Baculites Baculus Meek and Hayden, 1861 (Earliest Maastrichtian) from the Uppermost Pierre Shale in the Raton basin of Northeastern New Mexico and its Significance

Paul L. Sealey and Spencer G. Lucas
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BACULITES BACULUS MEEK AND HAYDEN, 1861 (EARLIEST MAASTRICHTIAN) FROM THE UPPERMOST PIERRE SHALE IN THE RATON BASIN OF NORTHEASTERN NEW MEXICO AND ITS SIGNIFICANCE

Paul L. Sealey and Spencer G. Lucas

New Mexico Museum of Natural History and Science, 1801 Mountain Road, NW, Albuquerque, NM 87104

Abstract — We document the ammonite *Baculites baculus* Meek and Hayden, 1861 from the uppermost part of the Pierre Shale (22.5 m below the base of the Trinidad Sandstone) west of Raton in northeastern New Mexico. *B. baculus* was also collected from the upper Pierre, 80 km southwest of Raton near Cimarron, about 40 m below the base of the Trinidad Sandstone. The highest ammonite zone previously reported from northeastern New Mexico was the upper Campanian *Baculites reesidei* Zone, and the earliest Maastrichtian *B. baculus* Zone is three ammonite zones higher. *B. baculus* in the uppermost Pierre Shale thus places the Campanian-Maastrichtian stage boundary at the base of that zone in the uppermost Pierre and demonstrates that the Pierre Seaway regressed from northeastern New Mexico later than previously thought.

INTRODUCTION

In the Raton Basin of northeastern New Mexico, the Upper Cretaceous Pierre Shale consists of marine deposits of the Western Interior Seaway during its final regression from the state. Cobban (1976) reported indications of 12 ammonite zones in the Pierre Shale in northeastern New Mexico, listing the ammonites and inoceramids that are the most useful zone indicators. The highest zone reported by Cobban (1976) and Flores (1987) is the upper Campanian *Baculites reesidei* Zone. This zone was inferred by the occurrence of the bivalve *Inoceramus oblongus* Meek, 1871 west of Cimarron (Cobban, 1976) and the ammonite *Hoploscaphites nodosus* (Owen, 1852) 30–45 m below the top of the Pierre Shale near Raton (Flores et al., 1985; Flores, 1987). Lee (1917) also reported *Scaphites nodosus* (*H. nodosus*) about 15 m below the top of the Pierre Shale near Raton. These latter reports of *H. nodosus* from Raton suggest that the uppermost Pierre Shale is no younger than the *B. reesidei-jenseni* Zones in this area based on taxonomic revisions of the *"nodosus* group" of scaphitid ammonites (Landman et al., 2010). However, these scaphites instead may belong to the early Maastrichtian *H.* cf. *H. sargklofak* Landman, Kennedy, and Larson, 2015 group, which is found from the *B. baculus* through the *B. clinolobatus* zones in the Western Interior (Landman et al., 2015) and at a similar stratigraphic position only a few kilometers farther north in the Colorado portion of the Raton Basin (Berry, 2017). They could also be *H. plenus* (Meek and Hayden, 1860) or *H. criptonodosus* (Riccardi, 1983), which occur in the lowermost Maastrichtian *B. baculus* Zone (Larson et al., 1997).

Here, we document the *Baculites baculus* Zone, which is three ammonite zones higher than the *B. reesidei* Zone and supports the inference that scaphitid ammonites from the uppermost Pierre previously attributed to the "*nodosus* group" actually belong to a younger group of scaphitid ammonites. The purpose of the present report is to describe, illustrate and place in a measured stratigraphic section *B. baculus* from the Pierre Shale in the Raton Basin of northeastern New Mexico and to discuss its significance to our understanding of the timing of the regression of the Western Interior Seaway from northeastern New Mexico. In this paper, NMMNH refers to the New Mexico Museum of Natural History and Science, Albuquerque. All dimensions of fossils are given in millimeters.

STRATIGRAPHIC CONTEXT

In the Raton Basin of northeastern New Mexico-southeastern Colorado, the Upper Cretaceous Pierre Shale is 700 m thick (Johnson and Wood, 1956). In northeastern New Mexico, most of this thick stratigraphic unit is in the subsurface or intermittently exposed on the southern High Plains south and southeast of Raton. However, west and southwest of Raton, as far south as Cimarron, the upper ~200 m of the Pierre Shale is exceptionally well exposed in canyons and along the escarpment that borders the western edge of the High Plains.

Along that escarpment, just north of NM–555 west of Raton, about 42 m of the uppermost Pierre Shale are well exposed and fossiliferous. This section (Fig. 1), as elsewhere in the Raton Basin, exposes two distinct facies of the upper Pierre Shale: (1) a lower, offshore marine shale facies, that consists of gray and dark gray shale with a few thin sandstone beds and bentonites as well as horizons of yellowish brown limestone concretions; and (2) an overlying, lower shoreface facies of siltstone and sandy shale with several interbeds of laminar or crossbedded sandstone. Crossbedded sandstone at the base of the Upper Cretaceous Trinidad Sandstone conformably overlies the lower shoreface facies of the Pierre Shale (Fig. 1).

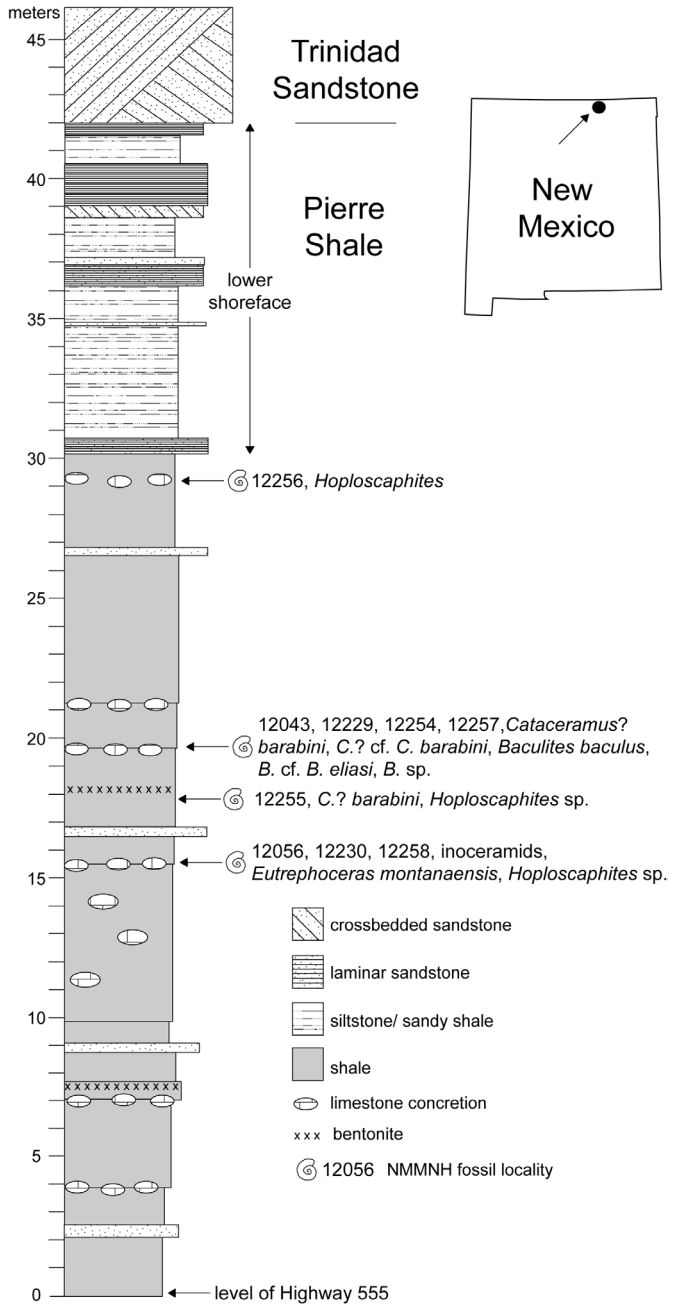

FIGURE 1. Index map and stratigraphic section of the upper part of the Pierre Shale and base of the Trinidad Sandstone in York Canyon west of Raton, showing the stratigraphic position of *Baculites baculus* and other molluscan fossil taxa.

In the offshore marine facies north of NM–555, fossils of ammonites and other mollusks (mostly inoceramid bivalves) are present in the limestone concretion intervals. In our section (Fig. 1), there are four stratigraphic levels with fossils (ascending order):

1. Bed 14 yielded inoceramid bivalves (locality 12056), the nautiloid *Eutrephoceras montanaensis* (locality 12230) and the ammonite *Hoploscaphites* (locality 12258).
2. Bed 18 yielded the inoceramid *Cataceramus*? *barabini*, *Hoploscaphites* and an unidentified heteromorphic ammonoid (locality 12255).
3. Bed 20 yielded *Cataceramus*? *barabini*, *Baculites baculus* (locality 12043), *Cataceramus*? cf. *C. barabini*, *Baculites* cf. *B. eliasi* (locality 12257), and *Baculites* sp. (localities 12229, 12254).
4. A concretion level 1 m below the top of bed 25 yielded *Hoploscaphites* (locality 12256).

Particularly significant is the occurrence of *Baculites baculus* documented here, 22.5 m below the base of the Trinidad Sandstone, as it indicates an early Maastrichtian age (see later discussion).

Baculites baculus is also present in the upper Pierre Shale at Cerrososo Canyon, 80 km southwest of Raton, and we also document that record here. However, our stratigraphic studies at Cerrososo Canyon are not complete, so we only estimate its stratigraphic distance below the base of the Trinidad Sandstone. This distance is ~40 m, which is to be expected, as all time lines (in this case base of the Maastrichtian) in the upper Pierre-Trinidad stratigraphic interval should climb stratigraphically to the northeast as that is the direction in which the Western Interior Seaway regressed during the latest Cretaceous.

AMMONITE ZONES

Cobban (1976) reported 12 ammonite zones in the Pierre Shale in northeastern New Mexico. We also recognize these zones and one additional zone, the *Baculites baculus* Zone (Table 1). These ammonite zones contain other index mollusks including other ammonites, nautiloids, bivalves and gastropods (Table 2).

SYSTEMATIC PALEONTOLOGY

Phylum MOLLUSCA
Class CEPHALOPODA Cuvier, 1797
Order AMMONOIDEA Zittel, 1884
Suborder AMMONITINA Hyatt, 1889
Family BACULITIDAE Gill, 1871
Genus *BACULITES* Lamarck, 1799
Baculites baculus Meek and Hayden, 1861
Figures 2-3

1861 *Baculites baculus* Meek and Hayden, p. 445.
1876 *Baculites ovatus* var. *baculus* Meek and Hayden; Meek, p. 397, text-figs. 51, 52.
1973 *Baculites baculus* Meek and Hayden; Gill and Cobban, p. 10, text-figs. 3d, 7a.
1983 *Baculites baculus* Meek and Hayden; Riccardi, pl. 26, figs. 6-10.
1993 *Baculites baculus* Meek and Hayden, 1861; Kennedy, p. 110, pl. 4, figs. 10, 20, 21.
1997 *Baculites baculus* Meek and Hayden, 1861; Larson et al., p. 34, 38, unnumbered figs.

Holotype: The holotype is from the "Fox Hills Sandstone near Glenrock, Wyoming" and is the original of Meek (1876, text-figs. 51, 52).

Referred Material: NMMNH locality 12043: P-80460, large, incomplete adult; NMMNH locality 12251: P-80462, partial shell; NMMNH locality 12252: P-80463, partial shell.

TABLE 1. Western Interior biostratigraphic ammonite zones present in the Pierre Shale in the Raton Basin in northeastern New Mexico with corresponding inoceramid zones. A single asterisk means the index taxon has been collected from the study area. A double asterisk signifies an inferred zone. Table modified from Slattery et al. (2018, fig. 3).

Stage	Substage	Ammonite Zone	Inoceramid Zone
Maas. (pars)	Lower	*Baculites clinolobatus*	"*Inoceramus*" *balchii*
		Baculites grandis	*Trochoceramus radiosus*
		*Baculites baculus**	"*Inoceramus*" *incurvus*
			*Endocostea typica***
Campanian (pars)	Upper	*Baculites eliasi*	"*Inoceramus*" *redbirdensis*
		Baculites jenseni	"*Inoceramus*" *oblongus**
		*Baculites reesidei***	
		*Baculites cuneatus***	"*Inoceramus*" *altus***
		*Baculites compressus***	
		*Didymoceras cheyennense**	
		*Exiteloceras jenneyi**	*Sphaeroceramus pertenuiformis***
		*Didymoceras stevensoni**	
		*Didymoceras nebrascense**	*"Inoceramus" tenuilineatus***
	Middle	*Baculites scotti**	
		Baculites reduncus	
		*Baculites gregoryensis**	
		*Baculites perplexus**	*Cataceramus subcompressus***
		Baculites sp. (smooth)	
		*Baculites asperiformis**	
		Baculites maclearni	*"Inoceramus" azerbaydjanensis*
		Baculites obtusus	
	Lower	*Baculites* sp. (weak flank ribs)	
		Baculites sp. (smooth)	*Cataceramus balticus**
		Scaphites hippocrepis III*	

Description: NMMNH P-80460 from locality 12043 is a moderately preserved, large, incomplete, adult shell of *Baculites baculus* in two pieces, slightly flattened on one lateral side (Fig. 2). The smaller piece, which is all phragmocone, has a stoutly ovate cross section with a flattened dorsum and broadly rounded venter. The venter and dorsum are smooth. The flanks bear moderately strong, broad, crescentic ribs (Kennedy, 1993, p. 110). The poorly-preserved suture has simple, broad, rectilinear elements (Kennedy, 1993, p. 110). The larger piece, mostly body chamber, has a length of 215 mm and a maximum diameter of 65.3 mm. The cross section is stout and almost quadrate, with the venter a little narrower than the dorsum. The flanks bear low, but fairly strong, broad, arcuate undulations that efface before the ventrolateral shoulder. The degree of taper is low. These are characteristics of *B. baculus* (Meek and Hayden, 1861, p. 445).

NMMNH P-80462 (Fig. 3A-D) from locality 12251 is a moderately well preserved partial shell of *Baculites baculus* with iridescent nacreous layer. The cross section is stout ovate with a flattened dorsum and broadly rounded flanks and venter. The flanks bear strong, broad, arcuate undulations that start at the dorsolateral shoulder and occupy most of the flank. At the upper flank, the undulations project sharply forward as ribs that arc at a sharp angle over the venter, where they become weak striations. Numerous weak striations also form a broad, convex arc over the dorsum. The shell has a low angle of taper.

NMMNH P-80463 (Fig. 3E-H) from locality 12252 is a fairly well preserved partial shell of *Baculites baculus* with an iridescent nacreous layer. It has a stout, ovate cross section with slightly rounded flanks, a flattened dorsum and a much narrower, rounded venter. The flanks bear low, fairly broad, arcuate undulations on their lower two-thirds. From the upper flanks, these undulations or ribs project sharply forward and cross the venter as weak, convex striations. In turn, they project forward over the dorsolateral shoulder and cross the dorsum as faint convex striations on the shell layer.

Remarks: The NMMNH specimens of *Baculites baculus* are most similar to their smaller, presumed ancestor *B. undatus* Stephenson, 1941, which occurs much lower in the section with

TABLE 2. Associated fauna by ammonite zone and locality in the Pierre Shale in the Raton Basin, New Mexico. Locality numbers with an L prefix = NMMNH localities and those with a D prefix or no prefix = USGS localities.

Ammonite Zone	Locality nos.	Specimens
Scaphites hippocrepis III	8352, D4835, D4836, D3647	*Cataceramus balticus* (Böhm, 1907), *Glyptoxoceras* sp., *Baculites* sp., *Scaphites* (*Scaphites*) *hippocrepis* (DeKay, 1828) III Cobban, 1969
Baculites asperiformis	D4838	Inoceramids, *Glyptoxoceras*?, *Baculites asperiformis* Meek, 1876
Baculites perplexus	D3653, D7017	*Cataceramus*?, *Baculites perplexus* Cobban, 1962a
Baculites gregoryensis	D6030	Inoceramids, *Eutrephoceras* sp., *Placenticeras* sp., *Didymoceras* sp., *Baculites gregoryensis* Cobban, 1952
Baculites scotti	D4814, D4815, D7488, D7489, D7492	*Cymbophora* sp., "*Inoceramus*" *convexus* Hall and Meek, 1855, *Drepanochilus* sp., *Baculites scotti* Cobban, 1958
Didymoceras nebrascense	D4817, D7012	"*Inoceramus*" aff. "*I.*" *convexus* Hall and Meek, 1855, *Didymoceras nebrascense* (Meek and Hayden, 1856)
Didymoceras stevensoni	6561, D4819, D7007, D7009	*Ostrea plumosa* Morton, 1833, inoceramids, *Placenticeras meeki* Böhm, 1898, *Didymoceras stevensoni* (Whitfield, 1877), *Solenoceras* cf. *S. crassum* (Whitfield, 1877), *Baculites crickmayi* Williams, 1930, *Baculites* cf. *B. rugosus* Cobban, 1962b, *Hoploscaphites* sp.
Exiteloceras jenneyi	5731, D4572, D4820, D11609, L-12047, L-12055	Inoceramids, *Eutrephoceras* sp., *Placenticeras meeki* Böhm, 1898, *Exiteloceras jenneyi jenneyi* (Whitfield, 1877), *Baculites crickmayi* Williams, 1930, *Baculites rugosus* Cobban, 1962b
Didymoceras cheyennense	5594, D11602, D4825	"*Inoceramus*" sp., *Eutrephoceras* sp., *Didymoceras cheyennense* (Meek and Hayden, 1856), *Baculites rugosus* Cobban, 1962b (late form), *Baculites corrugatus* Elias, 1933, *Hoploscaphites nodosus* (Owen, 1852), *Hoploscaphites brevis* (Meek, 1876)
Baculites compressus?	D7484, D4826	*Pseudoperna* cf. *P. congesta* (Conrad, in Nicollet, 1843), *Lucina* sp., *Astarte evansi* (Hall and Meek) Whitfield, 1880, "*Inoceramus*" sp., *Baculites undatus* Stephenson, 1941, *Hoploscaphites* cf. *H. rugosus* (Stephenson, 1941)
Baculites cuneatus?	D4828, D4829	"*Inoceramus*" cf. "*I.*" *oblongus* Meek, 1871, *Placenticeras* sp., *Baculites* aff. *B. rugosus* Cobban, 1962b
Baculites reesidei?	D4830	"*Inoceramus*" *oblongus* Meek, 1871, *Placenticeras costatum* Hyatt, 1903
Baculites baculus	L-12043, L-12251, L-12252	Solitary corals, *Cataceramus*? *barabini* (Morton, 1834), *Eutrephoceras montanaensis* (Meek, 1876), *Placenticeras* cf. *P. meeki* Böhm, 1898, *Placenticeras* cf. *P. costatum* Hyatt, 1903, *Baculites* cf. *B. eliasi* Cobban, 1958, *Baculites baculus* Meek and Hayden, 1861, *Hoploscaphites* sp.

a range of 45-61 m (150-200 ft) below the top of the Pierre Shale west of Raton and 79-88 m (260-290 ft) below the top west of Cimarron (Cobban, 1976). Likewise, at Berwind Canyon in south-central Colorado, *B. undatus* occurs within the lowest exposures of the Pierre Shale in the canyon (Berry, 2016; Sealey et al., 2019, *this volume*). *B. grandis* Hall and Meek, 1855, the descendant of *B. baculus* and the index taxon of the next higher ammonite zone, is larger and has an almost trigonal cross section. Additionally, *B. grandis* is known only from the northern part of the Raton Basin, where it has been collected from three localities in south-central Colorado (Berry, 2016, 2017).

Occurrence: Lowermost Maastrichtian *Baculites baculus* Zone.

DISCUSSION

Sealey and Lucas (2018) first reported the occurrence of *Baculites baculus* in the uppermost Pierre Shale near Raton in an abstract. *B. baculus* has been reported from the Pierre Shale in Colorado, Wyoming and from the Craie phosphatée de Ciply of Cuesmes in Belgium (Gill and Cobban, 1966; Kennedy, 1993; Berry, 2010, 2016, 2018). Riccardi (1983) documented *B. baculus* from the Bearpaw Formation in Saskatchewan. Larson et al. (1997) reported *B. baculus* from Colorado to eastern Montana and farther north in Alberta and Saskatchewan. *B. baculus* has also been reported from the Pierre Shale at Berwind Canyon in south-central Colorado (Berry, 2010, 2016; Sealey et al., 2019, *this volume*).

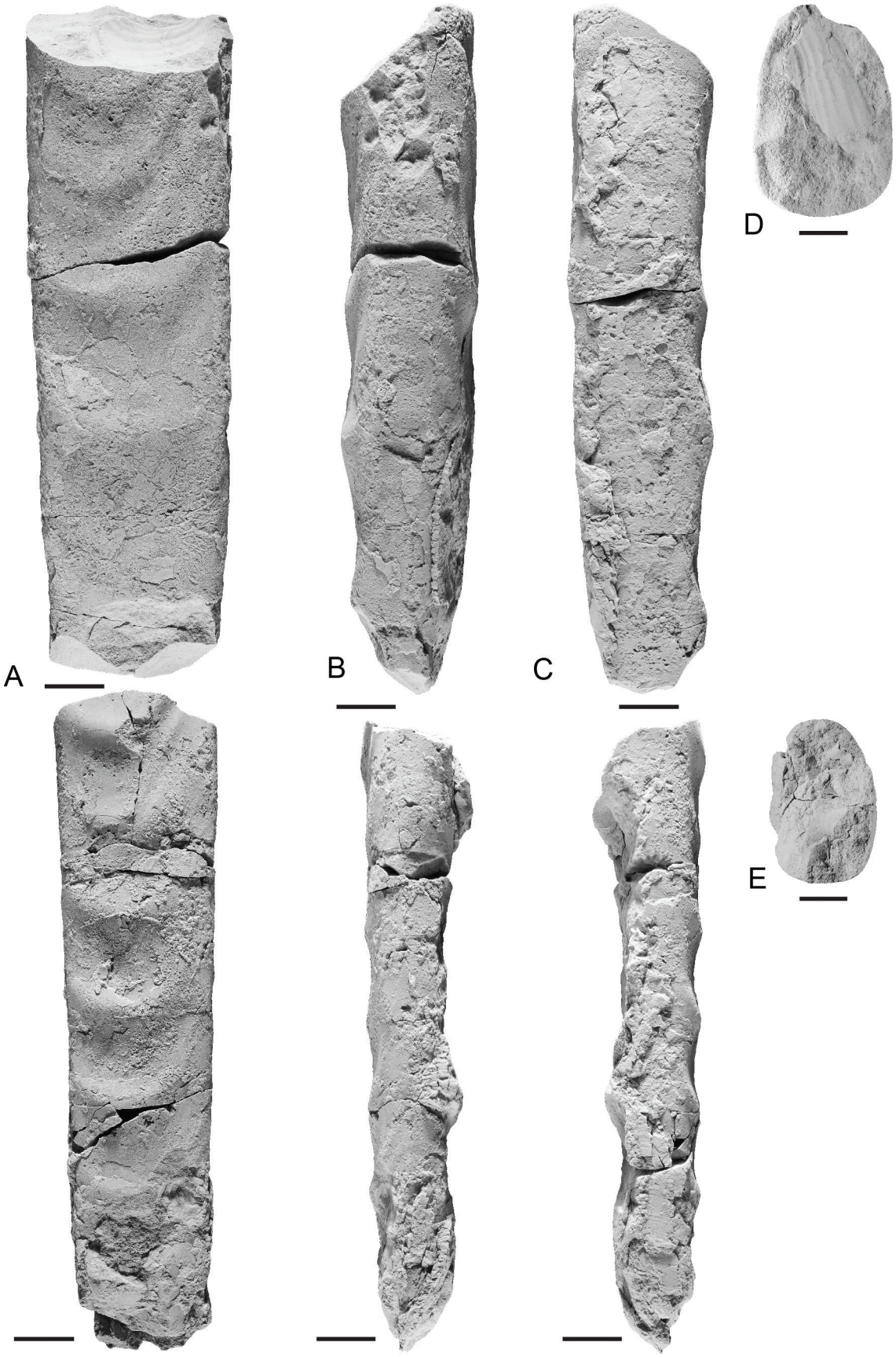

FIGURE 2. *Baculites baculus* Meek and Hayden, 1861 from the uppermost Pierre Shale west of Raton in York Canyon. **A-E** (in two parts), **A**) lateral, **B**) ventral, **C**) dorsal, **D**) adoral cross section of body chamber, and **E**) adoral cross section of phragmocone, NMMNH P-80460 from locality 12043. Scale bars equal 2 cm.

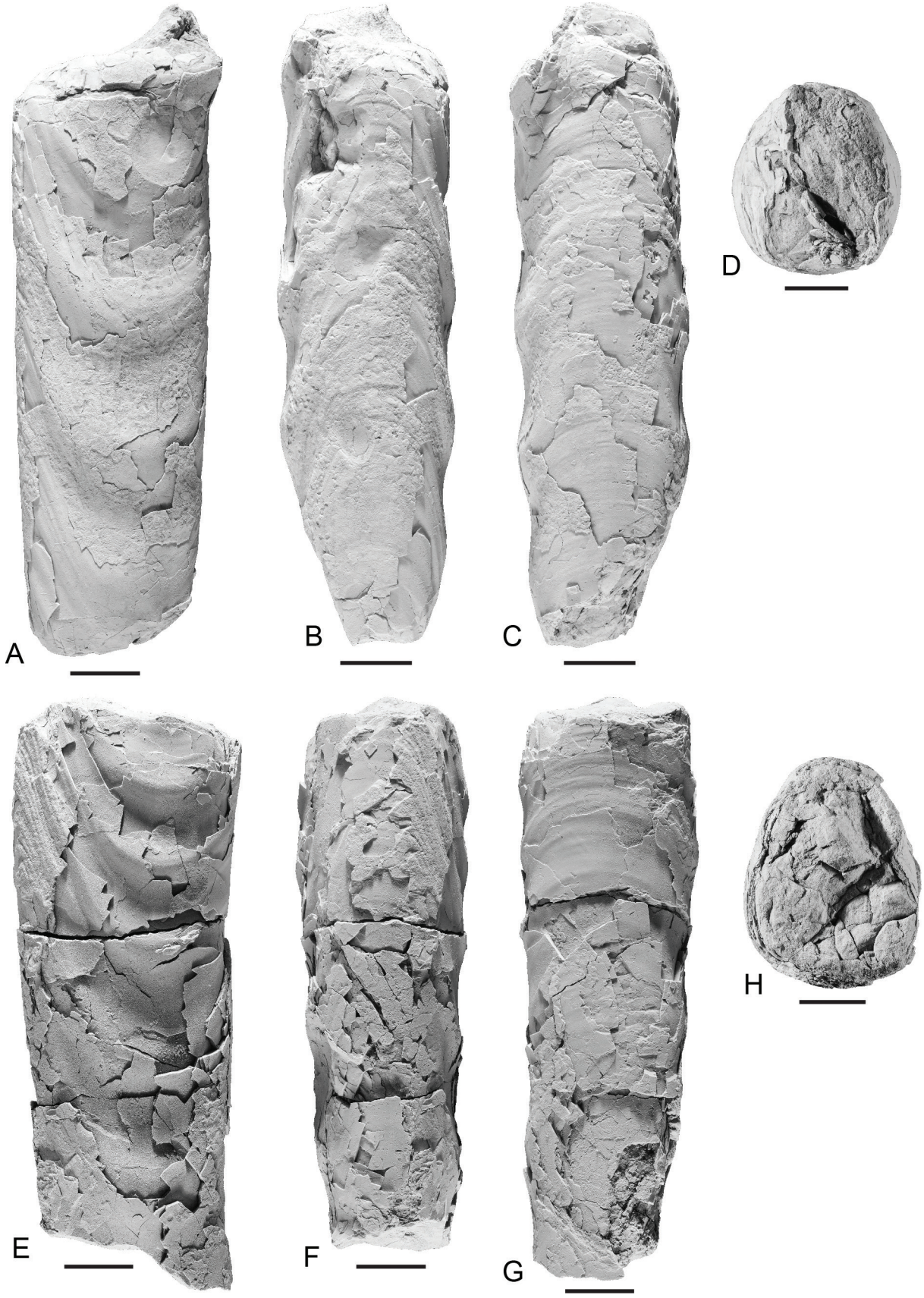

FIGURE 3. *Baculites baculus* Meek and Hayden, 1861 from the upper Pierre Shale 80 km southwest of Raton in Cerrososo Canyon. **A-D**, **A**) lateral, **B**) ventral, **C**) dorsal and **D**) adapical cross sectional views, NMMNH P-80462 from locality 12251; **E-H**, **E**) lateral, **F**) ventral, **G**) dorsal and **H**) cross sectional views, NMMNH P-80463 from locality 12252. Scale bars equal 2 cm.

Using palynostratigraphy, Tschudy (1973) placed the Campanian-Maastrichtian stage boundary near the top of the Vermejo Formation in northeastern New Mexico. However, because the *Baculites baculus* Zone is in the uppermost Pierre Shale west of Raton, this places the Campanian-Maastrichtian stage boundary at the base of that zone, stratigraphically well below the Vermejo Formation. The boundary is further constrained by the occurrence of a juvenile of *Baculites* cf. *B. eliasi* within the *B. baculus* Zone in the uppermost Pierre there. *B. eliasi* and *B. baculus* co-occur near the base of the *B. baculus* Zone in the Western Interior (Gill and Cobban, 1966; Larson et al., 1997, p. 144; Berry, 2016, p. 76).

Importantly, we also collected the index inoceramid *Cataceramus*? *barabini* (Morton, 1834) from the lower Trinidad at Vermejo Park. As *C. barabini* is characteristic of the *B. eliasi*-*B. baculus* zones in the Western Interior (Walaszczyk et al., 2001), this presumably means that the *B. baculus* zone extends locally into the Trinidad Sandstone. Likewise, Lee (1917) reported *C. barabini* from near the top of the Pierre Shale at Vermejo Park and from the top of the Pierre and middle Trinidad at Raton.

Across northern New Mexico, the shoreline of the Western Interior Seaway regressed to the north and northeast during late Campanian to early Maastrichtian time. The uppermost lower Maastrichtian *Baculites clinolobatus* Zone occurs in the uppermost part of the Pierre Shale near Trinidad, Colorado (Berry, 2018). The first/last occurrences (FO/LO) of the *B. clinolobatus* Zone are 69.67/69.28 Ma and the FO/LO of the *B. baculus* Zone are 72.18/70.62 Ma (Scott, 2014). By these estimates of the LO of *B. baculus* and the FO of *B. clinolobatus*, regression of the Pierre Seaway from Raton to Trinidad, took slightly less than one million years. Therefore, the occurrence of the *Baculites baculus* Zone in the Raton area establishes an earliest Maastrichtian age for the uppermost Pierre Shale there, places the Campanian-Maastrichtian stage boundary at the base of that zone in the uppermost Pierre and demonstrates that the Pierre Seaway regressed from northeastern New Mexico during early Maastrichtian time.

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