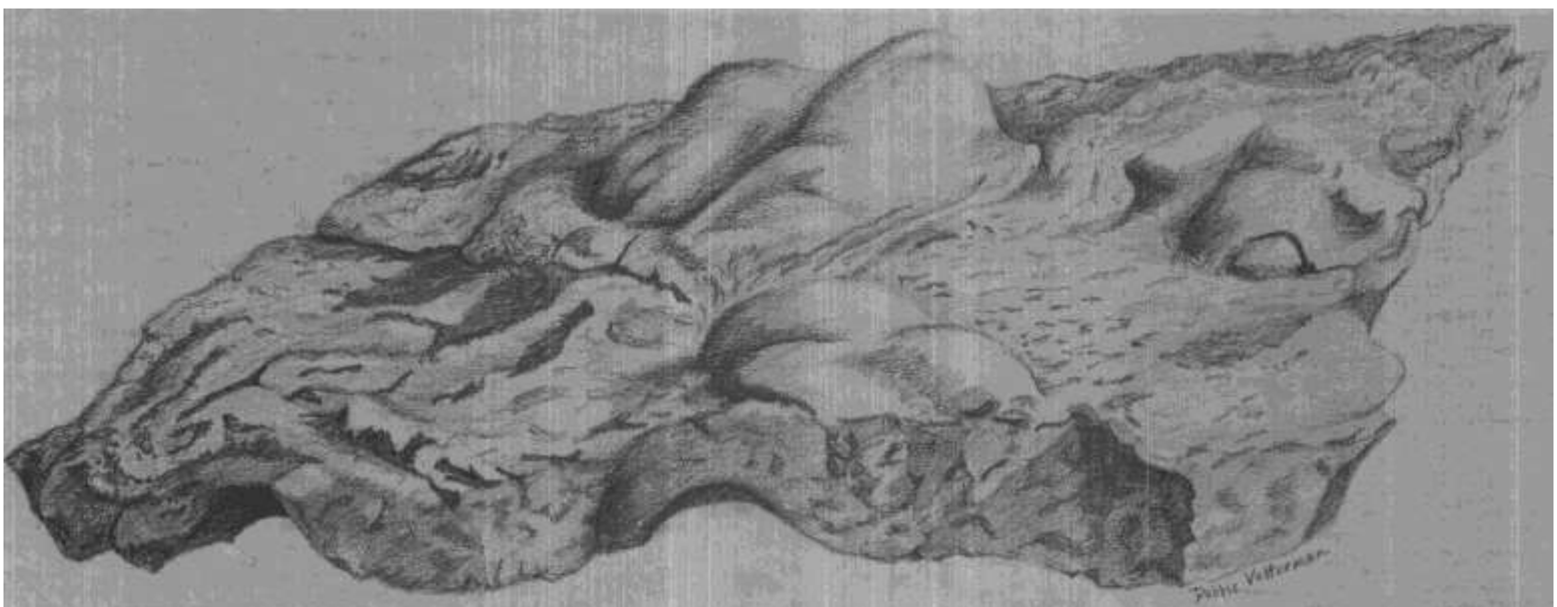
Circular 180 1981

Contributions to mid-Cretaceous paleontology and stratigraphy of New Mexico



Calcarenite bed (28 × 28 × 3 cm) preserving Cretaceous discontinuity surface, southwest New Mexico

New Mexico Bureau of Mines & Mineral Resources

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

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Contributions to mid-Cretaceous paleontology and stratigraphy of New Mexico

compiled by Stephen C. Hook

SOCORRO 1981

First Printing, 1981

Published by Authority of State of New Mexico, NMSA 1953 Sec. 63-1-4
Printed by University of New Mexico Printing Plant, April 1981

Available from New Mexico Bureau of Mines & Mineral Resources, Socorro, NM 87801 Price $4.00

Preface

This circular is the first in a planned series of short papers on the paleontology and stratigraphy of the mid-Cretaceous (Albian, Cenomanian, and Turonian) of New Mexico. Mid-Cretaceous rocks are economically important because they are associated with or are accepted as the primary source rocks for much of the oil and gas production from the Cretaceous in the Rocky Mountain states.

Rocks of mid-Cretaceous age present many problems concerning age relationships and correlation because of the presence in the Western Interior seaway of both warm-water (Tethyan) and cool-water (North Temperate) provinces and because of complex orogenic events and shoreline movements.

Problems in stratigraphic nomenclature and correlation of mid-Cretaceous rocks are common to many areas in New Mexico, including the coal-bearing strata exposed near the New Mexico-Arizona border in west-central New Mexico; the isolated exposures of Upper Cretaceous rocks in the Deming, Silver City, Las Cruces, Truth or Consequences, and El Paso areas; and the Gallup Sandstone of west-central and northwest New Mexico. The answers to some of these problems will be found in stratigraphic studies of rocks exposed in Texas, Arizona, Mexico, and Colorado. A detailed faunal zonation is of primary importance for correlation within and between basinal areas.

These papers, and others to follow, will contribute to a synthesis of the mid-Cretaceous paleontology and stratigraphy in the southern part of the Western Interior. In addition they will be useful to the Mid-Cretaceous Events (MCE) projects of the International Geological Correlation Programme (IGCP) of the International Union of Geological Sciences (IUGS/UNESCO). The goals of MCE are to establish a workable global biostratigraphic zonation for the middle part of the Cretaceous so that geological, geophysical, biological and climatic events can be studied and correlated in time and space.

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February 24, 1981

A contribution to Project
Mid-Cretaceous Events

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LATE GREENHORN (MID-CRETACEOUS) DISCONTINUITY SURFACES, SOUTHWEST NEW MEXICO

by Stephen C. Hook, *Paleontologist, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico,* and
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Abstract

Oyster-encrusted and partly phosphatized internal molds of ammonites from a condensed sequence in the mid-Cretaceous Colorado Formation, southwest New Mexico, reveal discontinuity surfaces within rocks of late Greenhorn age. Three discontinuity surfaces in the upper 1.0 m (3 ft 2 inches) of the Bridge Creek Limestone Member of the Colorado Formation indicate a complex and repetitive history of deposition, erosion, and sedimentary omission during early Turonian time. All three discontinuity surfaces show hardground development; the upper two surfaces have been partially phosphatized. Evidence from elsewhere in New Mexico and from Colorado and Texas indicates that discontinuity surfaces may be common, though previously unrecognized, in rocks of late Greenhorn age. The Bridge Creek Limestone Member is formally extended into southern New Mexico for use in the Colorado Formation of the Cooke's Range and in the Mancos Shale in the Oscura, Carthage, Jornado del Muerto, and Truth or Consequences areas. *Neocardioceras juddii* (Barrois and de Guerne), an internationally important lower Turonian guide fossil, is reported from North America for the first time.

Introduction

During late Cenomanian and early Turonian (mid-Cretaceous) time, a series of thin limestone beds interbedded with calcareous shale was deposited over much of the Western Interior Seaway of North America. Many of the limestone beds in this sequence—the Bridge Creek Limestone Member of the Greenhorn Formation and its equivalents—are apparently time parallel and are traceable over immense distances. Hattin (1979) has traced or correlated the most widespread of these marker beds over areas of no less than 388,000 sq km (150,000 sq mi), from south-central New Mexico to the Black Hills of South Dakota. We regard the base of this limestone sequence throughout west-central New Mexico as an isochronous surface (Hook and others, 1980). In the Cooke's Range of southwest New Mexico, limestone beds of Bridge Creek age were deposited only during the time represented by the late Cenomanian ammonite zone of *Sciponoceras gracile* (Shumard) and the early Turonian ammonite zone of *Neocardioceras juddii* (Barrois and de Guerne) (Fig. 1). During this time the Greenhorn sea was at or near its transgressional maximum in New Mexico (Fig. 2) and throughout the Western Interior (Reeside, 1957, fig. 9).

Deposition of the Bridge Creek Limestone Member of the Greenhorn Formation in Colorado (Cobban and Scott, 1972) and in Kansas (Hattin, 1975, 1979) was thought to have been slow but continuous on nearly planar surfaces with condensed sequences representing deposition on local highs. Evidence for hardground development was lacking (Hattin, 1975, p. 94; 1979).

Recent work by us on rocks of Bridge Creek age in New Mexico, southeast Colorado, and west Texas has revealed evidence for widespread, submarine erosion surfaces. In this paper we discuss in detail three discontinuity surfaces in the Bridge Creek Limestone Member of the Colorado Formation in the Cooke's Range of southwest New Mexico (Fig. 2). We also briefly discuss evidence for similar discontinuity surfaces of Bridge Creek age in Colorado, Texas, and elsewhere in New Mexico.

We are following Bromley's (1975, p. 399-400) use of two terms: *discontinuity surface* is used to mean a minor break in the sedimentary column, chiefly intraformational, that has not involved large-scale erosion in a vertical sense; and *omission surface* is used to mean a discontinuity surface that marks temporary halts in deposition but involves little or no erosion. However, we are using Bathurst's (1971, p. 395) definition of *hard-ground* as a discontinuity surface that has been bored, corroded, or eroded, and/or encrusted by sessile organisms.

Bathurst also noted that the primary signs of hardground development are often accompanied by other characteristic—although not diagnostic—features including crusts of, or impregnation by, glauconite, calcium phosphate, and iron and magnesium salts. All of these qualities indicate that the hardground was lithified prior to the deposition of the overlying sediment. Bromley's (1975) definition of hardgrounds as synsedimentarily lithified sea floors is too restrictive.

ACKNOWLEDGMENTS—We thank Thomas Hyatt of Deming, New Mexico, who graciously allowed us access to the sections of Colorado Formation discussed in this report. Robert Burkholder of the U.S. Geological Sur-

Ammonite Zone		Stage	
Prionocyclus quadratus, Scaphites corvensis		Turonian	upper
Prionocyclus novimexicanus	*Scaphites nigricollensis*	Turonian	upper
Prionocyclus novimexicanus	*Scaphites whitfieldi*	Turonian	upper
Prionocyclus wyomingensis	*Scaphites ferronensis*	Turonian	upper
Prionocyclus wyomingensis	*Scaphites warreni*	Turonian	upper
Prionocyclus macombi	*Coilopoceras inflatum*	Turonian	upper
Prionocyclus macombi	*Coilopoceras colleti*	Turonian	upper
Prionocyclus hyatti, Scaphites carlilensis		Turonian	middle
Collignoniceras woollgari	*C. woollgari regulare*	Turonian	middle
Collignoniceras woollgari	*C. woollgari woollgari*	Turonian	middle
Mammites nodosoides		Turonian	lower
Watinoceras coloradoense, Vascoceras birchbyi		Turonian	lower
Nigericeras scotti		Turonian	lower
Neocardioceras juddii		Turonian	lower
Sciponoceras gracile, Metoicoceras gibbosum		uppermost Cenomanian	

FIGURE 1—Uppermost Cenomanian through Turonian ammonite zonation in the Western Interior of North America. The *Pseudaspidoceras* Zone of Cobban and Hook (1979, p. 6, 7) and Hook and Cobban (1979, fig. 1) is herein redesignated as the *Neocardioceras juddii* Zone.

vey, Denver, Colorado, prepared and photographed the fossils; Bradley B. House of the New Mexico Bureau of Mines and Mineral Resources, Socorro, made the outcrop photographs and prepared the line drawings. Robert M. North of the New Mexico Bureau of Mines and Mineral Resources ran and interpreted the x-ray-diffraction patterns. Chemical analyses were made at the New Mexico Bureau of Mines and Mineral Resources under the direction of Lynn Brandvold. C. M. Molenaar and M. E. MacLachlan of the U.S. Geological Survey, Denver, critically reviewed this paper.

Bridge Creek Limestone Member, Colorado Formation, in Cooke's Range

We are herein extending the Bridge Creek Limestone Member terminology into southern New Mexico for use in the Colorado Formation in the Cooke's Range and in the Mancos Shale in the Oscura, Jornada del Muerto coal field, Carthage, and Truth or Consequences areas (Fig. 2). The Bridge Creek Limestone Member is the uppermost of the three members of the Greenhorn Formation of southeast Colorado (Cobban and Scott, 1972) and northeast New Mexico (Hook and Cobban, 1980, fig. 4). In ascending order, the lower two members of the Greenhorn Formation are the Lincoln Limestone Member and the Hartland Shale Member.

Rocks that are lithologically and faunally similar to the lower part of the Bridge Creek Member of the Greenhorn Formation occur in the Mancos Shale of southern New Mexico near White Oaks (Hattin, 1979), Oscura, Carthage (Rankin, 1944, p. 11; Cobban and Hook, 1979, fig. 3a), and Truth or Consequences, and in the Jornada del Muerto coal field (Tabet, 1979, p. 13). They also occur in the Colorado Formation of the Cooke's Range (Fig. 2). A similar sequence of interbedded thin limestones and limy shales occurs in the lower part of the shale tongue of the Mancos overlying the Twowells Tongue of the Dakota Sandstone in west-central New Mexico (Hook and others, 1980) and in northwest New Mexico in the San Juan Basin (Landis and others, 1973; Molenaar, 1973). In the past this sequence of rocks has been referred to—either formally or informally—as the Greenhorn Limestone (Rankin, 1944; Lamb, 1968, 1973; McCubbin, 1969; Molenaar, 1973, 1974); however, this sequence is laterally and temporally equivalent to only the basal part of the Bridge Creek Limestone Member of the Greenhorn Formation (Hook and others, 1980). Therefore, we prefer the name Bridge Creek Limestone Member for this sequence of rocks in southern New Mexico because it more accurately conveys the stratigraphic and biostratigraphic relationships of these rocks to the Greenhorn Formation of southeast Colorado and northeast New Mexico.

The contact between the Bridge Creek Member and the underlying calcareous shale is drawn at the base of the lowest persistent bed of limestone. In southern New Mexico this limestone bed is generally nodular to concretionary, and it is up to 15 cm (6 inches) thick. The contact between the top of the Bridge Creek Member and the overlying calcareous shale is drawn at the top of the highest persistent bed of limestone, generally a 5-10-cm (2-4-inch) thick calcarenite composed of *Inoceramus* or oyster debris. Although calcareous shale is generally

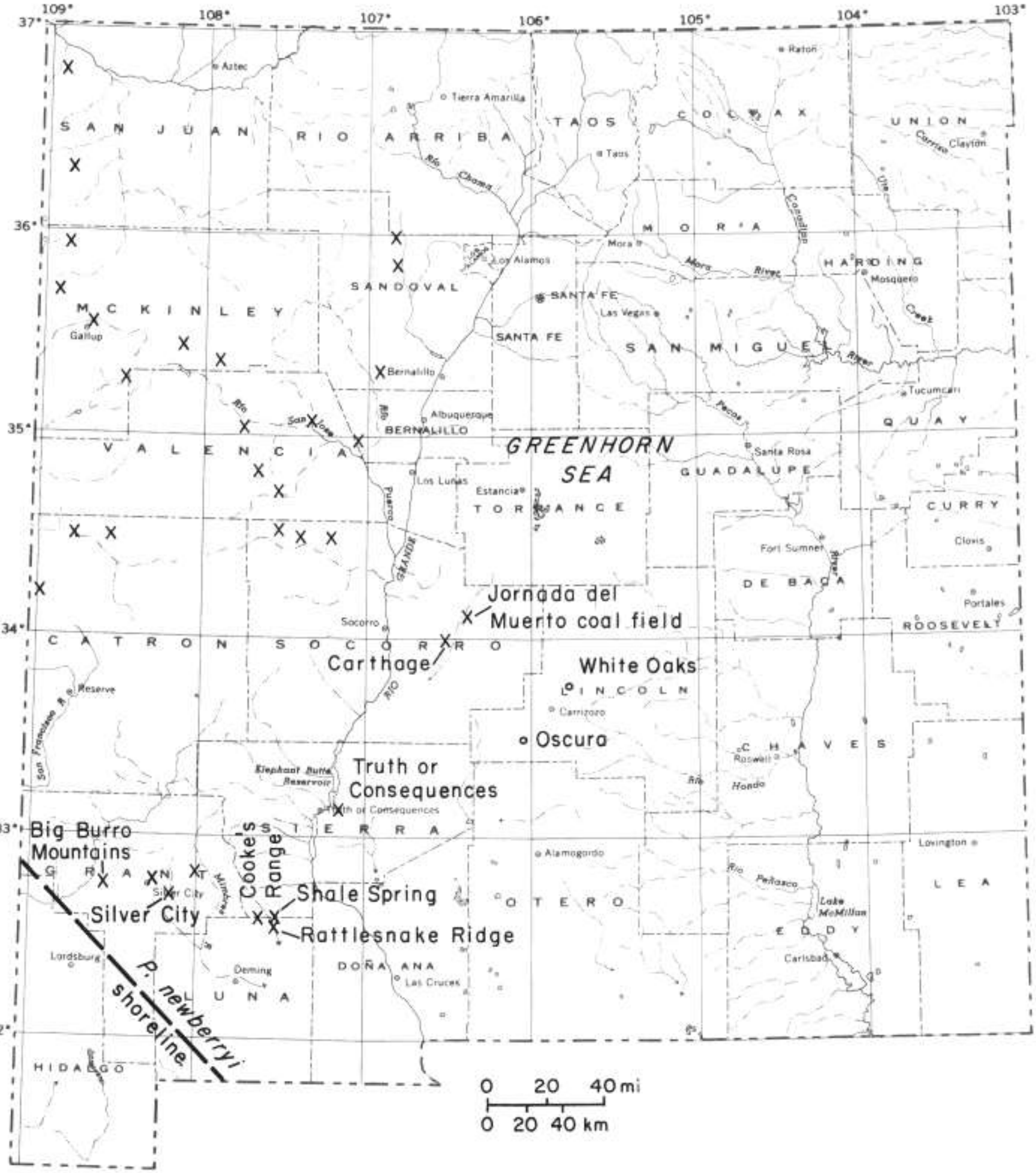

FIGURE 2—MAP OF NEW MEXICO SHOWING LOCALITIES WHERE *PYCNODONTE NEWBERRYI* (STANTON) HAS BEEN COLLECTED AND THE APPROXIMATE POSITION OF THE CRETACEOUS SHORELINE DURING THE TIME REPRESENTED BY THE COMBINED *SCIPONOCERAS GRACILE* AND *NEOCARDIOCERAS JUDDII* ZONES.

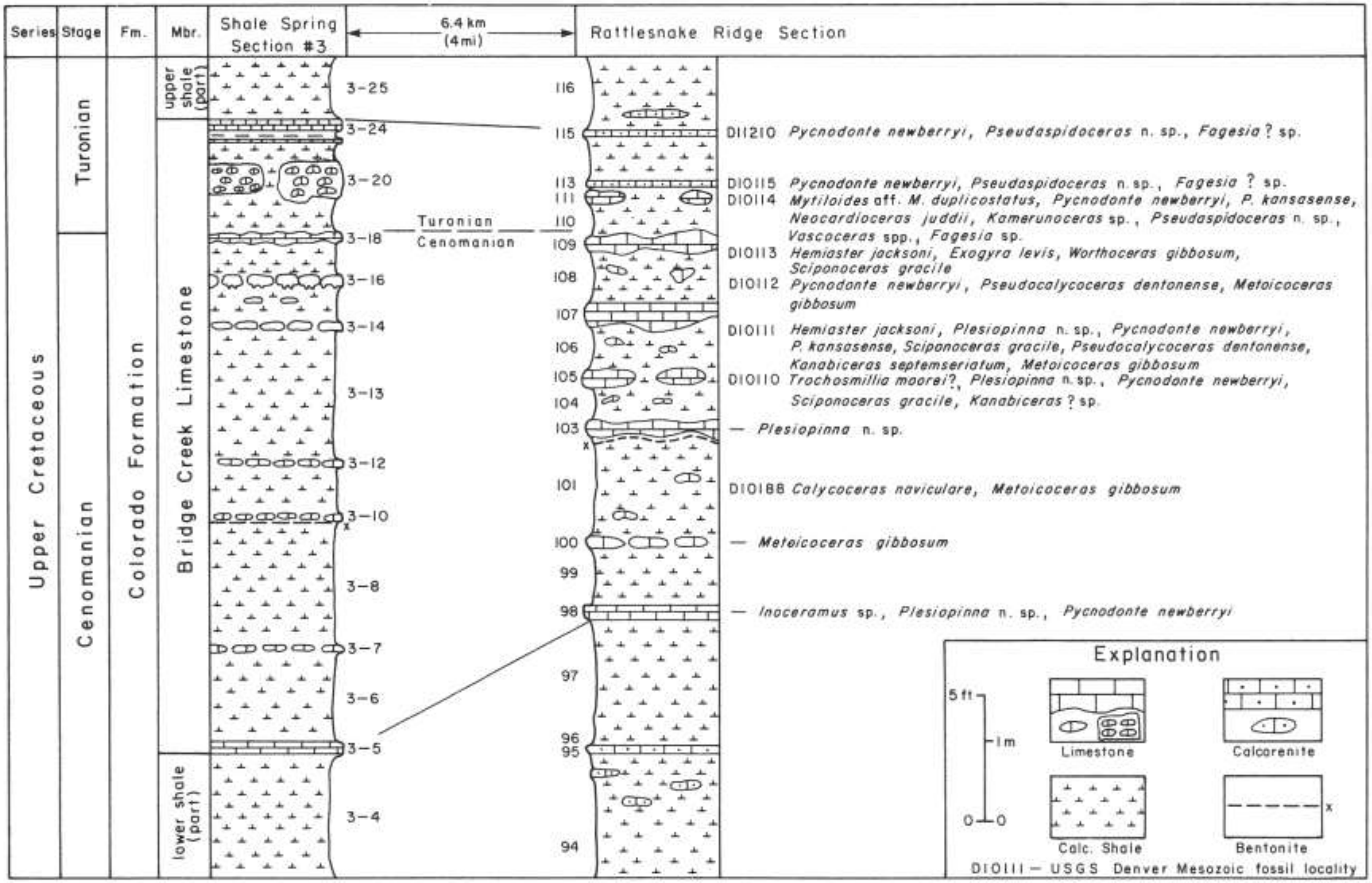

FIGURE 3—Graphic sections of the Bridge Creek Limestone Member of the Colorado Formation at two localities in the Cooke's Range, Luna County, New Mexico. The Rattlesnake Ridge measured section was measured in NE¼NE¼ sec. 13, T. 21 S., R. 9 W.; the Shale Spring measured section no. 3 was measured in NE¼NW¼ sec. 30, T. 20 S., R. 8 W.

the dominant lithology, the hard, resistant limestone beds in the member are more conspicuous and stand in topographic relief above the softer shales. The greatest measured thickness of the Bridge Creek Member in southern New Mexico is 17 m (50 ft) at Carthage; in northwest New Mexico, it is 20 m (60 ft) at Gallup.

Throughout southern New Mexico, the base of the Bridge Creek Member lies within the late Cenomanian *Sciponoceras gracile* Zone (Hook and Cobban, 1979, fig. 5; Cobban and Hook, 1979, fig. 3A; and Hook and others, 1980), as it does at its principal reference section near Pueblo, Colorado (Cobban and Scott, 1972). The top of the Bridge Creek Member in southern New Mexico is, however, diachronous and can lie as low as the early Turonian *Neocardioceras juddii* Zone or as high as the late early Turonian *Mmmites nodosoides* Zone. Near Pueblo, Colorado, the top of the Bridge Creek lies in the basal part of the middle Turonian *Collignoniceras woollgari woollgari* Subzone (Cobban and Hook, 1979, fig. 3B).

The Upper Cretaceous sedimentary rocks in the Cooke's Range were originally called the Colorado Shale by Darton (1916, 1917). Darton was apparently following Paige's (1916) usage of the Colorado Shale in the Silver City area. Paige considered the Colorado Shale of the Silver City area to be the equivalent of the Benton Shale of the Colorado Group. Lasky (1936) divided the Colorado Formation of the Silver City area into a lower shale member and an upper sandstone member. Although the name Colorado Formation is a misnomer, it is still the accepted terminology for the Silver City-Cooke's Range area (Jones and others, 1967; Cunningham, 1974).

The Bridge Creek Limestone Member of the Colorado Formation in the Cooke's Range is exceptionally well developed in exposures about 5 km (3 mi) south of Cooke's Peak at the north end of Rattlesnake Ridge in the NE 1/4 NE 1/4 sec. 13, T. 21 S., R. 9 W., Luna County, New Mexico. Here the Bridge Creek is 6 m (19 ft) thick, lies 30 m (100 ft) above the base of the Colorado Formation, and consists of nine beds of limestone interbedded with highly calcareous shale (Fig. 3). Individual limestone beds range from 2.5 cm (1 inch) to 23 cm (9 inches) thick. The upper two limestone beds (units 113 and 115) are calcarenites composed primarily of shell debris from the oyster *Pycnodonte newberryi* (Stanton). The lower six limestone beds (units 98, 100, 103, 105, 107, and 109) are hard, dense, very fine grained rocks that form conspicuous ledges. Most are concretionary to nodular limestones that pinch and swell and are locally absent (Fig. 4). Units 103, 105, and 107 weather to a conspicuous dark yellowish orange. Most of the limestone beds are burrowed and/or bioturbated, and all are fossiliferous. All contacts of limestone with shale are sharp.

Fossils collected from the Bridge Creek Member indicate that the basal six limestone beds (units 98-109) were deposited during the time represented by the latest Cenomanian ammonite zone of *Sciponoceras gracile* (Shumard), whereas the upper three limestone beds were deposited during the time represented by the earliest Turonian ammonite zone of *Neocardioceras juddii*. Fossils are abundant throughout the Bridge Creek Member and are generally well preserved. Ammonites and bivalves are usually preserved as internal molds, whereas the oysters and echinoids are preserved as slightly altered original shells.

Unit 111 is of particular paleontologic interest because 1) almost every limestone nodule is an internal mold of an ammonite, and 2) these ammonites—for example, *Pseudaspidoceras*, *Vascoceras (Vascoceras)*, and *Neocardioceras juddii* (Barrois and de Guerne)—are Tethyan in origin and provide a means of international correlation. Along the limited outcrop belt of unit 111, ammonite molds literally pave the ground.

Neocardioceras juddii (P1. 1, figs. 6-8) is a small ornate ammonite that was originally described from the Paris Basin in France (Barrois and de Guerne, 1878). *Neocardioceras juddii* occurs in the Plenus Marls of the Paris Basin and at the base of the Middle Chalk of England as well as in the age-equivalent rocks in Germany and Czechoslovakia. In England, *N. juddii* occurs in nodules and pebbles overlying a hardground that contains the widely distributed *Sciponoceras gracile* fauna, which we regard as latest Cenomanian in age. In the Cooke's Range, the *N. juddii* fauna is partly phosphatized and shows evidence of erosion and reworking; it immediately overlies concretionary limestone beds that contain the *S. gracile* fauna. In the Western Interior, *N. juddii* has been collected from one locality in Trans-Pecos Texas, 13 localities in southwest New Mexico, one locality in northeast Arizona, and one locality in south-central Montana. This paper is the first to formally report the occurrence of this important international guide fossil in North America. Accordingly, the *Pseudaspidoceras* Zone of Cobban and Hook (1979) and Hook and Cobban (1979) is herein redesignated as the *Neocardioceras juddii* Zone (Fig. 1).

In the Big Burro Mountains west of Silver City, *N. juddii* ranges through 1.3 m (4 ft) of section. In the Cooke's Range, *N. juddii* has a range of less than 1.0 m (3 ft). The upper part of Bridge Creek Member in the Cooke's Range (units 110-115) therefore represents a condensed sequence.

Early Turonian hardgrounds

The rocks depicted on Fig. 3 as calcareous shale were originally deposited as soft, calcareous muds. With few exceptions, the preserved macroinvertebrates were not adapted to living on such soft substrates. The most notable exception is the oyster *Pycnodonte newberryi* (Stanton), which occurs in great numbers throughout the Bridge Creek Member in the Cooke's Range and in age-equivalent rocks in the Four Corners States. Although *P. newberryi* has been regarded as a member of the attached epifauna in paleoecological studies (for ex-

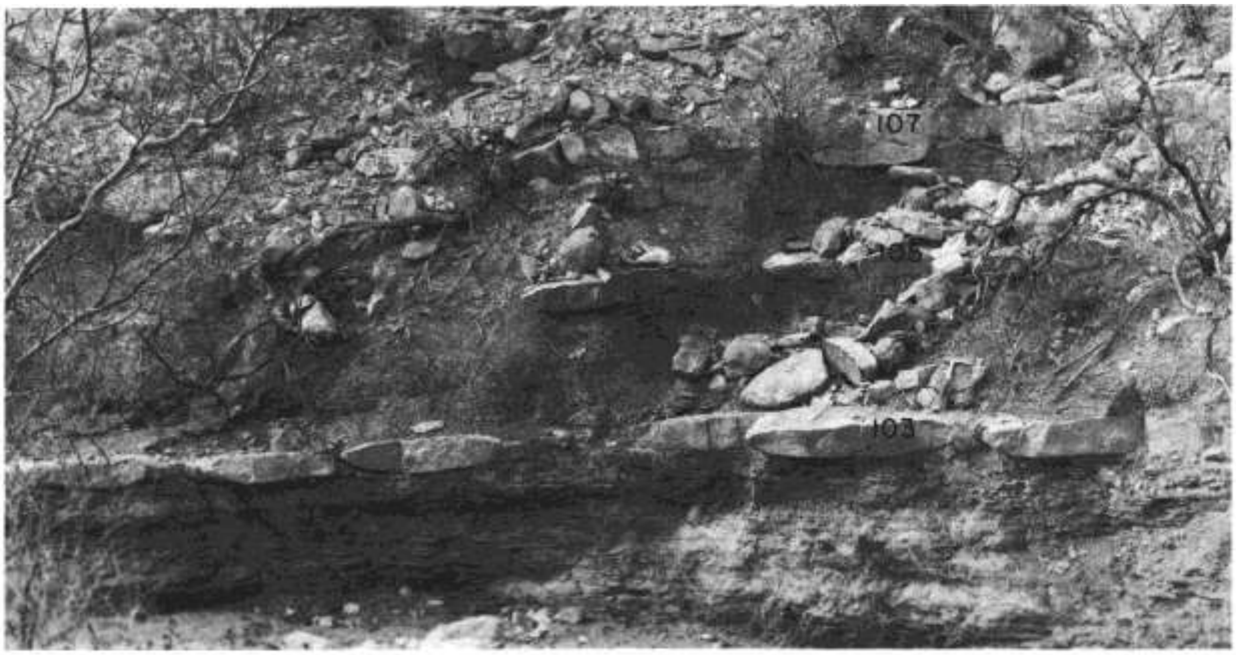

FIGURE 4—Photograph of the lower part of the Bridge Creek Limestone Member at the Rattlesnake Ridge section. Note the pinching and swelling of unit 103, the discontinuity of unit 105, and the downswelling of unit 107. Hammer to right of center on unit 103 for scale.

ample, Koch, 1980), the species probably lived unattached as adults. Attachment areas on left valves of *P. newberryi* (Pl. 2, fig. 4) are either very small and circular or are absent. Presumably, the spat of *P. newberryi* attached to small objects on the ooze-covered bottom, probably to small shells or their fragments. The configuration of the attachment areas on two specimens from Carthage (Fig. 2) show attachment to *Sciponoceras* shells; a third shows attachment to an echinoid. Eventually, the weight of the oyster was enough to dislodge the attachment particle, which rested in the soft mud. This dislodgment could have occurred in a manner similar to that illustrated by Stenzel (1971, p. N1072-N1076, fig. J67) for the Lower Cretaceous oyster *Texigryphaea roemeri* (Marcou). Regardless of the exact mechanism of becoming free living, *P. newberryi* was beautifully adapted to soft-bottom conditions and dominates the fauna in terms of sheer numbers of individuals. Above all else, *P. newberryi* was not an encrusting species.

Encrustations of the oyster *Pycnodonte kansasense* Bottjer, Roberts, and Hattin on internal molds of ammonites (Pl. 1, figs. 1-4, 9-11; Pl. 2, figs. 7-11; Pl. 3, figs. 1, 2) in unit 111 led us to the realization that this level represented a submarine erosion surface upon which a discontinuous hardground was developed. *Pycnodonte kansasense,* according to the original description (Bottjer and others, 1978), is a small, moderately inequilateral oyster with a large attachment area that is commonly the same size as the attached left valve. Uncrowded specimens are subcircular and have low upturned margins; crowded specimens are irregularly shaped and have high, usually thickened, upturned margins. Right valves mimic the attached left valves and have fine, closely spaced radial gashes and closely spaced growth lines. Both valves are thin and have a combination of laminar and vesicular internal structure. The species was originally reported from the zone of *Mytiloides mytiloides* (Mantell) of Kansas, above rocks containing *P. newberryi* (Fig. 1). The occurrence of *P. kansasense* in unit 107 (Fig. 3) in the *Sciponoceras gracile* Zone considerably extends the known vertical range of this species.

The ammonite molds that make up unit 111 have been concentrated into a single, discontinuous, nodule bed 8 cm (3 inches) thick lying 45 cm (18 inches) above the uppermost *Sciponoceras gracile-bearing* limestone (Fig. 3). All molds are in a horizontal position (Fig. 5) and most are corroded on one side (Pl. 1, figs. 8, 9; Pl. 2, fig. 9; Pl. 3, figs. 1, 4). No preferred orientation can be seen in terms of whether the corroded side of the ammonite mold is up or down. Of 12 specimens collected or examined in place, seven had the corroded side up, and five had the corroded side down. Many molds are encrusted with one generation of *Pycnodonte kansasense* (Pl. 2, figs. 7, 8). Several specimens collected in place had their oyster-encrusted side down. A few specimens have oyster encrustations on all sides (Pl. 1, figs. 1-4). One specimen of *Pseudaspidoceras* was encrusted by both *P. kansasense* and a membraniporoid bryozoan. The molds are abundant; and where the present slope angle is small, they pave the ground.

Many of the molds are complete, although corroded; all are uncrushed; some have been fractured along septal surfaces; and most are abraded on one side. The smallest fragment that we collected from this interval consists of only three chambers. Very few of the ammonite molds are burrowed. Limestone matrix sur-

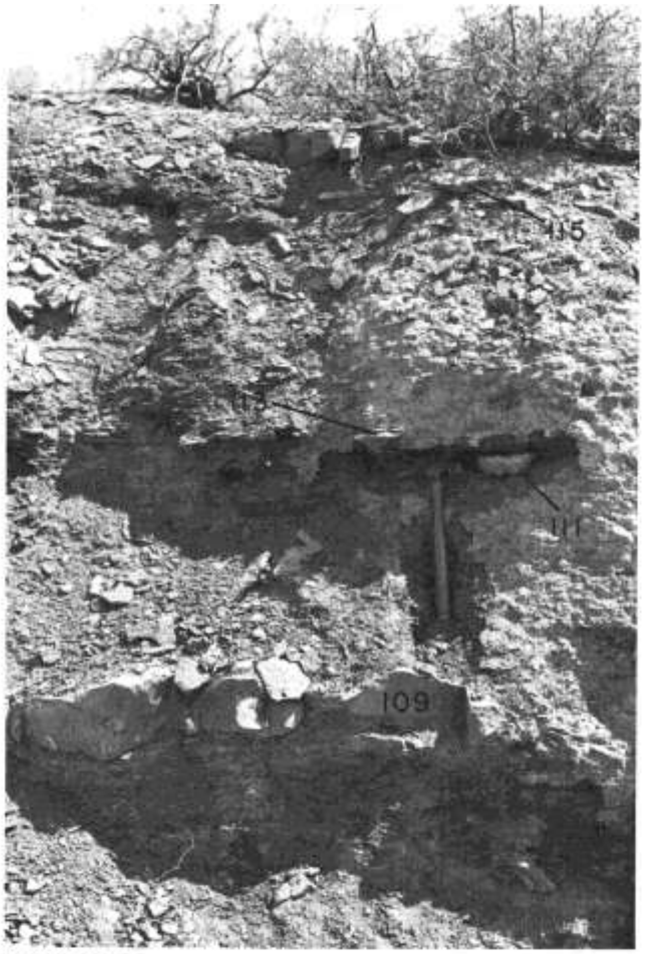

FIGURE 5—PHOTOGRAPH OF THE UPPER PART OF BRIDGE CREEK LIMESTONE MEMBER AT RATTLESNAKE RIDGE SECTION. The *Neocardioceras juddii* nodule bed occurs at top of hammer. Note the pinching and swelling of unit 109 and the absence of concretions in unit 110. The ammonite to the right of the hammer head is an internal mold of *Pseudaspidoceras*, which was recovered in place, cleaned, and posed for the picture. Limestone at top of picture is a discontinuous lens.

rounding the molds is slightly coarser grained, contains numerous foraminifera, is lighter colored, and often contrasts sharply with the mold (Pl. 1, fig. 11).

The next ledge-forming limestone above unit 111 is a 3-cm (1 1/4-inch) thick calcarenite composed of debris from *P. newberryi* shells; locally, this bed is a coquina. Ripple marks were noted on its upper surface. This calcarenite, unit 113, is normally separated from unit 111 by 2.5-4 cm (1-1 1/2 inches) of calcareous shale; locally it is in direct contact with unit 111. Scattered purplish-gray nodules composed of internal molds of single, worn ammonite chambers lie on and within this bed (cover sketch; Pl. 2, figs. 1, 2, 5, 6). A few of these purplish-gray nodules have been encrusted by oysters, although most are burrowed and many are pitted.

A thin section of a portion of a larger ammonite mold from the top of this bed (Fig. 6) revealed that this purplish-gray color is the result of a primary mineralization process and is not due to weathering. The mineralization penetrated the mold to a depth of about 1 mm both on its upper surface and within the cavity left when the septum dissolved, but prior to infilling of the overlying sediment, which now fills the cavity. Some of these molds are mineralized on only one side; others are mineralized on both sides, indicating that they were rolled over by currents or biological agents.

TABLE 1—CHEMICAL ANALYSES OF SAMPLES FROM THE BRIDGE CREEK LIMESTONE MEMBER OF THE COLORADO FORMATION, COOKE'S RANGE, NEW MEXICO (in weight percent).

lab. no.	description	total iron	manganese	phosphate
9746	body chamber of *Pseudaspidoceras* from unit 111	0.45	0.080	0.075
9748	purplish-gray ammonite chamber from unit 113	2.05	0.120	1.38
9749	calcarenite from unit 113	2.15	0.055	1.43

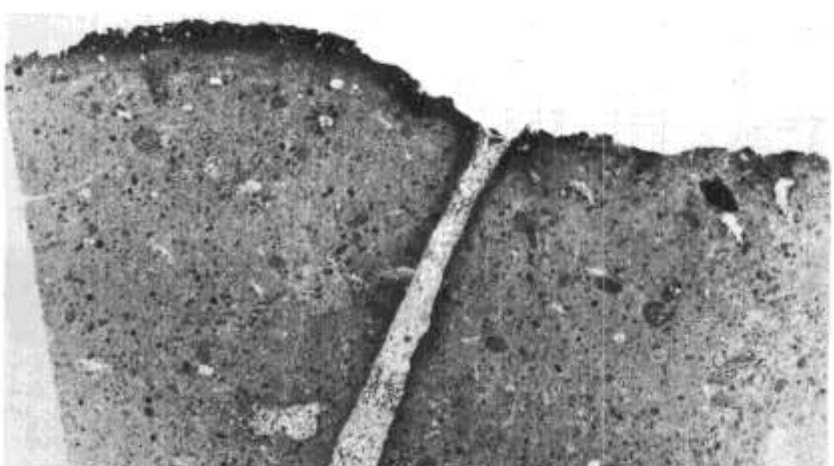

FIGURE 6—THIN SECTION OF A PORTION OF AN INTERNAL MOLD OF AN AMMONITE FROM UNIT 113 (×3.8) SHOWING DEPTH AND EXTENT OF MINERALIZATION. The depth of mineralization is approximately 1 mm. The diagonal cavity near the center of the photomicrograph is a matrix-filled septal cavity. Note that the mineralized rind is also evident on both sides of the septal cavity.

X-ray analyses of several of these purplish-gray molds revealed the presence of carbonate apatite ($Ca_{10}(PO_4)_6$-$(CO_3) \cdot H_2O$). Chemical analyses (table 1) indicated that both the molds and calcarenite of unit 113 are enriched in both phosphate and total iron content relative to the large ammonite molds in unit 111. The purplish-gray molds are also enriched in manganese relative to the calcarenite bed and the underlying ammonite molds. These chemical analyses indicate that the purplish-gray mineralized zone on the molds is probably the result of manganese and iron mineralization.

Unit 115 is a calcarenite bed 10 cm (4 inches) thick that is virtually identical to unit 113, which is 53 cm (21 inches) lower. Unit 115 also has purplish-gray, phosphatic ammonite molds and chambers lying on its upper surface. Groove and prod casts were observed on its lower surface, and ripple marks were observed on its upper surface.

The calcareous shale units separating these three limestone units from each other contain numerous disarticulated and abraded, but unfragmented, individuals of *P. newberryi.*

The evidence presented above indicates that these three units (111, 113, and 115) were deposited on erosion surfaces and that the eroded internal molds of ammonites provided a hard but discontinuous substrate during periods of sedimentary omission. Units 113 and 115 apparently represent a greater magnitude of erosion than does unit 111. The inferred geological history of this area during early Turonian time is one of three cycles of deposition, erosion, and sedimentary omission. These cycles can be listed as follows:

la) Deposition of a fraction of a meter to a few meters of sediment above unit 109, the uppermost limestone containing *Sciponoceras gracile.* Throughout this sediment were mud-filled ammonite shells, most of which were already corroded on one side during the sediment infilling process. The external mold of *Neocardioceras juddii* that occurs on the corroded portion of a *Pseudaspidoceras* internal mold could only have been impressed in soft sediment as the corroded and partially infilled ammonite shell lay exposed on the sea floor (Pl. 3, fig. 4).

lb) Concretionary lithification (prefossilization) of the sedimentary infills in the ammonite shells. The uncrushed nature of the ammonite molds suggests early diagenetic hardening of the infilled muds only a little below the sediment-water interface.

Kennedy and Garrison (1975, p. 356), citing evidence from Bathurst (1971, p. 364-365), envisioned the prefossilization process as a result of special physical/chemical conditions within the mud-filled shells that included bacterial decay of organic tissue and lack of agitation from currents and burrowing organisms. Under these conditions, cement crystals, which nucleate on grains, are more likely to grow unimpeded until they interlock, lithifying the infilled muds.

lc) Solution of the aragonitic shell. This step probably succeeded prefossilization because none of the ammonite molds is distorted.

1d) Erosion and concentration of the hardened internal molds, producing a lag deposit on the sea floor. These molds formed a discontinuous hardground in a soft substrate. The absence of ripup clasts and shale pebbles indicates that the bottom muds were still relatively unconsolidated.

le) Colonization of the hardground by epifauna, primarily oysters with some bryozoa, during a period of sedimentary omission. The presence of oysters on the corroded portion of molds (Pl. 1, fig. 9; Pl. 2, fig. 9) indicates that the oysters settled on the prefossilized molds and were not superimposed on the mold when the shell dissolved.

1f) Current activity great enough to abrade the exposed portions of the internal molds and to flip over some of the molds, exposing the other side to colonization.

2a) Resumption of deposition during which further generations of ammonite and oyster shells were buried. The cycle 1a-f was repeated, but with greater intensity of erosion and concomitant concentration of fragments of ammonite molds lying on a bed of oyster fragments. These molds formed a discontinuous hardground (see cover sketch) that was only sparingly colonized by epifauna.

2b) Phosphatization of the sea floor and manganese mineralization of the internal molds during sedimentary omission.

3) Repetition of cycle 1, with intensity as in cycle 2.

Phosphatization, according to the classic and often-quoted study of Ames (1959, p. 839) on the genesis of carbonate apatite, occurs under laboratory conditions similar to those inferred from the field evidence in the Cooke's Range:

1) a non-depositional environment,
2) limy sediments or limestone available for replacement,
3) calcium-saturated (or nearly saturated) sea water so that the limestone present is in near equilibrium with sea water,
4) pH = 7.0 or greater, and
5) PO_4^{-3} concentration of 0.1 ppm (parts per million) or greater.

Conditions 2 through 4 would seem to be satisfied merely because carbonate muds had been deposited under marine conditions. Although data are lacking on the exact concentration of phosphate in the Greenhorn sea, phosphate was sufficient for the replacement process to operate.

The amount of time represented by the rocks between the lower and upper omission surfaces (units 111-115) can be estimated by using the Late Cretaceous time scale of Obradovich and Cobban (1975) and assuming that each ammonite zone was of approximately equal duration. The three erosion surfaces all fall within a single ammonite zone, the *Neocardioceras juddii* Zone. Ammonite zones from the late Cenomanian *Dunveganoceras pondi* Zone to the early Turonian *Watinoceras coloradoense* Zone average 400,000 years per zone. The net sedimentation rate for the rocks deposited during the *N. juddii* Zone at Rattlesnake Ridge is approximately 0.2 m/100,000 years (0.8 ft/100,000 years).

An interpretation of the life span of the oysters offers some help in determining the magnitude of time the lower hardground (unit 111) was exposed for colonization; that is, the duration of sedimentary omission. Bottjer and others (1978) suggested a maximum pycnodont age of eight years for *Pycnodonte kansasense* based on a count of ligamental growth lines that they interpreted as annual growth increments. They also noted that second-generation specimens commonly encrusted first-generation specimens. Only one of the hundreds of oyster-encrusted molds from unit 111 examined by us shows encrustation of one generation of oysters by another (pl. 1a, fig. 10), although some molds are encrusted on both sides (pl. 1a, figs. 1-4; p1. 2, figs. 9-11), and a few other molds are encrusted by oysters with a bimodal size distribution indicating at least two generations of oysters. This line of reasoning suggests that this hardground was exposed for only a short period of time, perhaps only a few tens of years.

The depth of the mineralized rind on the internal molds and chambers from units 113 and 115 indicates that these hardgrounds, also, were exposed for only a relatively short period of time.

Discussion

Discontinuity surfaces similar to the three described in this paper are relatively common in the Cretaceous of Europe and England (for example, Voigt, 1959; Casey, 1961; Jefferies, 1963; Bromley, 1967, 1975; Kennedy and Garrison, 1975). To the best of our knowledge, this report is only the third to describe hardgrounds and phosphatization from the Upper Cretaceous of the Western Interior of North America. Tourtelot and Cobban (1968) described a phosphate nodule bed at the base of the Niobrara Formation in the Black Hills of South Dakota, and Kennedy and others (1977) described beds of hiatus- and breccia-concretions from the midTuronian of Texas and northern Mexico.

These Bridge Creek Member hardgrounds could be unique to southern New Mexico and to this part (early Turonian) of the Bridge Creek Member. Outcrops of Upper Cretaceous marine rocks are unknown southwest (landward) of the Cooke's Range, and the shoreline during the time represented by the *Pycnodonte newberryi* zone is inferred to have been less than 100 km (60 mi) southwest of the Cooke's Range (Fig. 2). The magnitude of the erosion interpreted in the Cooke's Range could be related to proximity to the shoreline. However, evidence from elsewhere indicates that this is not necessarily so.

A comparison of two measured sections of the Bridge Creek Member in the Cooke's Range (Fig. 3) shows some striking differences. Most notable is the absence of the *Neocardioceras juddii* nodule bed (unit 111) in the Shale Spring section. The *N. juddii* fauna, however, is preserved in a discontinuous bed of limestone conglomerate that is up to 46 cm (18 inches) thick (unit 3-20). The clasts in the conglomerate are phosphatized internal molds of ammonites; the ground mass is composed of intermixed fine-grained limestone and calcarenite (Fig. 7). We correlate this unit with units 111-113 at Rattlesnake Ridge. The uppermost *Sciponoceras gra* cile-bearing limestones match quite well between the two sections (units 109 and 3-18), but the remainder of the units, including the single bentonite bed in each section, do not match at all. We attribute the differences between the two measured sections, which are only 6.4 km (4 mi) apart, to erosion that occurred at slightly different times and/or that was of different magnitude.

Two internal molds of ammonites collected from unit 107 of the Rattlesnake Ridge section have encrustations of *Pycnodonte kansasense* on both sides and are convincing evidence for hardground development at that level. Deposition of limestone on erosion surfaces is a very plausible explanation for the downswelling noted in unit 107 and for the piping of unit 3-16 into the underlying shale. A detailed sedimentological analysis of the portion of the Bridge Creek Member deposited during *Sciponoceras gracile* time is being conducted by Marcus Johnson, under the direction of Donald Hattin, Indiana University (Johnson, written communication, 1978).

Evidence from Colorado, Texas, and elsewhere in New Mexico indicates that discontinuity surfaces are common and widespread in rocks of late Greenhorn (Bridge Creek) age:

1) Oyster-encrusted internal molds of *Metoicoceras gibbosum* Hyatt from the base of the Bridge Creek Limestone Member of the Mancos Shale at Carthage.
2) An oyster attachment scar on an internal mold of *Vascoceras (Greenhornoceras) birchbyi* Cobban and Scott from the Bridge Creek Limestone Member of the Greenhorn Formation near La Junta, Colorado.
3) Bored and abraded concretions containing *Mammites nodosoides* (Schlotheim) from the Mancos Shale at Truth or Consequences.
4) A coral thicket developed on a 7-cm (3-inch)

FIGURE 7—PHOTOGRAPH OF THE DISCONTINUOUS LIMESTONE CONGLOMERATE (UNIT 3-20) AT THE SHALE SPRING MEASURED SECTION NO. 3. Clasts in the conglomerate are phosphatized internal molds of ammonites.

thick bed of conglomeratic limestone, the clasts of which are internal molds of bivalves and *Mammites nodosoides* (Schlotheim) in the Mancos Shale at Truth or Consequences, above the level of no. 3 (above).

5) Oyster- and bryozoa-encrusted internal molds of *Mammites depressus* Powell from the Mancos Shale at Capitan, Puertecito, D Cross Mountain, and Fence Lake.
6) Oyster-encrusted and completely phosphatized internal molds of *Mammites depressus* Powell from a 15-cm (6-inch) thick nodule bed in the Boquillas Limestone near Kent, Texas. (This occurrence represents a disconformity, rather than just a discontinuity surface.)

Epiliths (encrusting organisms) on and borings into concretions and internal molds provide, as Kennedy and others (1977, p. 835) noted, the most compelling evidence for lithification, erosion, and subsequent exposure of the concretions and molds on the sea floor. In addition, epiliths and borings are generally easily observable field criteria that can lead to a recognition of erosion surfaces that otherwise might be overlooked.

The interpretation of the depositional history of an area that is based in part on encrusted internal molds depends on the time of encrustation. Calcitic or phosphatic epifauna that have encrusted aragonitic shells can be superimposed on the internal molds through diagenetic solution of the aragonite (Seilacher, 1960; 1963, fig. 8; and 1971, p. 17). The field evidence gathered from the upper part of the Bridge Creek in the Cooke's Range overwhelmingly indicates that the oysters encrusted the prefossilized internal molds of ammonites. This evidence includes the following:

1) Encrustation of the corroded portions of the internal molds (Pl. 3, fig. 1; Pl. 1, fig. 9). The corrosion or breakage of the shell occurred during the sediment infilling process as indicated by the impression of *Neocardioceras juddii* on the corroded portion of the *Pseudaspidoceras* mold shown in Pl. 3, fig. 4.
2) Encrustation of the abraded portions of the internal mold (Pl. 2, figs. 10, 11), including abraded septal surfaces. The oysters are relatively unabraded and fresh-looking in contrast to the mold.
3) Lack of distortion of either the molds or the oysters.
4) The exact conformity of the oyster shells to the surface of the internal molds. This exact molding is particularly striking in umbilical regions, around tubercles, and in depressions left by partially dissolved septa and lobe voids (Pl. 1, fig. 9).
5) Xenomorphic papillae on the inner surface of left valves of encrusted oysters (Pl. 2, figs. 7, 8, 11; Pl. 3, fig. 1) indicate that the oysters encrusted the molds after the papillae formed. Microscopic examination of unencrusted papillae revealed the fine, reticulate pattern of worn bryozoa. The papillae apparently formed from differential sea-floor weathering of the internal molds of ammonites encrusted by bryozoa.

Bathurst (1971, p. 400) noted that "the nature of hardgrounds poses three main questions: (1) why were these horizons cemented more densely than the [surrounding rocks], (2) what accompanying changes, if any, were there in bathymetry and current regime, and

(3) why was there a hiatus in sedimentation?" In this paper we have effectively answered just the first of Bathurst's questions. The remaining two questions can only be answered after a detailed, regional study of the sedimentology of the Bridge Creek Limestone Member has been completed.

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PLATE 1a

(All figures are natural size.)

Figures

1-4, 9-11 *Pseudaspidoceras* n. sp.

1-4 Figured specimen USNM 307355, from the Colorado Formation at USGS Mesozoic locality D10114 in NE 1/4 NE 1/4 sec. 13, T. 21 S., R. 9 W., Luna County, New Mexico, showing oysters attached on ventral, dorsal, and both flank surfaces.

9-11 Figured specimen USNM 307358, from the same locality, showing oysters attached on three surfaces.

5-8 *Neocardioceras juddii* (Barrois and de Guerne)

5, 6 Hypotype USNM 307356, from the same locality as figs. 1-4. Top and bottom views of a concretion containing *N. juddii* and a fragment of *Pseudaspidoceras.*

7, 8 Hypotype USNM 307357, from the same locality showing the good side and the corroded side.

PLATE 1

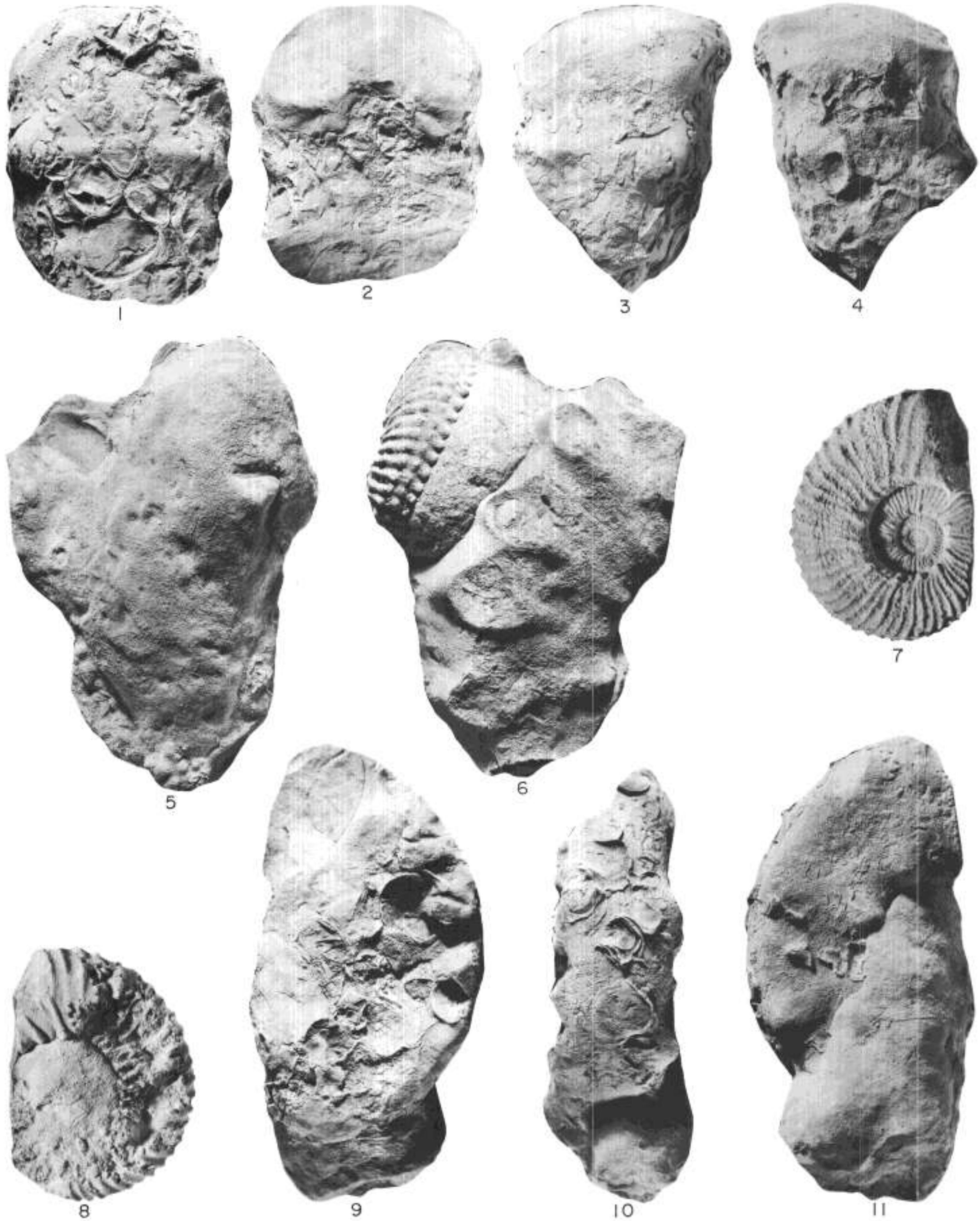

PLATE 2

(All figures are natural size.)

Figures	
1a, 2, *5*	*Fagesia* or *Vascoceras* sp. 1a, 2 Figured specimen USNM 307359, from the Colorado Formation at USGS Mesozoic locality D10115 in NE 1/4 NE 1/4 sec. 13, T. 21 S., R. 9 W., Luna County, New Mexico, showing opposite sides of a chamber filling. 5 Figured specimen USNM 307360, from the same locality, showing most of a bored septa1 surface.
3, 4	*Pycnodonte newberryi* (Stanton) Exterior and interior views of a left valve, hypotype USNM 307366, from the Colorado Formation at USGS Mesozoic locality D10112 at the same locality as figs. 1a, 2, 5.
6-11	*Pseudaspidoceras* n. sp. 6 Figured specimen USNM 307361, from the same locality as figs. 1a, 2, 5, showing burrowed septal surface. 7, 8 Figured specimen USNM 307362, from USGS Mesozoic locality D10114 at the same locality as figs. 1a, 2, 5 showing oysters on ventral and lateral sides. 9-11 Figured specimen USNM 307363, from the same locality showing oysters on three sides.

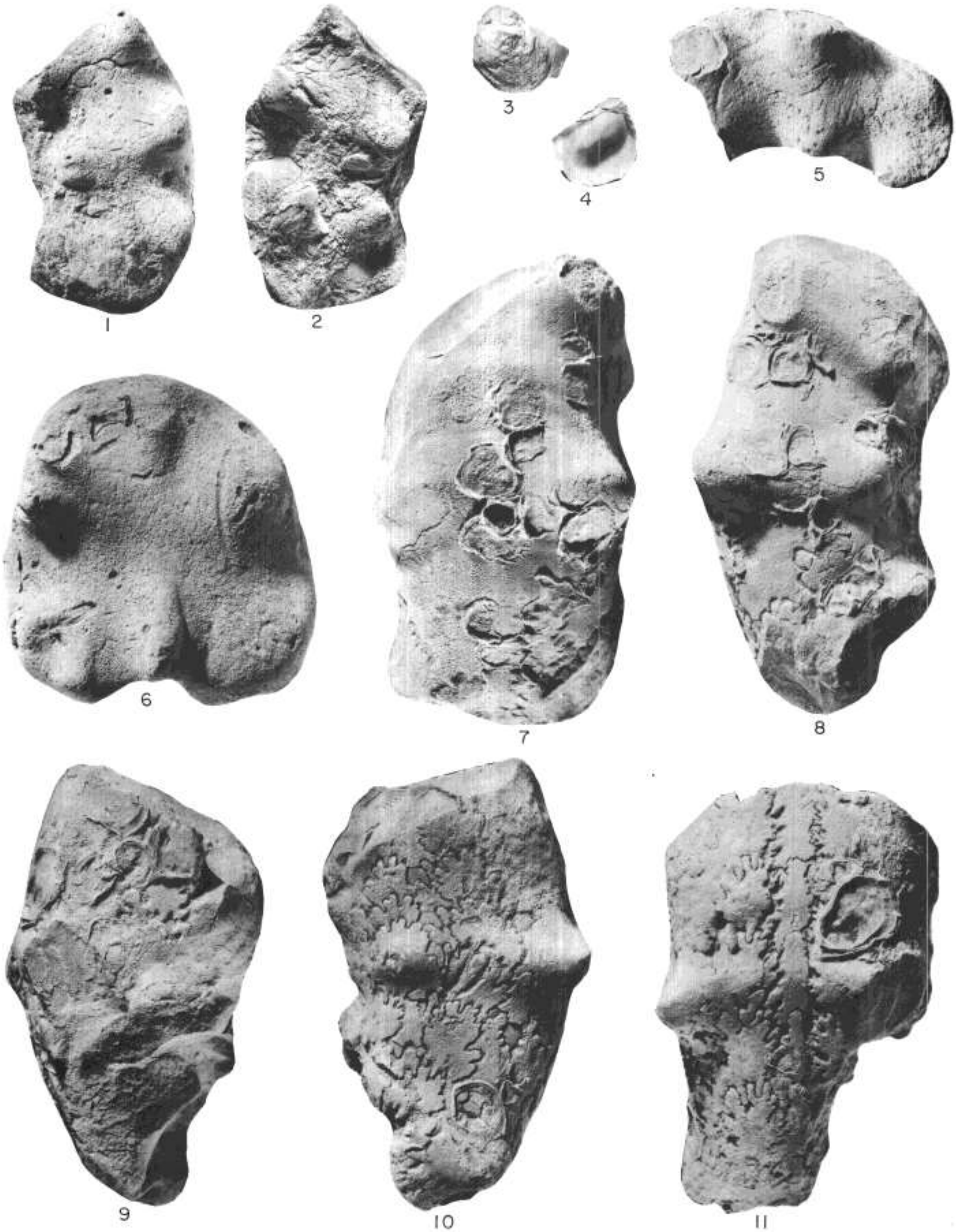
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PLATE 3

(All figures are natural size.)

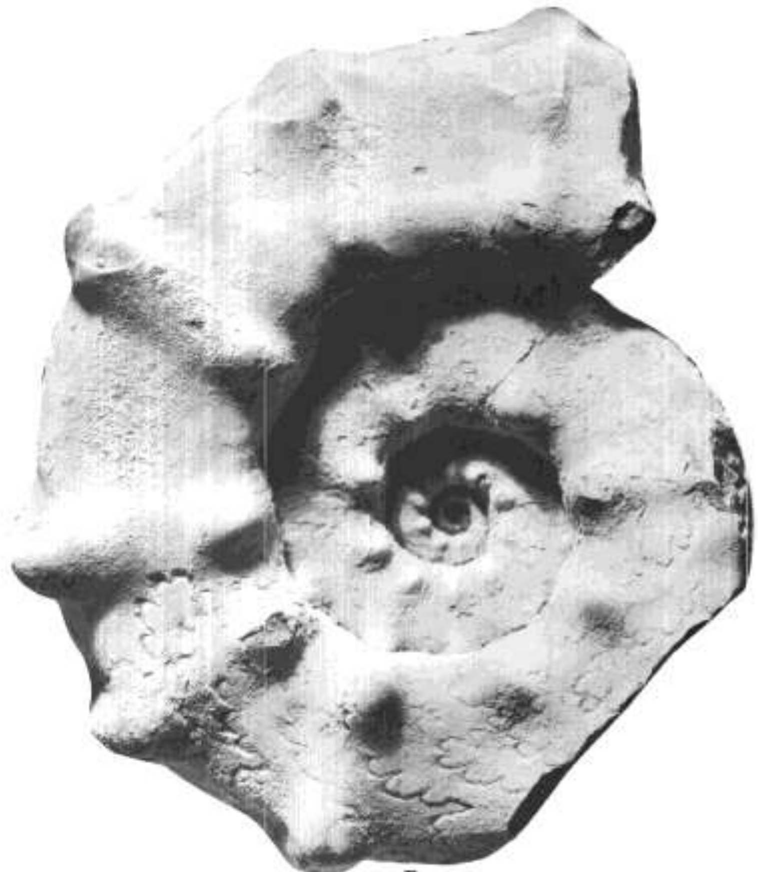
Figures

1-4 *Pseudaspidoceras* n. sp.

1a, 2 Figured specimen USNM 307364, from the Colorado Formation at USGS Mesozoic locality D10114 in NE 1/4 NE 'A sec. 13, T. 21 S., R. 9 W., Luna County, New Mexico, showing oysters attached to both the good side and the corroded side.

3, 4 Figured specimen USNM 307365, from the same locality showing both the good side and the corroded side; the corroded side has an impression of the dense ribbing of *Neocardioceras juddii.*

1



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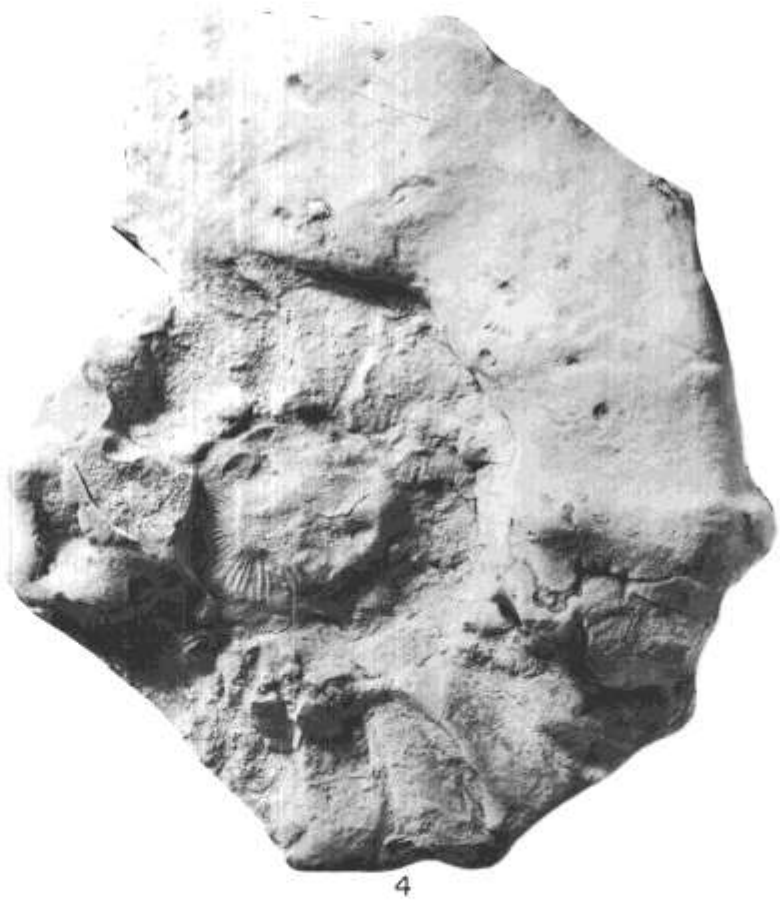
2



4

NEW TURRILITID AMMONITE FROM MID-CRETACEOUS (CENOMANIAN) OF SOUTHWEST NEW MEXICO

by William A. Cobban, *Paleontologist, U.S. Geological Survey, Denver, Colorado,* and
Stephen C. Hook, *Paleontologist, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico*

Abstract

A new species of a helically coiled ammonite, *Neostlingoceras kottlowskii* Cobban and Hook, is described and illustrated. The species occurs in the lowest upper Cenomanian ammonite zone *(Dunveganoceras pondi-Calycoceras? canitaurinum)* in the Western Interior and possibly in the underlying zone of *Plesiacanthoceras wyomingense* of latest middle Cenomanian age. Most specimens of *N. kottlowskii* have come from the Colorado Formation in southwest New Mexico, but a few examples are known farther north from the Mancos Shale in west-central New Mexico, from the Benton Shale of north-central Colorado, and from the Belle Fourche Shale and Greenhorn Formation of the Black Hills area in northeastern Wyoming. The genus *Neostlingoceras* is reported from North America for the first time.

Introduction

Helically coiled ammonites representing the family Turrilitidae Meek (1876, p. 477) are fairly abundant in rocks of Cenomanian age in southwestern New Mexico. Most of these ammonites occur as flattened imprints in shaly rocks, but uncrushed specimens occur locally in limestone concretions. Many of the occurrences represent a new species of *Neostlingoceras,* a genus not previously recorded from North America. This genus is extremely scarce in the Western Interior outside New Mexico. A few specimens have been found in the Benton Shale in north-central Colorado and in the Belle Fourche Shale and Greenhorn Formation in eastern Wyoming.

The holotype and figured paratypes of the new species, *Neostlingoceras kottlowskii* Cobban and Hook, are in the National Museum of Natural History in Washington, D.C. Plaster casts of some of the type specimens are kept in the U.S. Geological Survey's Mesozoic invertebrate collections at the Federal Center, Denver, Colorado, and in the Mesozoic invertebrate collections of the New Mexico Bureau of Mines and Mineral Resources, Socorro. The photographs were made by Robert E. Burkholder of the U.S. Geological Survey. Ranchers who kindly gave us permission to collect on their property are Dan Garrett of the Double Arrow Ranch, Winston, New Mexico, and Thomas Hyatt of the Hyatt Ranch, Deming, New Mexico.

Geographic distribution

The new species *Neostlingoceras kottlowskii* has been found at 11 localities in New Mexico and two localities each in Colorado and Wyoming. These localities are shown in Fig. 8; additional data regarding the localities, stratigraphic assignment, collectors, and faunal lists are given in table 2.

Biostratigraphic distribution

Most, if not all, occurrences of the new species *Neostlingoceras kottlowskii* are in the ammonite zone of *Dunveganoceras pondi* Haas (1949), but a few occurrences may be in the underlying zone of *Plesiacanthoceras wyomingense* (Reagan, 1924). The sequence of these two Cenomanian zones, bounded below by the zone of *Acanthoceras amphibolum* Morrow (1935) and above by the zone of *Dunveganoceras albertense* (Warren, 1930), was first noted by Cobban (1951, fig. 2, with *P. wyomingense* recorded as *Acanthoceras?* n. sp.). Rocks containing *Acanthoceras* are usually considered of middle Cenomanian age, applying a threefold division of Cenomanian time (for example, Kennedy and Hancock, 1977, fig. 1). In the Western Interior, the zone of *Dunveganoceras pondi* is considered the base of the upper Cenomanian (Kauffman and others, 1976, p. 23.13).

The northernmost occurrences of *Neostlingoceras kottlowskii* are in the Greenhorn Formation and Belle Fourche Shale on the west flank of the Black Hills uplift in eastern Wyoming (Fig. 8, locs. D10079, 12650). Both occurrences are probably in the ammonite zone of *Dun-*

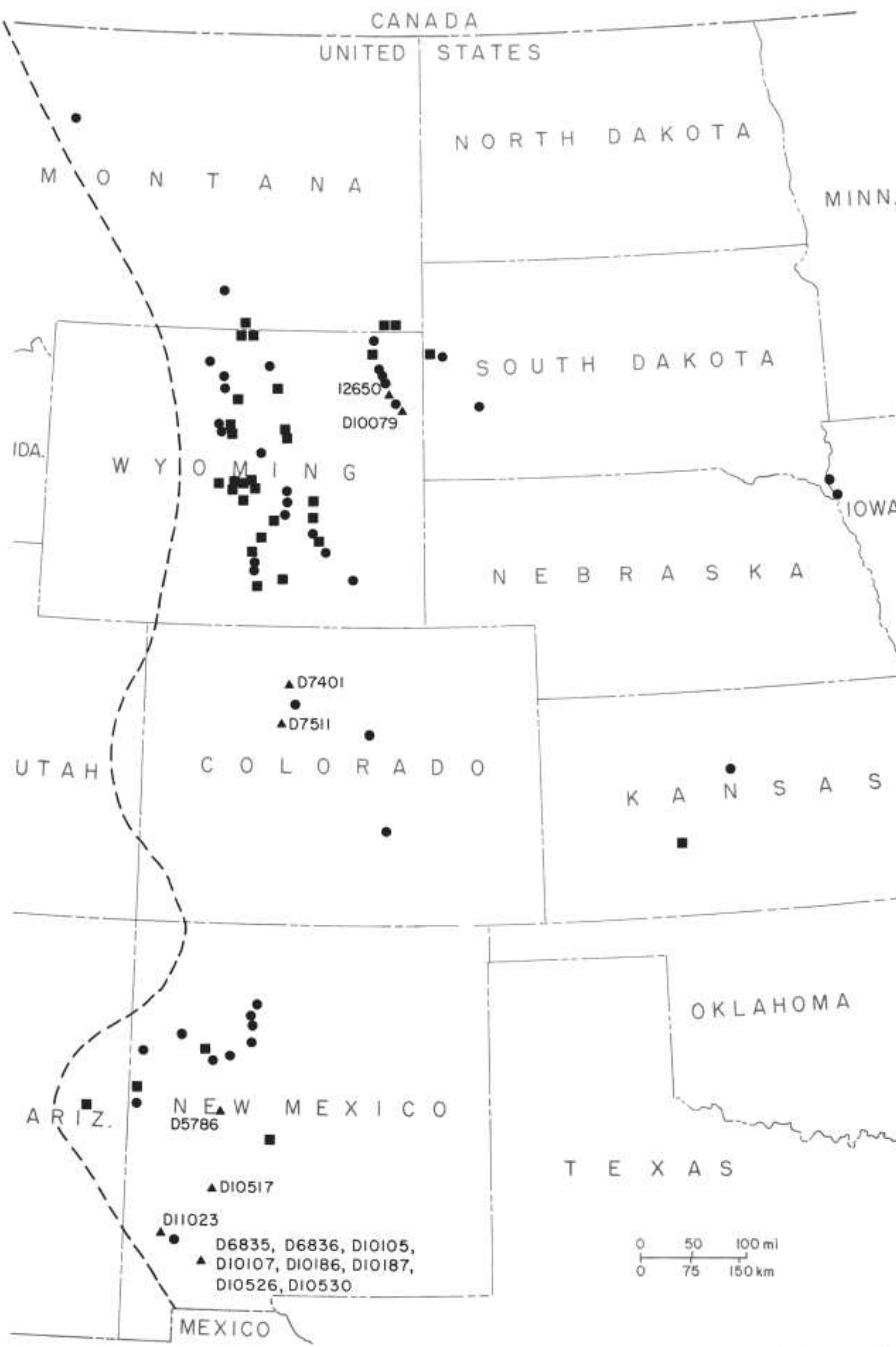


FIGURE 8—MAP OF THE WESTERN INTERIOR showing collecting localities of *Neostlingoceras kottlowski* Cobban and Hook, represented by ▲, *Plesiacanthoceras wyomingense* (Reagan), represented by ■, and either *Dunveganoceras pondi* Haas or *Calycoceras*? *canitaurinum* (Haas), represented by ●. The dashed line shows the approximate location of the Cretaceous western shoreline during the time represented by the zones of *Plesiacanthoceras wyomingense* and *Dunveganoceras pondi–Calycoceras*? *canitaurinum*.

TABLE 2—Localities where fossils were collected.

USGS Mesozoic locality no.	description of locality, stratigraphic assignment, collector(s), year of collection	fauna
D5786	About 6.7 km southeast of Puertecito in SE¼ sec. 33, T. 3 N., R. 5 W., Socorro County, New Mexico; Mancos Shale, from a thin bed of sandstone about 25 m below Twowells Tongue of the Dakota Sandstone; E. R. Landis and W. A. Cobban, 1967	*Idonearca* sp. *Inoceramus* sp. *Pycnodonte* sp. *Astarte* sp. *Stomohamites simplex* (d'Orbigny) *Neostlingoceras kottlowskii* Cobban and Hook *Calycoceras*? aff. *C.*? *canitaurinum* (Haas) *Metoicoceras* sp.
D6835	Cooke's Range in SE¼NE¼ sec. 30, T. 20 S., R. 8 W., Luna County, New Mexico; Colorado Formation, about 2 m above base; W. A. Cobban, 1968	*Inoceramus prefragilis* Stephenson *Neostlingoceras kottlowskii* Cobban and Hook
D6836	Same locality as D6835; Colorado Formation, about 3 m above base; W. A. Cobban, 1968	*Inoceramus prefragilis* Stephenson *Neostlingoceras kottlowskii* Cobban and Hook *Tarrantoceras* sp.
D7401	Northwest of Kremmling in NW¼NW¼ sec. 19, T. 3 N., R. 81 W., Grand County, Colorado. Benton Shale, from dark-gray shale below Codell Sandstone Member; G. A. Izett, G. R. Scott, and W. A. Cobban, 1969	*Inoceramus* cf. *I. ginterensis* Pergament *Pteria* sp. *Astarte* sp. *Stomohamites simplex* (d'Orbigny) *Metaptychoceras* sp. *Neostlingoceras kottlowskii* Cobban and Hook *Desmoceras* sp. *Metoicoceras* sp. *Borissiakoceras* sp.
D7511	Near Wolcott in NW¼NW¼ sec. 15, T. 4 S., R. 83 W., Eagle County, Colorado; Benton Shale, from calcareous shale 13.7 m below a sandstone unit in the upper part; G. A. Izett, 1970	*Inoceramus* cf. *I. ginterensis* Pergament *Pteria* sp. *Astarte* sp. *Metaptychoceras* sp. *Neostlingoceras kottlowskii* Cobban and Hook
D10079	USGS No. 1 Beaver Creek core hole in SW¼NW¼ sec. 30, T. 46 N., R. 63 W., Weston County, Wyoming; Greenhorn Formation, from calcareous shale at depth of 231.6–232.4 m; E. M. Merewether, 1976	*Inoceramus prefragilis* Stephenson *Stomohamites simplex* (d'Orbigny) *Neostlingoceras kottlowskii* Cobban and Hook *Tarrantoceras* n. sp. *Metoicoceras* sp. *Borissiakoceras* sp.
D10105	South of Rattlesnake Ridge in NW¼NW¼ sec. 18, T. 21 S., R. 8 W., Luna County, New Mexico; Colorado Formation, from basal 1.5-m-thick bed of sandstone; S. C. Hook, W. A. Cobban, and E. R. Landis, 1976; S. C. Hook, D. E. Tabet, and J. R. Wright, 1977	*Inoceramus prefragilis* Stephenson *Anisoceras plicatile* (J. Sowerby) *Neostlingoceras kottlowskii* Cobban and Hook *Damesites* n. sp. *Tarrantoceras* n. sp. *Calycoceras* sp. *Plesiacanthoceras*? sp. *Metoicoceras* n. sp. *Borissiakoceras* sp.
D10107	South of Rattlesnake Ridge in NW¼NW¼ sec. 18, T. 21 S., R. 8 W., Luna County, New Mexico; Colorado Formation, from thin-bedded limestone unit 6.7–11.0 m above base; S. C. Hook, W. A. Cobban, and E. R. Landis, 1976	*Inoceramus prefragilis* Stephenson *Neostlingoceras kottlowskii* Cobban and Hook *Damesites* n. sp. *Tarrantoceras* n. sp. *Calycoceras* sp. *Metoicoceras* n. sp.

TABLE 2 (continued)

USGS Mesozoic locality no.	description of locality, stratigraphic assignment, collector(s), year of collection	fauna
D10186	South of Rattlesnake Ridge in NW¼NW¼ sec. 18, T. 21 S., R. 8 W., Luna County, New Mexico; Colorado Formation, from lenticular limestone concretions 3.3 m above base; S. C. Hook, W. A. Cobban, J. R. Wright, and D. E. Tabet, 1977	*Inoceramus prefragilis* Stephenson *Stomohamites simplex* (d'Orbigny) *Neostlingoceras kottlowskii* Cobban and Hook *Damesites* n. sp. *Tarrantoceras* sp. *Calycoceras*? cf. *C.*? *canitaurinum* (Haas) *Euomphaloceras* sp. *Metoicoceras* sp. *Borissiakoceras* sp.
D10187	South of Rattlesnake Ridge in N½SE¼ and S½NE¼ sec. 13, T. 21 S., R. 9 W., Luna County, New Mexico; Colorado Formation, from 1.5-m-thick unit of grayish-orange-weathering, shaly, silty limestone 3.6–5.1 m above base; S. C. Hook and W. A. Cobban, 1977	*Inoceramus prefragilis* Stephenson *Exogyra* sp. *Neostlingoceras kottlowskii* Cobban and Hook *Damesites* n. sp. *Tarrantoceras* n. sp. *Metoicoceras* n. sp. *Borissiakoceras* sp.
D10517	Rouse Place in NE¼NW¼ sec. 13, T. 10 S., R. 8 W., Sierra County, New Mexico; Mancos Shale, from limestone concretions 15 m above base; S. C. Hook and W. A. Cobban, 1978	*Inoceramus* cf. *I. ginterensis* Pergament *Entolium* sp. *Lucina juvensis* Stanton *Astarte* sp. *Anisomyon apicalis* Sidwell *Entalis* sp. *Stomohamites simplex* (d'Orbigny) *Neostlingoceras kottlowskii* Cobban and Hook, n. sp. *Damesites* n. sp. *Tarrantoceras*? n. sp. *Metoicoceras* sp.
D10526	Rattlesnake Ridge in NE¼ sec. 7, T. 21 S., R. 8 W., Luna County, New Mexico; Colorado Formation, from thin beds of limestone 6.5–9.0 m above base; S. C. Hook and W. A. Cobban, 1978	*Inoceramus prefragilis* Stephenson *Neostlingoceras kottlowskii* Cobban and Hook *Damesites* n. sp. *Tarrantoceras* n. sp. *Metoicoceras* sp.
D10530	South of Rattlesnake Ridge in N½SE¼ sec. 13, T. 21 S., R. 9 W., Luna County, New Mexico; Colorado Formation, near top of basal sandstone bed; S. C. Hook, J. R. Wright, and W. A. Cobban, 1976, 1977	*Inoceramus prefragilis* Stephenson *Stomohamites simplex* (d'Orbigny) *Neostlingoceras kottlowskii* Cobban and Hook *Damesites* n. sp. *Tarrantoceras* n. sp. *Metoicoceras* sp.
D11023	Cane Spring Canyon in NW¼SE¼ sec. 8, T 17 S., R. 15 W., Grant County, New Mexico; Colorado Formation, float about 3 m above base; S. C. Hook and G. Stachura, 1976	*Neostlingoceras kottlowskii* Cobban and Hook *Calycoceras* sp.
12650	Near Thornton in sec. 7, T. 48 N., R. 65 W., Weston County, Wyoming; from a limestone concretion in the Belle Fourche Shale; W. W. Rubey, 1924	*Breviarca* sp. *Inoceramus* sp. *Aphrodina* sp. *Neostlingoceras kottlowskii* Cobban and Hook *Damesites* n. sp. *Borissiakoceras* sp.

veganoceras pondi Haas. In collections (D10079) from a core in the Osage oil field, *N. kottlowskii* is associated with *Inoceramus prefragilis* Stephenson at a depth of 232 m. *Damesites* n. sp. and *I. prefragilis* occur at a depth of 240 m. *Acanthoceras* sp. and *Borissiakoceras reesidei* Morrow occur at 244 m, and *A. amphibolum* Morrow and *B. reesidei* occur at 247 m. The ammonite zone of *Plesiacanthoceras wyomingense* (Reagan), which lies between the zones of *Acanthoceras amphibolum* and *Dunveganoceras pondi*, is absent on the outcrops in the Osage oil field, owing to an unconformity at the base of the Greenhorn Formation. Fossils indicative of the zone of *D. pondi* have been found in at least the lower 17 m of the Greenhorn on outcrops in the Osage oil field. The northernmost occurrence of *N. kottlowskii* (Fig. 8, loc. 12650) is from a limestone concretion in noncalcareous shale assigned to the Belle Fourche Shale. Owing to a rapid northward facies change from calcareous to noncalcareous shale, rocks of early and middle Greenhorn age in the Osage oil field are considered part of the Belle Fourche farther north (Robinson and others, 1964, fig. 6).

In the Middle Park area in north-central Colorado (Fig. 8, loc. D7401), impressions of *N. kottlowskii* occur in a calcareous shale unit in the Benton Shale. The associated imprints of small ammonites and bivalves have not been studied, and the zonal assignment of the collection is uncertain. Farther south, near Wolcott, in north-central Colorado (Fig. 8, loc. D7511), *N. kottlowskii* also occurs as imprints in a calcareous shale unit in the Benton.

Near Puertecito in west-central New Mexico (Fig. 8, loc. D5786), *N. kottlowskii* was found in a thin bed of sandstone in the Mancos Shale about 25 m below the Twowells Tongue of the Dakota Sandstone. Associated ammonites include *Calycoceras?* aff. *C.? canitaurinum* (Haas), which suggests an assignment to the zone of *Dunveganoceras pondi. Calycoceras? canitaurinum*, originally described as *Mantelliceras canitaurinum* Haas (1949, p. 9, pls. 1-3, 4, figs. 1, 2, 4; text figs. 1-4), is a common associate of *D. pondi* in the central and northern part of the Western Interior. *Dunveganoceras pondi* has not been found in New Mexico, but *C.? canitaurinum*, or a subspecies of it, has been found at many localities in the western half of the state.

The holotype and most of the figured paratypes of *N. kottlowskii* came from limestone concretions near the base of the Mancos Shale in the Sierra Cuchillo (Fig. 8, loc. D10517) northwest of Truth or Consequences, New Mexico. Associated ammonites are mostly undescribed but resemble species from the zones of *D. pondi* and *P. wyomingense* in the Black Hills area.

Neostlingoceras kottlowskii is abundant in the lower part of the Colorado Formation on the south side of the Cooke's Range in southwest New Mexico (Fig. 8, locs. D10105, D10107, D10186, D10187, D10526, D10530). Most specimens occur as imprints in shaly limestone, but a few uncrushed specimens are present in a bed of limestone concretions 3.3 m above the base of the Colorado. The lowest specimens (D10105) are in a bed of sandstone 1.5 m thick that forms the base of the Colorado and rests unconformably on the Sarten Sandstone of late Albian and early Cenomanian age. Among the fossils from this basal bed of sandstone is a horn from some large ammonite, such as *Plesiacanthoceras wyomingense.* Ammonites from the limestone concretions (D10186) about 2 m higher, however, include *Calycoceras?* cf. *C.? canitaurinum*, which suggests the zone of *D. pondi.* Possibly the base of the Colorado Formation in the Cooke's Range lies near the top of the zone of *P. wyomingense,* whereas the 8 or 9 m of shaly limestone and limy shale overlying the basal sandstone bed lie in the zone of *D. pondi.*

In the Silver City area (Fig. 8, loc. D11023), *N. kottlowskii* occurs sparsely in the basal beds of the Colorado Formation. The only associated fossil is an occasional *Calycoceras* sp.

Systematic paleontology

Family TURRILITIDAE Meek, 1876

Subfamily TURRILITINAE Meek, 1876

GENUS *Neostlingoceras* Klinger and Kennedy, 1978

TYPE SPECIES: *Turrilites carcitanensis* Matheron, 1842

Klinger and Kennedy (1978, p. 14, 15) gave the following diagnosis of this genus:

> Sinistral, closely coiled turrilicones with a low apical angle (12-17°). Ornament consists of an upper row of distant, pointed tubercles separated by a broad, flat to slightly concave zone from up to 3 rows of smaller, more numerous tubercles, which may coalesce into a single transverse bulla. Faint ribs linking and intercalating between tubercles on the exposed whorl face may or may not be developed.

These authors noted that the genus occurred in lower Cenomanian rocks in Europe, Iran, North Africa, South Africa, Madagascar, southern India, and Japan.

Neostlingoceras kottlowskii Cobban and Hook, n. sp.

Plate 4

This sinistral species is characterized by its acute apical angle and three rows of tubercles, two of which are visible in side views; the upper row has larger and generally fewer tubercles than the lower one. A smooth depressed area a little below the middle of the flank separates these two rows of tubercles. The third row of tubercles, which lies on the underside of the whorl, consists of smaller tubercles than those in the lower flank row, although they are equal in number.

The holotype and most of the paratypes came from a bed of dark-gray, finely crystalline limestone concretions in the lower part of the Mancos Shale at USGS Mesozoic locality D10517 in sec. 13, T. 10 S., R. 8 W., Sierra County, New Mexico (Fig. 8, loc. D10517). Numerous fragments of turrilitids are present in these concretions (Pl. 4, fig. 28). Fifteen specimens are suitable for measurements of apical angles and tubercle counts. Apical angles range from 10 to 21 degrees, averaging 17 degrees. Tubercles in the upper row number 12-20 per whorl, averaging 17, and tubercles in the other rows number 12-26, averaging 21. Maximum whorl diameters of these 15 specimens range from 6.5 to 19.5 mm. Sutures are not preserved. Two small specimens have equal numbers of upper and lower tubercles on their largest whorls at diameters of 6.5 and 6.8 mm.

Whorls with diameters of less than 1 mm were not seen. The smallest spires from loc. D10517, consist of 5 or 6 smooth whorls 1.0-4.5 mm in diameter. These early whorls have slightly convex to nearly flat flanks at first; they later become slightly depressed in the middle of the flank. At a diameter of about 4.5 mm, slight shoulders develop at the base of the whorl and just above the middle of the flank. At some diameter between 4.7 and 5.0 mm, the upper shoulder breaks up into slightly bullate tubercles, and the lower shoulder becomes more pronounced. Smaller nodate tubercles form on the lower shoulder at some whorl diameter between 5.7 and 6.0 mm. The area between the two rows of tubercles remains depressed and smooth. At a diameter between 9 and 11 mm a low ridge develops on the underside of the whorl very close to the lower row of tubercles; and at some diameter between 10 and 12 mm, this ridge breaks up into small nodate, clavate, or bullate tubercles.

The holotype (Pl. 4, figs. 14-16) is a spire 40 mm high that consists of four whorls having an apical angle of 17 degrees. The upper row of tubercles, located just above the middle of the flank, has 17 nodate tubercles per whorl. The lower flank row has 23 tubercles per whorl; these are nodate to slightly bullate and are about one-half as large as those in the upper row. The third row, on the underside of the whorl, has bullate tubercles that are slightly smaller than those in the lower flank row.

Neostlingoceras kottlowskii resembles *N. carcitanensis* (Matheron) from the lower Cenomanian in having an acute apical angle, in having its two visible rows of tubercles separated by a smooth depressed area, and in having fewer and larger tubercles in the upper row than it does in the lower. The two species differ, however, in that *N. kottlowskii* has more tubercles per whorl in the upper row. According to Wiedmann and Schneider (1979, p. 657), *N. carcitanensis* has 8-11 tubercles per whorl in the upper row; *N. kottlowskii* has 12-20. The lower Cenomanian turrilitids from Algeria, described by Dubourdieu (1953) as the new species *Hypoturrilites oberlini, H. betieri,* and *H. schneegansi,* have larger and fewer tubercles in the upper row than in the lower rows, but these species differ from *N. kottlowskii* in having an extra row of tubercles on the underside of the whorl.

This species was named for Frank E. Kottlowski, Director of the New Mexico Bureau of Mines and Mineral Resources, both in appreciation of his enthusiastic support of our research on the Upper Cretaceous rocks of New Mexico and in honor of his 30 years of public service with the New Mexico Bureau of Mines and Mineral Resources.

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PLATE 4

(All figures are natural size.)

Figures		*Page*
1–28	*Neostlingoceras kottlowskii* Cobban and Hook, n.sp.	26

1 Paratype USNM 306778, from a limestone concretion 15 m above the base of Mancos Shale at USGS Mesozoic locality D10517 in NE¼NW¼ sec. 13, T. 10 S., R. 8 W., Sierra County, New Mexico.

2 Paratype USNM 306779, from the same locality.

3 Paratype USNM 306780, from the same locality.

4 Paratype USNM 306781, from the same locality.

5 Paratype USNM 306782, from the same locality.

6 Paratype USNM 306783, from the same locality.

7 Paratype USNM 306784, from the same locality.

8 Paratype USNM 306785, from the same locality.

9 Paratype USNM 306786, from the same locality.

10 Paratype USNM 306787, from the same locality.

11 Paratype USNM 306788, from the same locality.

12 Paratype USNM 306789, from a thin-bedded limestone unit 6.5–9.0 m above base of Colorado Formation at USGS Mesozoic locality D10526 in NE¼ sec. 7, T. 21 S., R. 8 W., Luna County, New Mexico.

13 Paratype USNM 306790, from the same locality as fig. 1.

14–16 Holotype USNM 306777, from the same locality as fig. 1.

17 Paratype USNM 306791, from a limestone concretion 3.3 m above the base of the Colorado Formation at USGS Mesozoic locality D10186 in NW¼NW¼ sec. 18, T. 21 S., R. 8 W., Luna County, New Mexico.

18 Paratype USNM 306792 from the same locality as fig. 17.

19 Paratype USNM 306793, from a unit of thin-bedded limestone 3.6–5.1 m above the base of the Colorado Formation at USGS Mesozoic locality D10187 in S½NE¼ sec. 13, T. 21 S., R. 9 W., Luna County, New Mexico.

20 Paratype USNM 306794, from the 1.5-m-thick bed of sandstone at the base of the Colorado Formation at USGS Mesozoic locality D10105 in NW¼NW¼ sec. 18, T. 21 S., R. 8 W., Luna County, New Mexico.

21 Paratype USNM 306795, from the same locality as fig. 19.

22 Paratype USNM 306796, from the same locality as fig. 19.

23 Paratype USNM 306797, from the same locality as fig. 19.

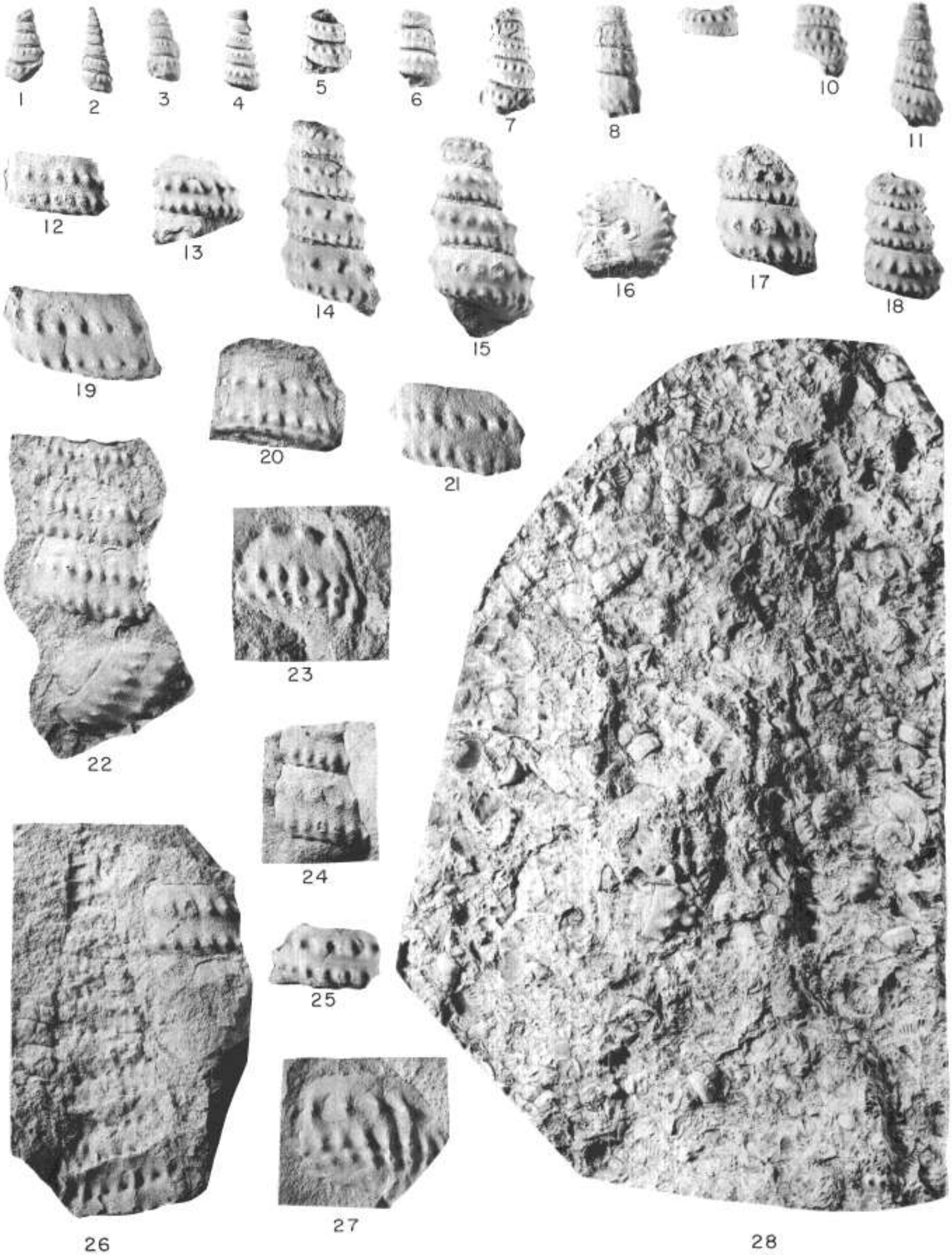
24 Paratype USNM 306798, from the same locality as fig. 20.

25 Paratype USNM 306799, from the same locality as fig. 1.

26 Paratype USNM 306800, from the same locality as fig. 12.

27 Paratype USNM 306801, from a thin-bedded limestone unit 6.7–11.0 m above the base of the Colorado Formation at USGS Mesozoic locality D10107 in NW¼NW¼ sec. 18, T. 21 S., R. 8 W., Luna County, New Mexico.

28 Paratype USNM 306802, from the same locality as fig. 1.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AN UNUSUALLY LARGE SPECIMEN OF THE TURONIAN AMMONITE *HOPLITOIDES* VON KOENEN FROM NEW MEXICO

by William A. Cobban, *Paleontologist, U.S. Geological Survey, Denver, Colorado,* and
Stephen C. Hook, *Paleontologist, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico*

Abstract

A phragmocone of *Hoplitoides wohltmanni* (von Koenen) 371 mm in diameter was found in the upper part of the Mancos Shale below the Tres Hermanos Sandstone Member in northwest Socorro County, New Mexico. The diameter of the complete adult (phragmocone plus body chamber) is estimated at 617-620 mm, which is larger than any previously recorded diameter of *Hoplitoides.* The phragmocone was associated with *Mammites depressus* Powell, an ammonite that occurs near the boundary of the early and middle Turonian.

Introduction

Recently, one of us (Hook) collected a well-preserved internal mold of a very large ammonite that seems referable to *Hoplitoides wohltmanni* (von Koenen) (Pl. 5). The specimen came from the upper part of the Mancos Shale underlying the Tres Hermanos Sandstone Member in northwest Socorro County, New Mexico. Although *Hoplitoides* is a large genus, specimens the size of the one from Socorro County have not previously been reported from the Western Hemisphere.

The specimen is float from a unit of dark-gray noncalcareous shale that contains gray limestone concretions at USGS Mesozoic locality D11318 in SW 1/4 sec. 20, T. 3 N., R. 8 W., D Cross Mountain 7 1/2-minute quadrangle. The only other ammonite species found in this part of the Mancos Shale at this locality is *Mammites depressus* Powell, which can be interpreted as either late early Turonian or early middle Turonian age. Locality D11318 is near localities D7066 and D10299 shown as numbers 42 and 43 on the index map of Cobban and Hook (1980, fig. 1).

The large phragmocone as well as a smaller one are at the National Museum of Natural History, Washington, D.C., and have U.S. National Museum catalog numbers.

ACKNOWLEDGMENTS-R. E. Burkholder, of the U.S. Geological Survey, made the photograph; G. R. Scott and N. J. Silberling, both of the U.S. Geological Survey, critically reviewed this paper.

Systematic paleontology

Family COILOPOCERATIDAE Hyatt, 1903

GENUS *Hoplitoides* von Koenen, 1898

TYPE SPECIES: *Hoplitoides latesellatus* von Koenen, 1898

Hoplitoides wohltmanni (von Koenen, 1898)

Plate 5; Figs. 9, 10

Neoptychites? (Hoplites) wohltmanni von Koenen, 1897, p. 12, p1. 1, fig. 2, pl. 2, figs. 3, 9.
Neoptychites? (Hoplites) lentiformis von Koenen, 1897, p. 11, p1. 2, figs. 1, 4, *7 .*
Hoplitoides wohltmanni (von Koenen), Solger, 1904, p. 133, pl. 5, fig. 7; text figs. 24-27.

Solger (1904, p. 131) summarized this species as having smooth or nearly smooth early whorls with a small siphonal furrow, later whorls with a narrowly rounded venter, and a suture characterized by a large lateral lobe divided into two or three stout branches. The species is large; von Koenen (1897, p. 12) recorded diameters of near 400 mm.

Hoplitoides wohltmanni was originally described from Turonian rocks of west Africa (Cameroon). The species has since been recorded from Trinidad (Reyment, 1972, p. 360, text fig. 4a), and Colombia [Reyment, 1972, p. 364, text figs. 3, 7(5), 8(1)]; and questionably from Nigeria (Reyment, 1955, p. 78, pl. 18, fig. 3; text fig. 36) and New Mexico (Cobban and Hook, 1980, p. 7, pl. 1, figs. 3, 4; text figs. 4, 5).

The large specimen from Socorro County is uncrushed and entirely septate. Its diameter is 371 mm, and its thickness is 132 mm (ratio 0.36). The umbilical diameter is 27.5 mm (ratio 0.07). The specimen is broken at a septum, and only the umbilical part of this septum is preserved. Whether this is the last septum before the body chamber cannot be determined. The diameter of the phragmocone at this septum is estimated to have been 420-438 mm. Assuming this is the last septum and that the body chamber occupied half a whorl, a diameter of about 620 mm is estimated for the entire shell. Very large specimens of *Hoplitoides* occur in

Cameroon. Von Koenen (1897, p. 12, 13) recorded a specimen of *Neoptychites*? (*Hoplites*) *wohltmanni* [*Hoplitoides wohltmanni*] nearly 400 mm in diameter and noted that a large phragmocone of *Neoptychites*? *ingens* von Koenen [*Hoplitoides ingens*] may have come from a specimen about 600 mm in diameter. Other large specimens of *Hoplitoides* from Cameroon were noted or illustrated by Riedel (1932, p. 127, pls. 24, 28, 29). A specimen of *H. sandovalensis* Cobban and Hook (1980, p. 9, pl. 4) from New Mexico has a diameter of 207 mm at the base of the body chamber.

The large specimen from Socorro County is smooth, and the venter, which is visible only on the outer whorl, is narrowly rounded. Another specimen of comparable size was found nearby. Its outer whorls were badly weathered, but the inner whorls at a diameter of 194 mm were well preserved. At this diameter the flanks are smooth, and the venter is narrowly rounded. The specimen was sawed in order to examine the rest of the inner whorls, and the cross section shown in Fig. 9 was obtained. The venter is rounded to a diameter of 4.0 mm. At a diameter of 5.8 mm, the venter is slightly flattened, and at 9.2 mm, it is well flattened. At diameters of 14.8 and 24.5 mm, the venter is sulcate. The venter is flattened at 41.0 mm and narrowly rounded at 69.5 mm.

The external suture (Fig. 10) closely resembles the one shown by von Koenen (1897, pl. 2, fig. 9) for *H. wohltmanni*. The broad, tilted lateral lobe is bifid, and both branches are bifid. This suture is typical of *H. wohltmanni*.

TYPES—Hypotypes USNM 307655, 307656.

Size-estimation techniques

In estimating the complete size of the larger specimen of *Hoplitoides wohltmanni*, we used two techniques that yielded similar results. Both techniques are based on the assumptions that the shell had grown logarithmically and that the growth rate remained constant.

The logarithmic or equiangular spiral is a curve with the property that the angle α between any radius vector and its tangent vector is constant. From this property of the curve, the relationship between the radius vector (r_θ), at angle θ, and α can be immediately derived; namely

$$\ln r_\theta = \theta \text{ cotangent } \alpha + C.$$

In this form of the equation for a logarithmic spiral, a linear relationship exists between the natural logarithm of the radii ($\ln r_\theta$) and the cumulative angle (θ), in radians. The slope of the best-fit line (regression line) yields the cotangent of the constant angle of the spiral, as well as the growth rate of the shell (Gutjahr and Hook, 1981). Fig. 11 shows how our measurements were made, and Fig. 12 shows the resulting plot of the ln r_θ vs. θ and the regression line. By projecting the position of the last septum and the inferred position of the end of the body chamber onto this regression line, the estimated size of the complete adult shell can be obtained. Using this regression method, we estimated the diameter of the complete adult shell at 617 mm and the diameter of the complete phragmocone at 438 mm.

The other estimation technique is a direct-measurement method using two photographs of the specimen that are of different magnification, for example, one natural size and one 60 percent of natural size. The

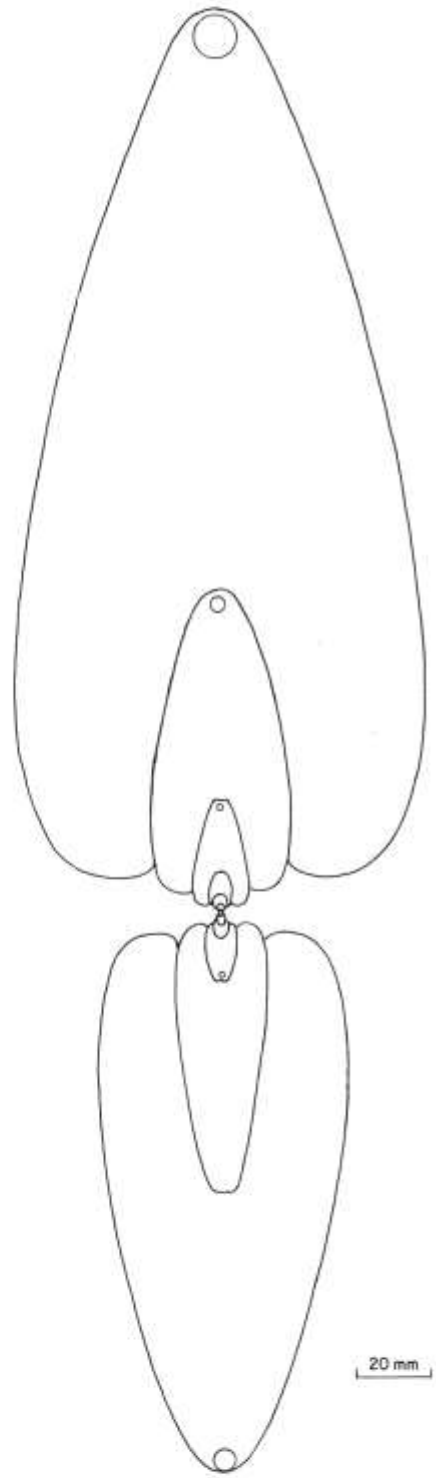

FIGURE 9—CROSS SECTION OF THE INNER WHORLS OF A SPECIMEN OF *HOPLITOIDES WOHLTMANNI* (VON KOENEN) FROM USGS MESOZOIC LOCALITY D11318; HYPOTYPE USNM 307656.

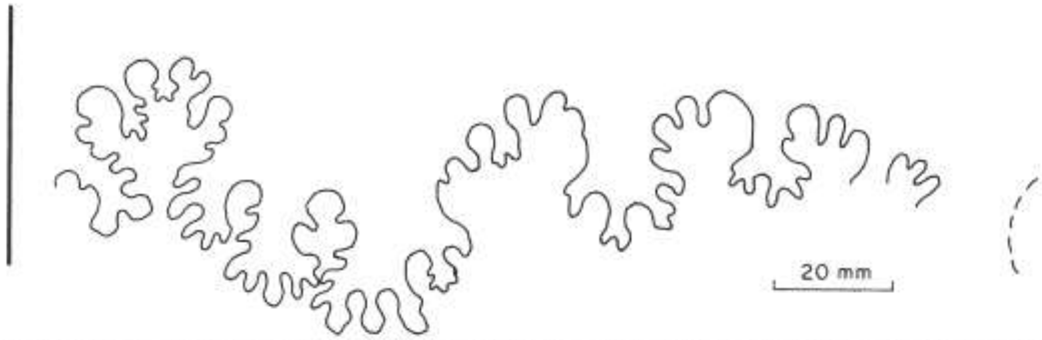

FIGURE 10—EXTERNAL SUTURE OF *HOPLITOIDES WOHLTMANNI* (VON KOENEN), AT A DIAMETER OF 286 MM, FROM USGS MESOZOIC LOCALITY D11318; HYPOTYPE USNM 307655.

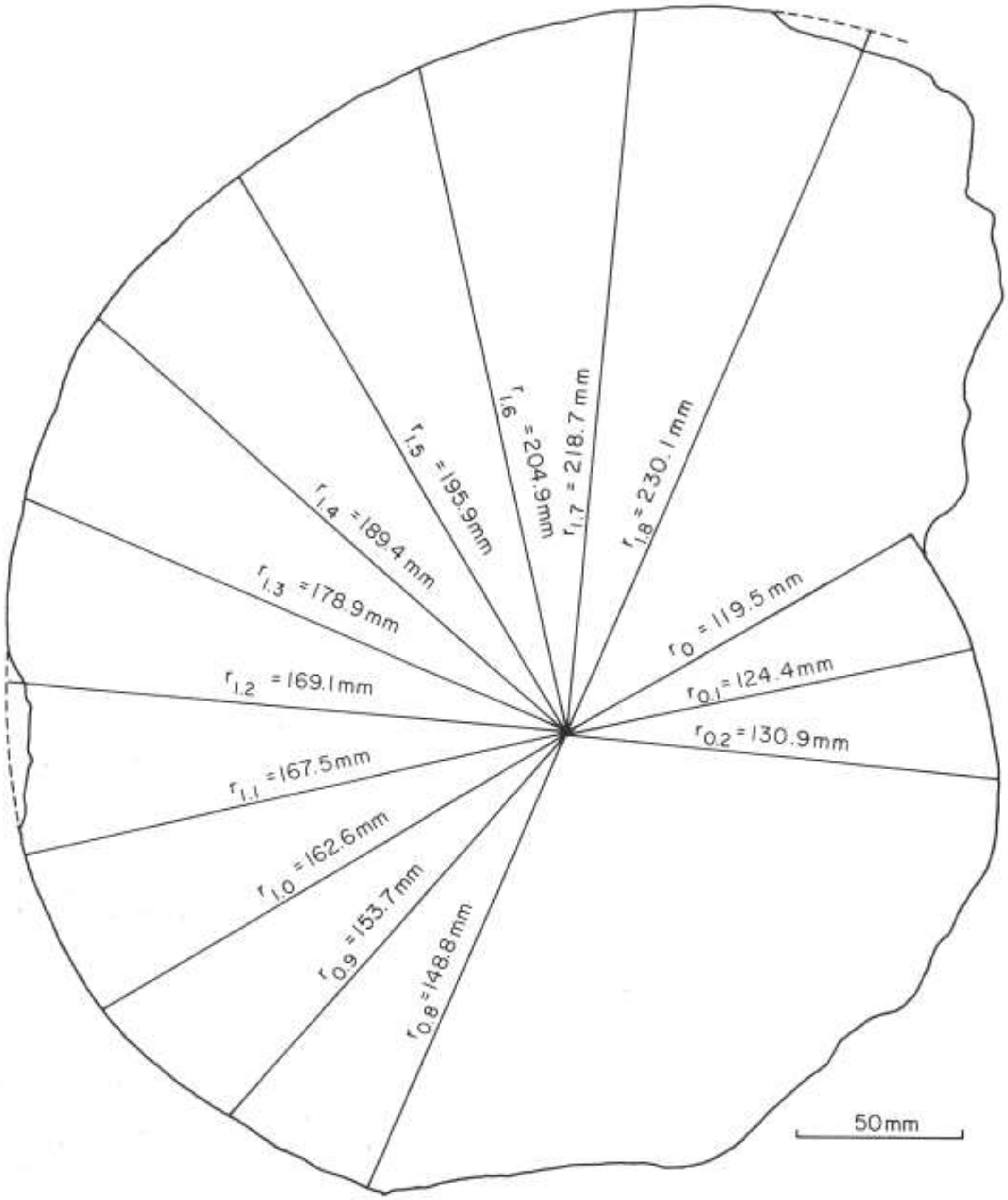

FIGURE 11—DIAGRAM SHOWING RADII MEASUREMENTS (r_θ) RELATIVE TO THE OUTER WHORL OF THE LARGE SPECIMEN OF *HOPLITOIDES WOHLTMANNI* (VON KOENEN); HYPOTYPE USNM 307655.

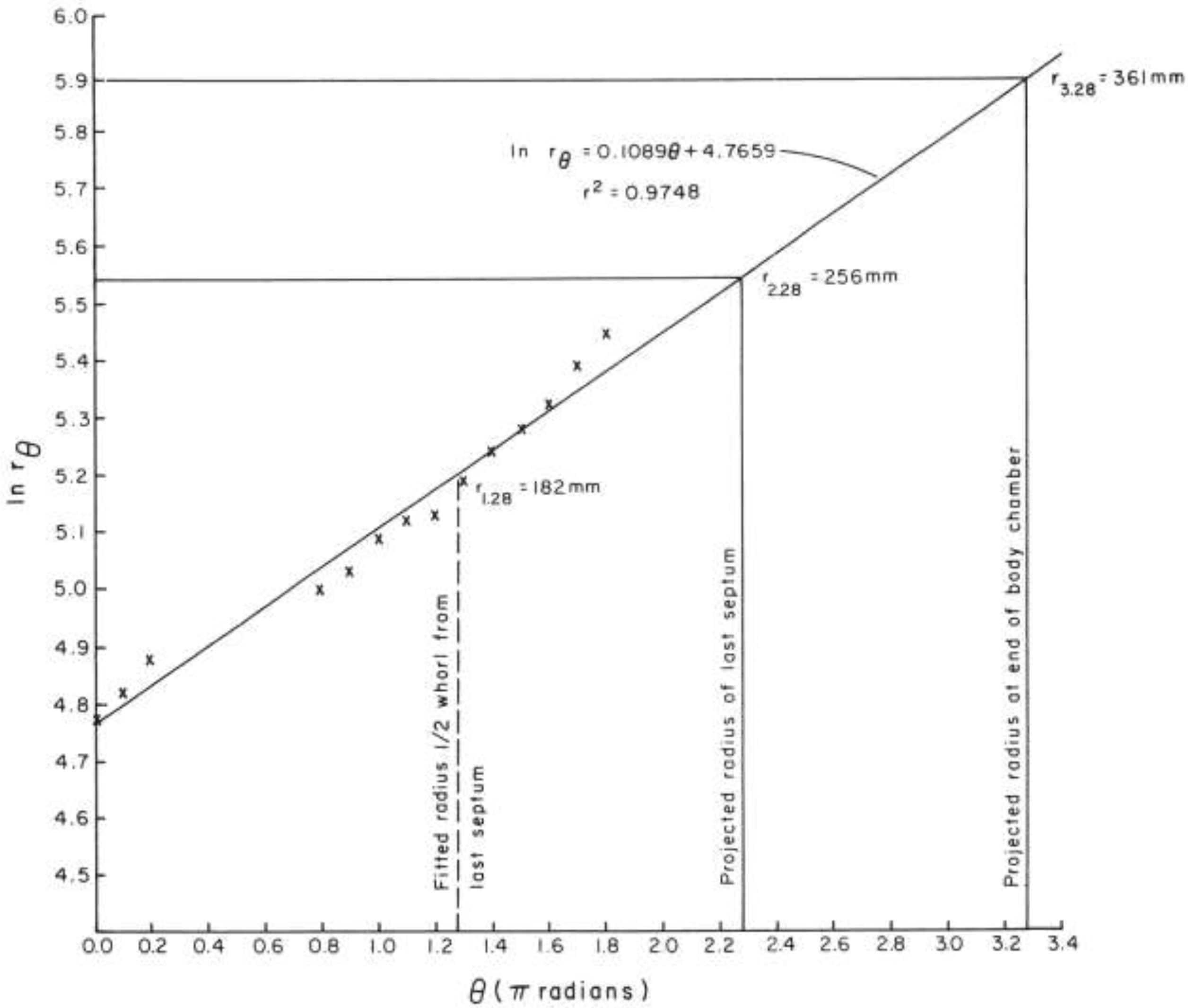

FIGURE 12—GRAPH OF $\ln r_\theta$ VERSUS θ showing best-fit regression line and projected radii at the end of the phragmocone and at the end of the body chamber of the large specimen of *Hoplitoides wohltmanni* (von Koenen); hypotype USNM 307655. The slope of the best-fit line, 0.1089, is the growth rate of the outer whorl; the intercept, 4.7659, is the natural logarithm of the initial radius of the outer whorl; and r^2, the correlation coefficient squared, indicates that 97.48 percent of the observed variation in the data is explained by the linear relationship.

centers of coiling are located on both photographs, and the smaller scale photograph is pinned to the larger through the centers of coiling. The smaller photograph is then rotated until the curvature of the shell matches that on the larger scale photograph. The position of the last septum and of the end of the body chamber are then projected onto the larger scale photograph; the diameters are measured directly on the larger photograph and then converted to natural size. Using this technique, the diameter of the complete shell was estimated at 620 mm and the diameter of the complete adult phragmocone at 420 mm. The estimated diameters using this method are within 5 percent of those obtained using the regression method.

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PLATE 5

Lateral view of a specimen of *Hoplitoides wohltmanni* (von Koenen) from the Mancos Shale at USGS Mesozoic locality D11318 in SW 'A sec. 20, T. 3 N., R. 8 W., Socorro County, New Mexico; hypotype USNM 307655; x 0.62.


50 mm

Typefaces:	Text in 10-pt. English Times, leaded two points References in 8-pt. English Times, leaded one point Display heads in 24-pt. English Times bold
Plate Section:	Reproduced with 300-line screen
Presswork:	Miehle Single Color Offset Harris Single Color *Offset*
Binding:	Saddlestitched with softbound *cover*
Paper:	Cover on 65-1b. Circa 83 miners gold Text on 70-1b. Quintessence Dull
Ink: Cover—PMS 477	Text—Black
Press Run:	750

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