northward displacement of Loma Prieta since the Late Cretaceous. Indeed, extensive tectonic displacement of Loma Prieta is strongly suggested by the very near shore oyster-rich assemblage found there but not known from turbidite facies of the Diablo Range. Although the latter should have been more proximal to near-shore source areas, their assemblages appear to be more offshore than those present in the oyster-rich interval near Loma Prieta.

In conclusion, the overriding influence on the composition of the oyster-rich assemblage at Loma Prieta appears to be its near-shore origin. The rarity of near-shore deposits of late Campanian to early Maastrichtian age in California may account for the fact that this assemblage is not widely developed in the State. The marked similarity of the Loma Prieta assemblage to the assemblage found in near-shore deposits near Folsom, Calif., suggests that this assemblage may have been present in similar habitats throughout California but was rarely preserved in the rock record. Additional documentation of complete fossil assemblages from the entire Pacific Northwest will allow a more complete analysis of the paleobiogeographic and paleoecologic information contained in the Upper Cretaceous rocks of the Sierra Azul and elsewhere.

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LOCALITY INFORMATION FOR FOSSIL LOCATIONS
MENTIONED IN TEXT AND TABLE 1

- USGS Mesozoic locality: M5368
Field identifier: 69-JLP-1
Collector: D.L. Jones
Loma Prieta Road
Latitude: 37°5.95' N.
Longitude: 121°51.44' W.
Elevation: 2,950 ft (899 m)
Township: 10 S.
Range: 1 E.
Section: 4, NE $\frac{1}{4}$ NE $\frac{1}{4}$
Santa Cruz County, California, Loma Prieta 7 $\frac{1}{2}$ -min quadrangle
- USGS Mesozoic locality: M5890
Field identifier: 71-LP-597
Collector: T. Simoni
Mt. Madonna Road north of Maymens Flat
Latitude: 37°5.15' N.
Longitude: 121°49.27' W.
Elevation: 2,940 ft (896 m)
Township: 10 S.
Range: 1 E.
Section: 2, SW $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$
Santa Clara County, California, Loma Prieta 7 $\frac{1}{2}$ -min quadrangle
- USGS Mesozoic locality: M6781
Field identifier: 77-CB-1804
Collector: M.C. Blake
Uvas Creek at Swanson Canyon
Latitude: 37°05.20' N.
Longitude: 121°47.50' W.
Elevation: 1,000 ft (305 m)
Township: 10 S.
Range: 2 E.
Section: 6, NE $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$
Santa Clara County, California, Loma Prieta 7 $\frac{1}{2}$ -min quadrangle
- USGS Mesozoic locality: M8524
Field identifier: 88-E-1
Collector: W.P. Elder
Northern side of Loma Prieta Road
Latitude: 37°05.95' N.
Longitude: 121°51.45' W.
Elevation: 2,950 ft (899 m)
Santa Cruz County, California, Loma Prieta 7 $\frac{1}{2}$ -min quadrangle
- USGS Mesozoic locality: M8525
Field identifier: 88-E-2
Collector: W.P. Elder
Northern side of Loma Prieta Road
Latitude: 37°05.91' N.
Longitude: 121°51.20' W.
Elevation: 2,950 ft (899 m)
Santa Clara County, California, Loma Prieta 7 $\frac{1}{2}$ -min quadrangle
- USGS Mesozoic locality: M8529
Field identifier: 88-E-5
Collector: W.P. Elder
Steep bank east of Loma Prieta
Latitude: 37°06.68' N.
Longitude: 121°50.04' W.
Elevation: 3,200 ft (976 m)
Township: 9 S.
Range: 1 E.
Section: 35, NW $\frac{1}{4}$
Santa Clara County, California, Loma Prieta 7 $\frac{1}{2}$ -min quadrangle
- USGS Mesozoic locality: M8535
Field identifier: 88-E-6
Collector: W.P. Elder
Concretions in talus on northeastern side of road
Latitude: 37°06.58' N.
Longitude: 121°50.04' W.
Elevation: 2,940 ft (896 m)
Township: 9 S.
Range: 1E.
Section: 35, NW $\frac{1}{4}$
Santa Clara County, California, Loma Prieta 7 $\frac{1}{2}$ -min quadrangle
- USGS Mesozoic locality: M8539
Field identifier: 88-MSJ-220
Collector: R.J. McLaughlin
Concretion on southwestern side of road on ridgetop
Latitude: 37°06.66' N.
Longitude: 121°49.99' W.
Elevation: 3,240 ft (988 m)
Township: 9 S.
Range: 1 E.
Section: 35, SE $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$
Santa Clara County, California, Loma Prieta 7 $\frac{1}{2}$ -min quadrangle
- USGS Mesozoic locality: M8540
Field identifier: 88-MSJ-890
Collector: R.J. McLaughlin
Sandstone on southwestern side of Mt. Madonna Road
Latitude: 37°05.15' N.
Longitude: 121°49.27' W.
Elevation: 2,940 ft (896 m)
Township: 10 S.
Range: 1 E.
Section: 2, SW $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$
Santa Clara County, California, Loma Prieta 7 $\frac{1}{2}$ -min quadrangle
- USGS Mesozoic locality: M8554
Field identifier: None
Collector: W.P. Elder
On intermittent creek crossing Loma Chiquita Road
Latitude: 37°06.65' N.
Longitude: 121°50.10' W.
Elevation: 3,000 ft (915 m)
Township: 9 S.
Range: 1 E.
Section: 35, SE $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$
Santa Clara County, California, Loma Prieta 7 $\frac{1}{2}$ -min quadrangle
- USGS Mesozoic locality: M8575
Field identifier: 89-E-28
Collector: W.P. Elder
Southern bank of Lake Elsmen east of dam
Latitude: 37°07.79' N.
Longitude: 121°55.73' W.
Elevation: 1,200 ft (366 m)
Township: 9 S.
Range: 1 W.
Section: 24, SW $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$
Santa Clara County, California, Los Gatos 7 $\frac{1}{2}$ -min quadrangle
- USGS Mesozoic locality: M8576
Field identifier: 89-E-29
Collector: W.P. Elder
Southern side of Williams Reservoir
Latitude: 37°07.17' N.
Longitude: 121°54.22' W.
Elevation: 1,400 ft (427 m)
Santa Clara County, California, Laurel 7 $\frac{1}{2}$ -min quadrangle

PLATES 1–5

Contact photographs of the plates in this report are available, at cost, from the
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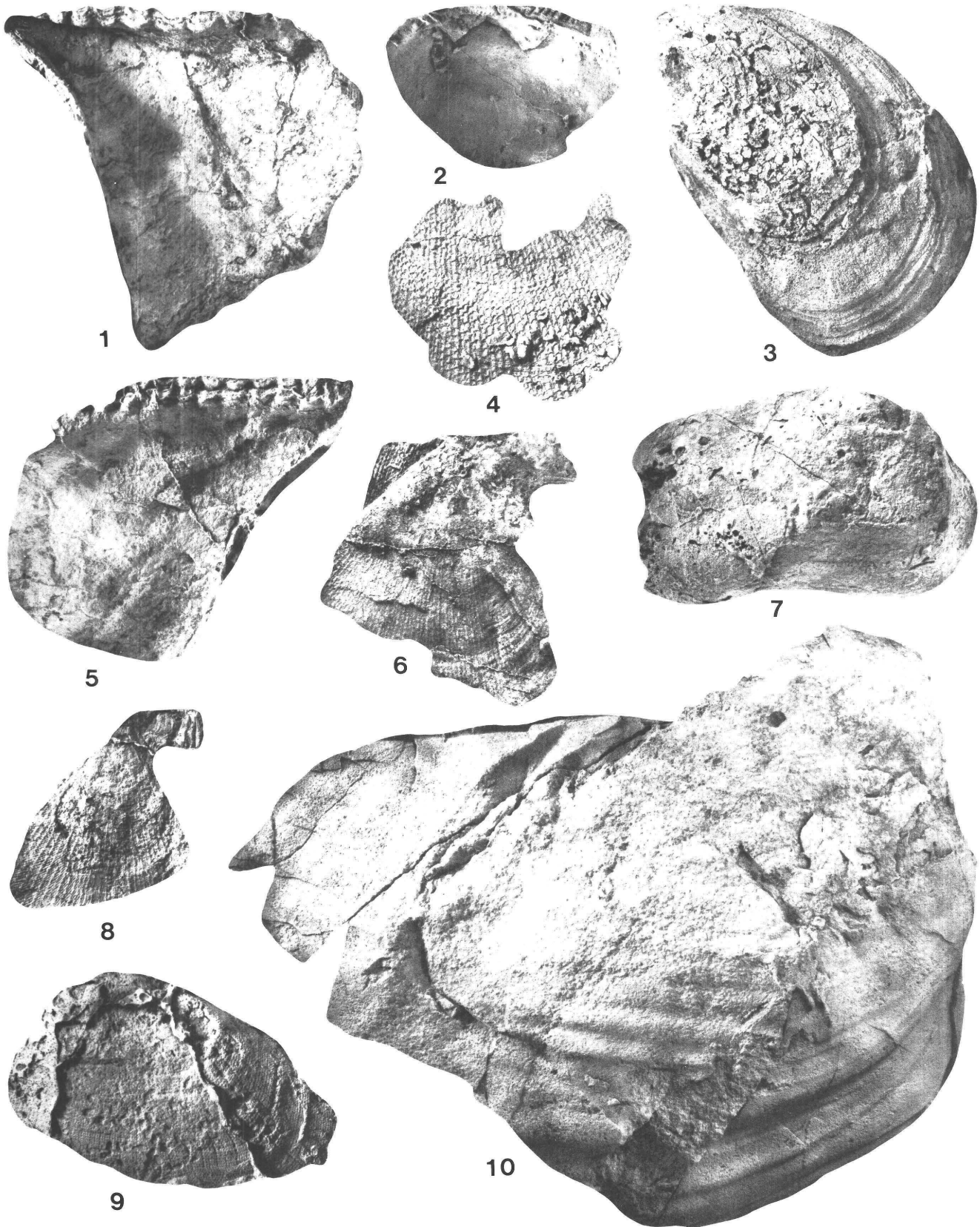
PLATE 1

Late Cretaceous Mollusks

[All figures natural size and from U.S. Geological Survey (USGS) Mesozoic locality M8525 except as indicated. Localities shown in text fig. 1. All specimens are repositied in the U.S. Museum of Natural History (USNM), Washington, D.C.]

Figures 1, 5. *Isognomon* sp.

1. Latex cast of hinge and internal mold of right valve. USNM 444989.
5. Latex cast of hinge and internal mold of left valve. USNM 444990.
- 2, 7, 9. *Barbatia* sp.
 2. Latex cast of hinge and internal mold of right valve. USNM 444991.
 7. Internal mold of right valve. USNM 444992.
 9. Latex cast of external mold of left valve. USNM 444993 ($\times 1.25$).
3. *Mytilus* sp. cf. *M. quadratus* Gabb, 1869. Internal mold of left valve from USGS Mesozoic locality M8576 showing posterior adductor muscle scar on upper right. External mold shows ornament consisting of lamellar growth lines similar to those visible on internal mold. USNM 444994.
- 4, 6, 8. *Lyrioclamys traskii* (Gabb), 1864
 4. Latex cast of external mold of a specimen having numerous squamose radial ribs; valve unknown. USNM 444995.
 6. Latex cast of external mold of right valve having complete posterior and partial anterior auricle. USNM 444996.
 8. Latex cast of right valve having complete anterior auricle. USNM 444997 ($\times 1.5$).
10. *Inoceramus (Endocostea?)* sp. aff. *I. (E.?) cymbaeformis* Pergament, 1974. Internal mold of right valve. USNM 444998 ($\times 0.75$).



LATE CRETACEOUS MOLLUSKS

PLATE 2

Late Cretaceous Mollusks

[All figures natural size and from U.S. Geological Survey (USGS) Mesozoic locality M8525 except as indicated. Localities shown in text fig. 1. All specimens are repositied in the U.S. Museum of Natural History (USNM), Washington, D.C.]

Figures 1–4. *Spondylus subnodosus* (Packard), 1922

1. Latex cast of hinge and internal mold of left valve. USNM 444999.
2. Latex cast of composite internal-external mold of left valve. USNM 445000.
3. Latex cast of partial external mold of left valve(?). Primary ribs showing small nodes and secondary radiating ribs are evident. USNM 445001 ($\times 1.5$).
4. Latex cast of external mold of left valve showing primary and secondary ribs and small nodes. USNM 445002 ($\times 1.5$).

5, 8–10. *Lyrio-chlamys traskii* (Gabb), 1864

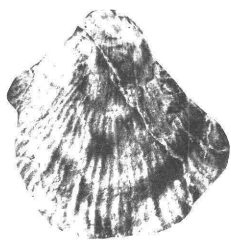
5. Latex cast of external mold of partial left valve of juvenile from USGS Mesozoic locality M8576. USNM 445003 ($\times 2$).
8. Latex cast of external mold of unknown partial valve of juvenile. USNM 445004 ($\times 2$).
9. Latex cast of external mold of unknown partial valve of adult showing squamose radial ribs and divaricate ribs in interspaces. USNM 445005 ($\times 2$).
10. Latex cast of external mold of unknown partial valve showing squamose radial ribs and divaricate ribs in interspaces and lamellar growth lines. USNM 445006 ($\times 1.5$).

6, 7, 11. *Inoceramus* (*Endocostea*?) sp. aff. *I. (E.?) cymbaeformis* Pergament, 1974.

6. Dorsal view of latex cast of internal mold of right valve. USNM 445007 ($\times 0.75$).
7. Posterior view of latex cast of internal mold of right valve showing flexure of posterior margin. USNM 445007 ($\times 0.75$).
11. Latex cast of internal mold of right valve. USNM 445007 ($\times 0.75$).



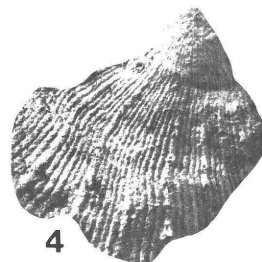
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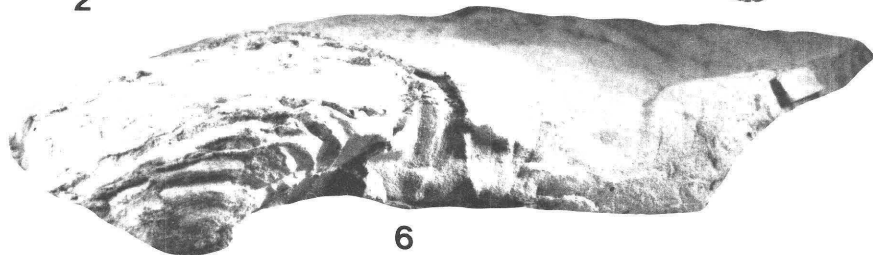
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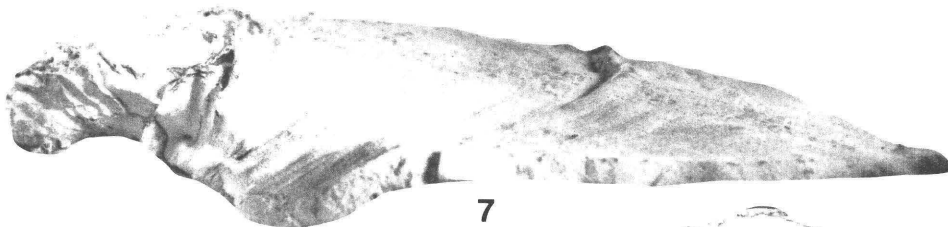
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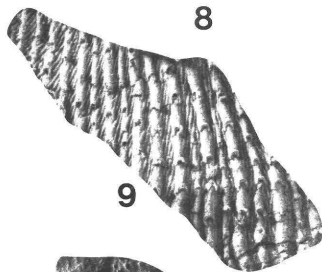
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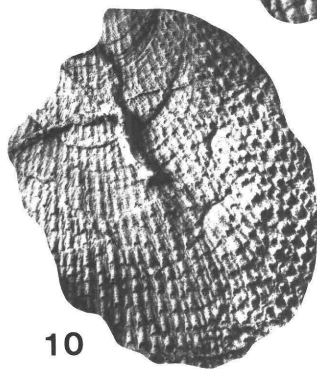
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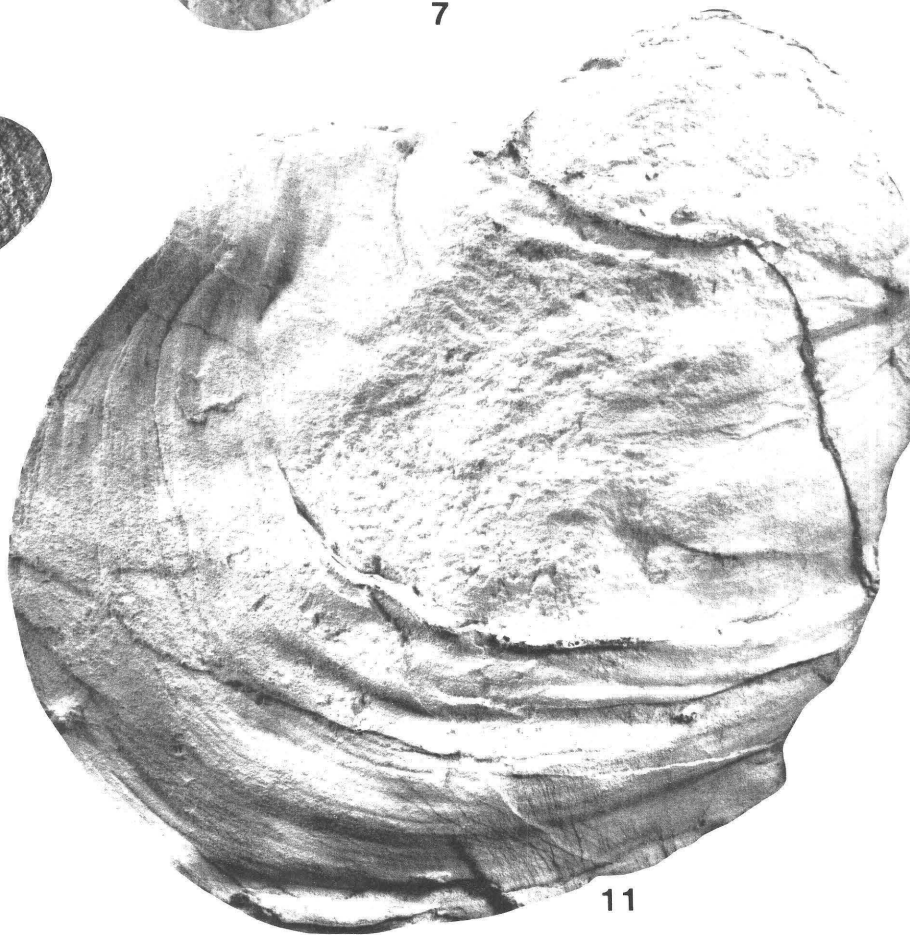
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11

LATE CRETACEOUS MOLLUSKS

PLATE 3

Late Cretaceous Mollusks

[All figures natural size and from U.S. Geological Survey (USGS) Mesozoic locality M8525 except as indicated. Localities shown in text fig. 1. All specimens are repositied in the U.S. Museum of Natural History (USNM), Washington, D.C.]

Figures 1–4, 7, 11, 12. *Acesta* n.sp. A

1. Latex cast of hinge and internal mold of left valve showing oblique, posteriorly located resilifer. USNM 445008.
2. Latex cast of external mold of left valve. USNM 445008.
3. Latex cast of external mold of left valve. USNM 445009.
4. Latex cast of external mold of right valve showing squamose ribbing on adult. USNM 445010.
7. Latex cast of external mold of left valve showing squamose ribbing on adult and deformation of posterior side, probably reflecting contact with a foreign object during growth. USNM 445011.
11. Latex cast of external mold of left valve from USGS Mesozoic locality M8576 showing elongate anterior auricle and anterior sulcus. USNM 445012.
12. Latex cast of external mold of posterior portion of left valve of a large specimen. Note flange around posterior margin. USNM 445013.

5, 9. *Lima* n.sp. A

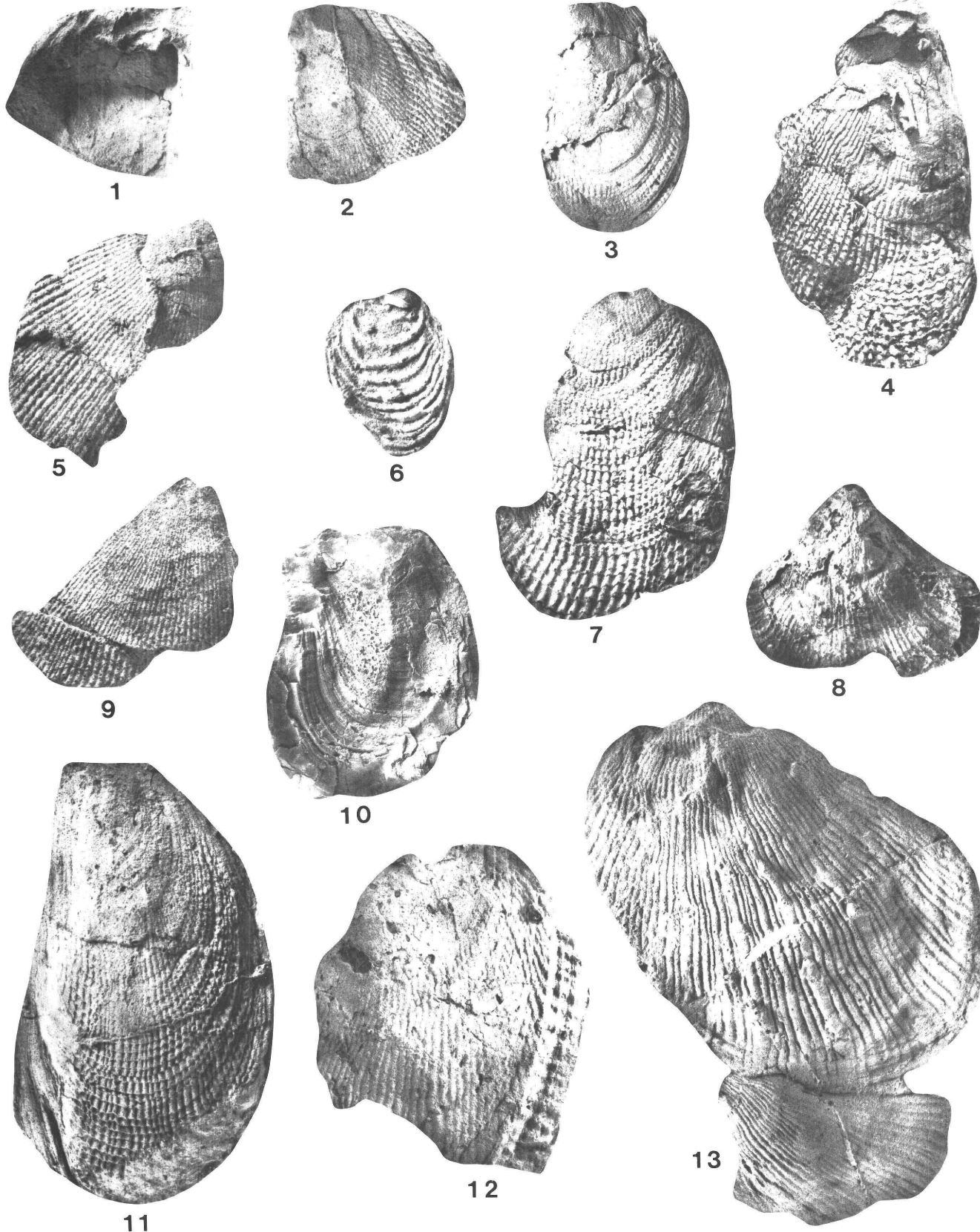
5. Latex cast of external mold of right valve from USGS Mesozoic locality M8576. USNM 445014 (×2).
9. Latex cast of external mold of right valve from USGS Mesozoic locality M8576. USNM 445015 (×2).

6, 10. *Amphidonte* (*Amphidonte*) *parasitica* (Gabb), 1864

6. Latex cast of external mold of juvenile right valve. USNM 445016 (×2).
10. Exterior of right valve. Note faint radial striae on posteroventral surface. USNM 445017.

8, 13. *Spondylus subnodosus* (Packard), 1922

8. Latex cast of external mold of left valve. USNM 445018.
13. Latex cast of external mold of two left valves from USGS Mesozoic locality M8576. USNM 445019.



LATE CRETACEOUS MOLLUSKS

PLATE 4

Late Cretaceous Invertebrates

[All figures natural size and from U.S. Geological Survey (USGS) Mesozoic locality M8525 except as indicated. Localities shown in text fig. 1. All specimens are repositied in the U.S. Museum of Natural History (USNM), Washington, D.C.]

Figures 1–3. Cidaroid echinoid spines

1. Latex cast of external mold of basal part of spine. USNM 445020 ($\times 2$).
2. Latex cast of external mold of midportion of spine. USNM 445021 ($\times 1.5$).
3. Latex cast of external mold of spine near apex. USNM 445022 ($\times 2$).

4, 5. Patellacean gastropod

4. Top view of latex cast of external mold from USGS Mesozoic locality M8576. USNM 445023 ($\times 2$).
5. Side view of latex cast of external mold from USGS Mesozoic locality M8576. USNM 445023 ($\times 2$).

6. *Callianassa?* sp. Latex cast of external mold of manus. USNM 445024 ($\times 2$).

7, 8. *Hipponix dichotomus* (Gabb), 1864

7. Top view of internal mold from USGS Mesozoic locality M8576. Fragmented external mold shows ornament like that developed on figured internal mold. USNM 445025 ($\times 2$).
8. Side view of internal mold from USGS Mesozoic locality M8576. Fragmented external mold shows ornament like that developed on figured internal mold. USNM 445025 ($\times 2$).

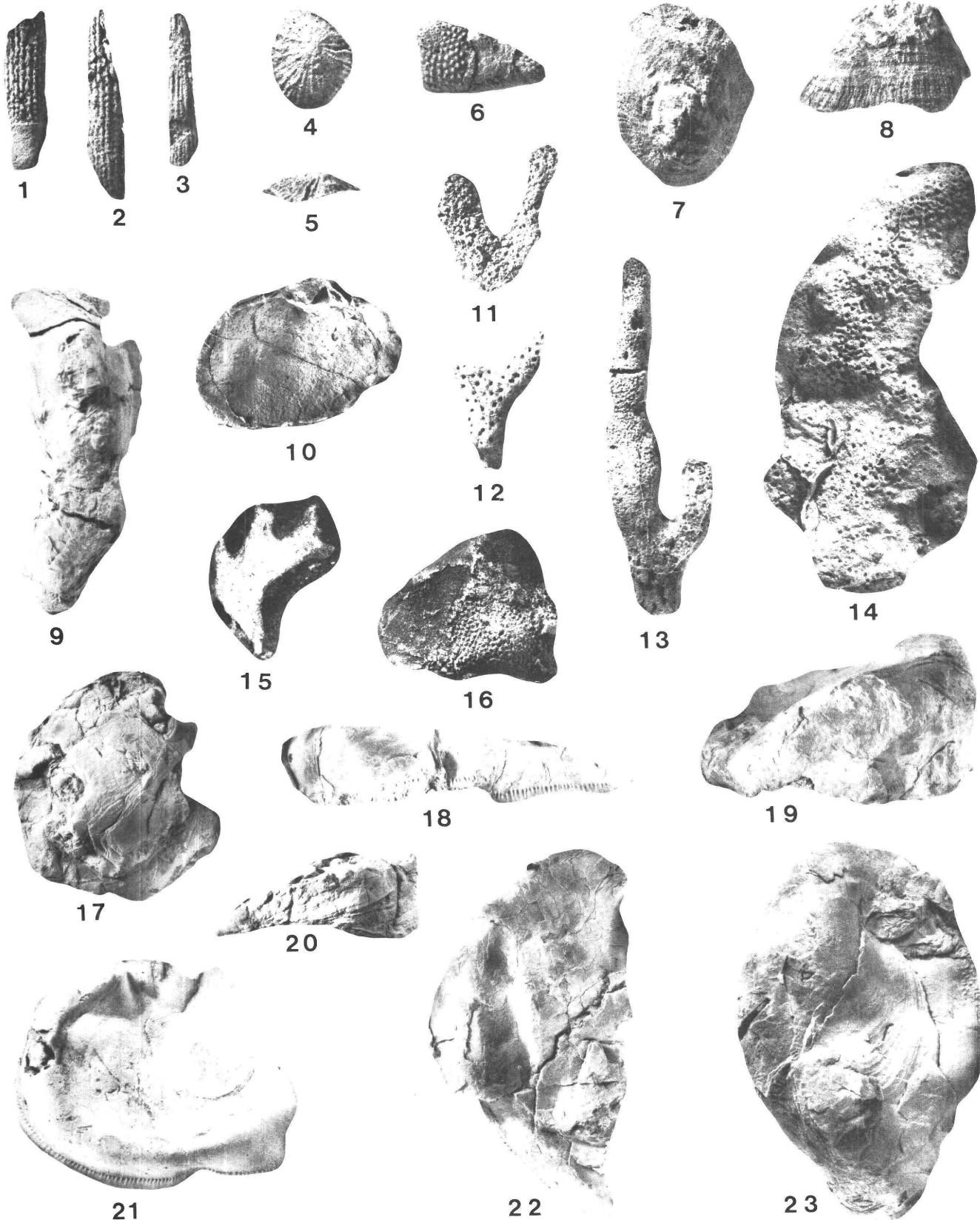
9, 17–23. *Amphidonte (Amphidonte) parasitica* (Gabb), 1864

9. Top view of left valve of elongate morphotype. USNM 445026.
17. Top view of left valve of ovate morphotype. USNM 445027.
18. Anteroventral view of left valve of typical morphotype. USNM 445028.
19. Anterior view of left valve of typical morphotype. USNM 445029.
20. Anterior view of left valve of ovate morphotype having a carinate umbilical ridge. USNM 445027.
21. Internal mold of left valve of ovate morphotype showing adductor muscle scar and chomata along anterior and ventral margins. USNM 445030.
22. Bottom view of left valve of typical morphotype. USNM 445028.
23. Bottom view of left valve of typical morphotype. USNM 445029.

10. *Crassatella* sp. cf. *C. conradiana* (Gabb), 1864. Latex cast of hinge and internal mold. USNM 445031.

11–15. Calcispongea

11. Latex cast of external mold of ramous morphotype from USGS Mesozoic locality M8576. USNM 445032 ($\times 2$).
12. Latex cast of external mold of ramous morphotype. USNM 445033 ($\times 2$).
13. Latex cast of external mold of ramous morphotype from USGS Mesozoic locality M8576. Note acrothoracian barnacle borings on upper third of specimen. USNM 445034.
14. Latex cast of external mold of encrusting morphotype. USNM 445035 ($\times 1.5$).
15. Replaced branch of flabellate morphotype. USNM 445036.
16. External mold of encrusting Cheilostome bryozoan. USNM 445037 ($\times 2$).



LATE CRETACEOUS INVERTEBRATES

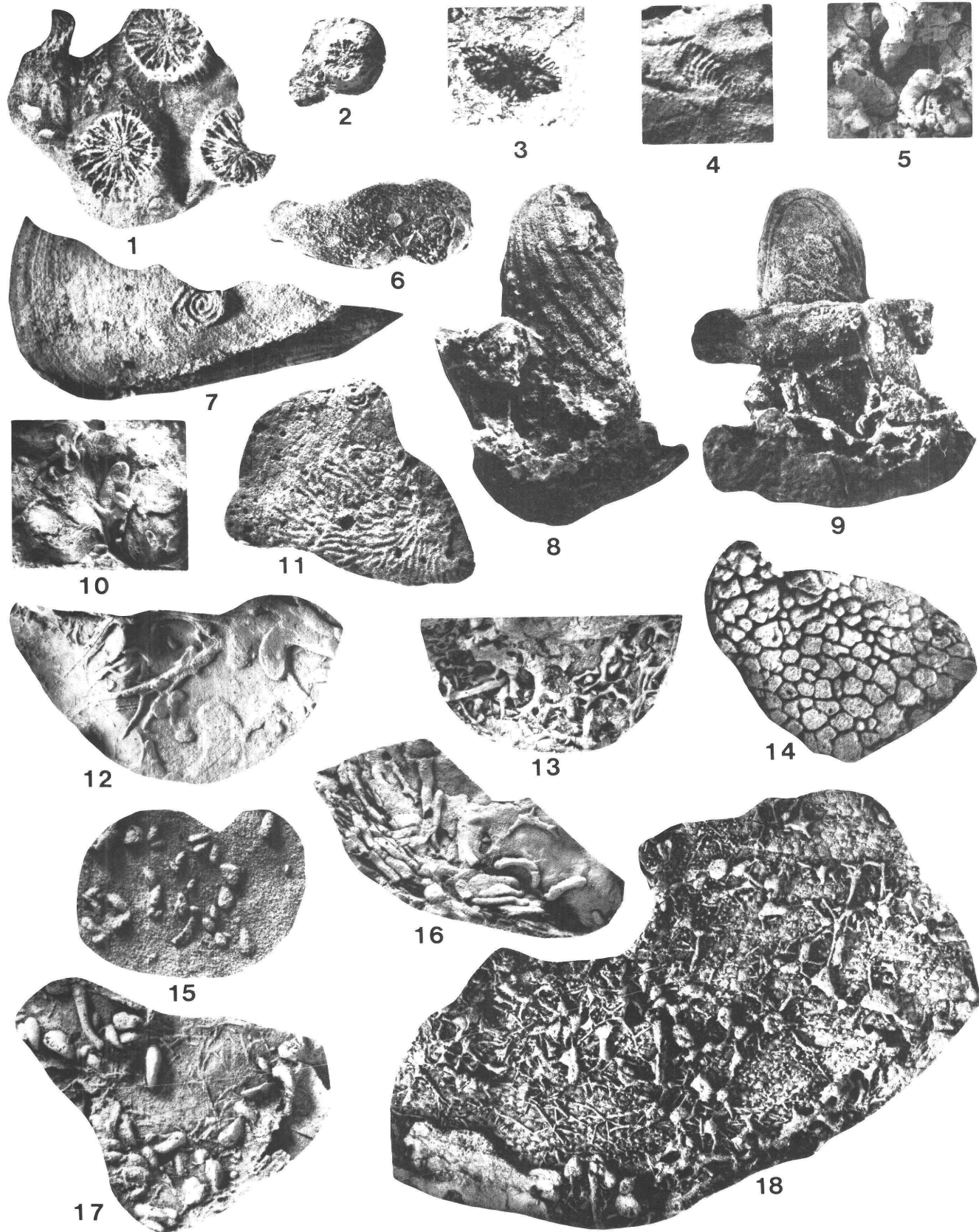
PLATE 5

Late Cretaceous Coral and Ichnofossils

[All figures natural size and from U.S. Geological Survey (USGS) Mesozoic locality M8525 except as indicated. Localities shown in text fig. 1. All specimens are repositied in the U.S. Museum of Natural History (USNM), Washington, D.C.]

Figures 1, 2. Astrangiidae? sp.

1. Latex cast of external mold. USNM 445038 ($\times 2$).
2. Latex cast of external mold. USNM 445039 ($\times 2$).
3. Sandstone casts of borings, of possible algal origin, in void produced by dissolution of a shell fragment. USNM 445040 ($\times 3$).
4. Rasplike trace of possible isopod or gastropod origin on internal mold of *Spondylus* shell. USNM 445041 ($\times 3$).
5. Sandstone cast of large arcuate borings having oblique constrictions. Bored substrate is unknown (possibly wood or a *Spondylus* shell fragment). Borings may have been produced by bivalves. USNM 445042.
6. Sandstone casts of borings on internal mold of *Amphidonte*. Borings probably produced by early stage of clionid sponge boring activity. USNM 445043 ($\times 2$).
7. *Spirorbis*-like serpulid worm tube encrusting a mytilid shell fragment from USGS Mesozoic locality M8576. USNM 445044 ($\times 1.5$).
- 8, 9. Ichnogenus *Gastrochaenolites*?
 8. Sandstone mold of sac-shaped boring having oblique constrictions. Bored substrate unknown (see pl. 5, fig. 9 caption). USNM 445045 ($\times 2$).
 9. Sandstone mold of sac-shaped boring having oblique constrictions. USNM 445045 ($\times 2$). Bored substrate unknown, but the presence of *Entobia* borings (USNM 445058) at the lower right indicates a carbonate substrate. Tubular boring in foreground also has oblique constrictions and resembles borings illustrated in plate 5, figure 5.
- 10, 12, 16. Ichnogenus *Maeandropolydora*?
 10. Sandstone cast of meandering borings on mold of *Amphidonte* shell. USNM 445046.
 12. Sandstone cast of arcuate to meandering borings on mold of *Amphidonte* shell. USNM 445047.
 16. Sandstone cast of arcuate borings on mold of *Amphidonte* shell. USNM 445054.
11. Latex cast of dendritic pattern of unknown origin (possibly bryozoan) present on external mold of unknown shell fragment from USGS Mesozoic locality M8576. USNM 445048. Also note *Spirobis*-like worm tube at top of fragment. USNM 445049.
- 13, 14, 18. Ichnogenus *Entobia*
 13. Sandstone cast of borings in dissolution void of unknown shell. *Entobia* reflecting middle stages of clionid sponge boring activity. USNM 445050. Also note several acrothoracian barnacle borings (*Rogerella*) at right center. USNM 445051.
 14. Sandstone cast of borings in dissolution void of *Spondylus* shell. *Entobia* reflecting late stages of clionid sponge boring activity. USNM 445052.
 18. Sandstone cast of borings in dissolution void of *Lyriochlamys* shell. *Entobia* reflecting early to middle stages of clionid sponge boring activity. USNM 445053 ($\times 2$).
- 15, 17. Ichnogenus *Rogerella*
 15. Sandstone cast of acrothoracian barnacle borings on external mold of unknown shell from USGS Mesozoic locality M8576. USNM 445055 ($\times 2$).
 17. Sandstone cast of acrothoracian barnacle borings on external mold of unknown shell. USNM 445056. Also note small branching tubular burrows of possible clionid origin at upper right. USNM 445057 ($\times 2$).



LATE CRETACEOUS CORAL AND ICHNOFOSSILS

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