STRATIGRAPHIC FRAMEWORK AND CORRELATION OF A PRINCIPAL REFERENCE SECTION OF THE MANCOS SHALE (UPPER CRETACEOUS), MESA VERDE, COLORADO

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Abstract—A principal reference section is proposed for the Mancos Shale in its type area of southwestern Colorado (northern rim of the San Juan Basin). The section is located at the north end of Mesa Verde National Park, where the exposures were trenched and the rocks described with centimeter-scale resolution through the 682 m formation. The Mancos was thoroughly examined for fossils and a molluscan biostratigraphy is presented herein. In addition, bulk samples were collected throughout and a detailed gamma-ray survey conducted, thereby permitting correlation with subsurface geophysical logs. The Mancos Shale spans the upper Cenomanian through basal Campanian Stages at the Mesa Verde principal reference section, and is bounded by the Dakota Sandstone below and the Point Lookout Sandstone above. Eight members are recognized, two of which are new. Stratigraphic nomenclature of the Colorado Front Range can be applied in this region of the Colorado Plateau. The upper Cenomanian Graneros Member overlies the Dakota Sandstone and is 24.1 m thick. Numerous thin beds of light-gray limestone and marlstone characterize the lower to middle Turonian Bridge Creek Limestone Member, which is 13.8 m thick at Mesa Verde. The Fairport, Blue Hill, and Juana Lopez Members are 28.2, 75.5 m, and 42.6 m thick, respectively. Several ledges or benches of well-cemented fossiliferous calcarenite mark the middle and upper parts of the upper Turonian Juana Lopez Member. The 16.2 m-thick upper Turonian Montezuma Valley Member is named herein; it correlates with the upper part of the D-Cross Tongue of the Mancos Shale in the southern and southwestern parts of the San Juan Basin. At Mesa Verde, a major regional disconformity separates uppermost Turonian rocks of the *Prionocyclus quadratus* ammonite zone from upper middle Coniacian rocks of the *Scaphites ventricosus* Zone. The "Carlile-Niobrara" disconformity is represented by a sharp shale-on-shale contact and disseminated glauconite and fine quartz sand in the basal meters of the overlying Smoky Hill Member. The Smoky Hill Member (middle Coniacian-middle Santonian) is 88.6 m thick, the upper 23 m of which forms a prominent gray bench of calcareous shale. This unit correlates with the upper part of the lower shale, lower limestone and middle shale units of the Smoky Hill Member, Niobrara Formation, near Pueblo, Colorado. Capping the Mancos Shale section is the 393.0 m-thick upper Santonian-basal Campanian Cortez Member, named herein. Six informal units representing two coarsening upwards sequences are recognized within the Cortez Member. The lowest of these informal units (289.0–335.7 m) is gradational with the underlying Smoky Hill Member and correlates with the uppermost part of the middle shale unit and the middle chalk unit of the Smoky Hill Member, Niobrara Formation. A middle sandy unit (389.6–451.7 m) may partially correlate with the Emery Sandstone of central Utah. The uppermost part of the Cortez Member contains sandy mudstone and thicker sandstone beds, and is gradational with the overlying Point Lookout Sandstone through a 22 m interval (660–682 m). The principal reference section of the Mancos Shale is an important lithostratigraphic and biostratigraphic tie point between the thick siliciclastic-dominated sequences deposited on the western margin of the Western Interior Sea, and the thinner carbonate-rich central and eastern sequences.

INTRODUCTION

The Mancos Shale is a thick, widespread Upper Cretaceous formation of the Colorado Plateau region, where the unit consists predominantly of marine shales and mudstones (Fig. 1). Subordinate lithologies include thin beds of limestone, calcarenite, bentonite, concretions, dolomitic mudstone and sandstone. The Mancos is bounded below by the transgressive Dakota Sandstone and above by regressive deposits of the Mesa Verde Group, among others, including the Tres Hermanos Formation, Gallup Sandstone, Crevasse Canyon Formation, Toreva Sandstone, Straight Cliffs Formation, Blackhawk Formation and Point Lookout Sandstone (Dyman et al., 1993; Elder and Kirkland, 1993a, b). In the northern part of the San Juan Basin, the Mancos Shale records nearly continuous marine deposition from late Cenomanian to earliest Campanian time.

This paper summarizes the lithostratigraphy and molluscan biostratigraphy of the Mancos Shale in the type area, southwestern Colorado (northern rim of the San Juan Basin). Because an adequately defined or described type section had not been designated previously, we are establishing a principal reference section for the Mancos Shale. The Mancos Shale was named by Cross (in Cross and Purington, 1899) for "typical exposures" that occur in the Mancos River Valley between the LaPlata Mountains and Mesa Verde near Mancos, Colorado (Fig. 2). He estimated a thickness of 1200 ft in the type area and furnished a brief description. While acknowledging that fossils of the Mancos Shale are characteristic of several distinct formations east of the Front Range, Cross concluded that subdivision of the Mancos west of the Front Range is not practical.

Cross et al. (1899, p. 4) noted that "the whole formation is well exposed along the north face of the Mesa Verde near Mancos" and included (fig. 3) a photograph of Mancos Shale slopes along the northern edge of Mesa Verde, where today the national park is located (Fig. 3). Later investigators measured and described the nearly continuous exposures of Mancos Shale along the northern face of Mesa Verde National Park, below the sandstone cliffs that form the prominent erosional headland known as Point Lookout. The first detailed study of the Mancos Shale in the type area was that of Pike (1947), who described the lithology and collected fossils from a section below Point Lookout. He recognized five faunal zones within the 668 m section. Wanek (1959) measured 609 m of Mancos Shale but excluded the transitional interval with the overlying Point Lookout Sandstone. We measured a total Mancos thickness of 682 m in the section exposed below Point Lookout and recognize eight members, two of which are new (Fig. 4; Table 1).

We propose the Mesa Verde section as the principal reference section for the Mancos Shale because (1) this section lies within the type area as defined by Cross (in Cross and Purington, 1899), (2) this is the only place in or near the type area where a complete Mancos Shale section, from the Dakota Sandstone below to the Point Lookout Sandstone above, can be measured and described, and (3) we were able to trench the entire Mancos section so as to expose fresh rock, describe the section with centimeter-scale detail, conduct a thorough macrofossil survey, and collect closely spaced gamma-ray data that permit correlation of the outcrop section with nearby subsurface geophysical logs through the Mancos Shale.

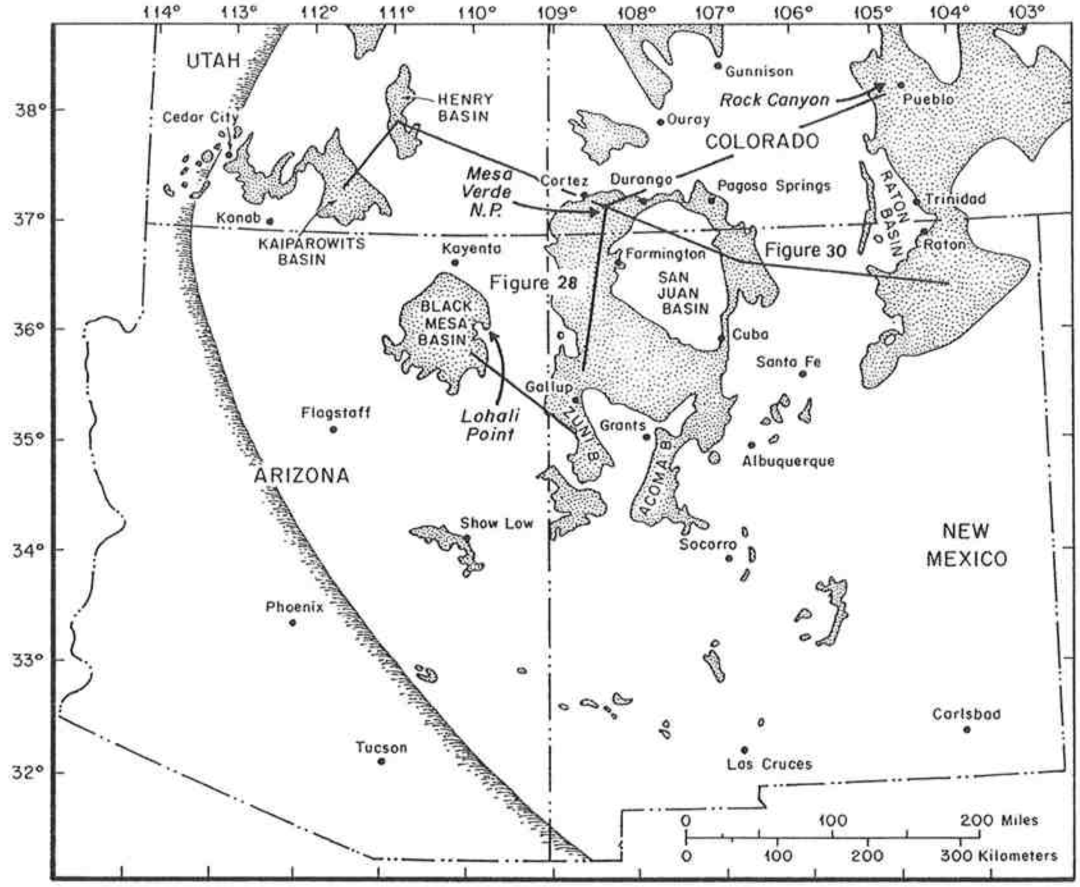

FIGURE 1. Map depicting Cretaceous outcrops (stippled) of the southern Colorado Plateau and adjacent areas (modified after Molenaar, 1983). Curved line through Utah and Arizona shows the approximate position of the western shoreline at peak transgression of the Western Interior Sea during early Turonian time (Molenaar, 1983; Cobban and Hook, 1984) (from Leckie et al., 1991).

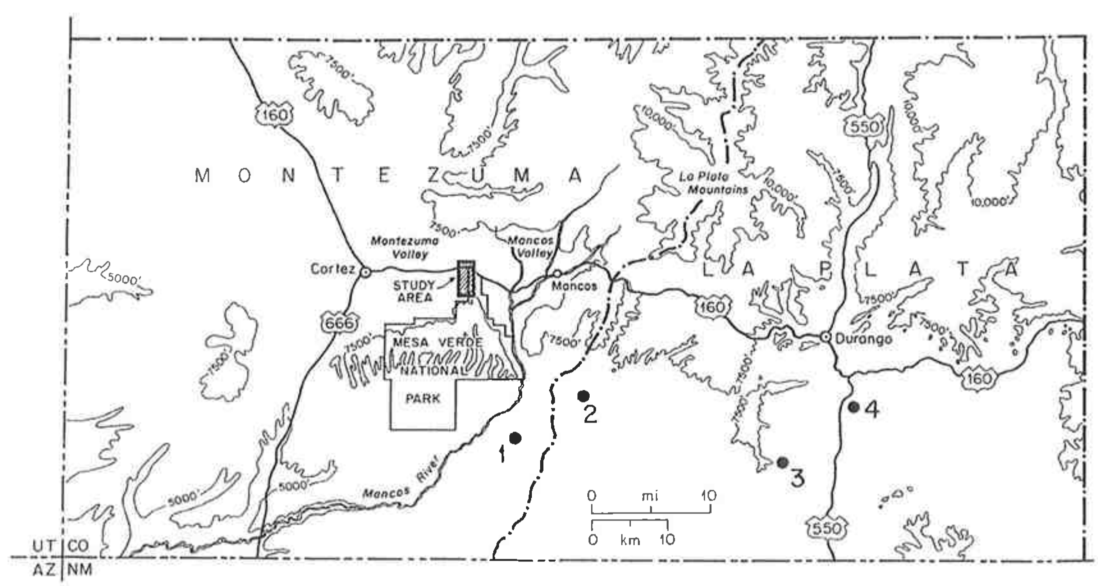

FIGURE 2. Map of La Plata and Montezuma counties, Colorado, showing location of Mesa Verde National Park and the principal reference section of the Mancos Shale (diagonal ruling). Numerals (1–4) mark the locations of boreholes that yielded geophysical log profiles that we correlated with the Mancos outcrop gamma-ray profile (Fig. 9). 1 = Houston Oil & Minerals Corp. Ute Mountain No. 44–34 (sec. 34, T34N, R14W); 2 = Cities Service Oil Co. Story A No. 1 (sec. 15, T34N, R13W); 3 = Skelly Oil Co. Ute-E No. 1 (sec. 9, T33N, R10W) (= Well #34 of Molenaar and Baird, 1989); 4 = Fuelco Craig No. 1 (sec. 16, T34N, R9W) (= Well #8 of Molenaar and Baird, 1989).

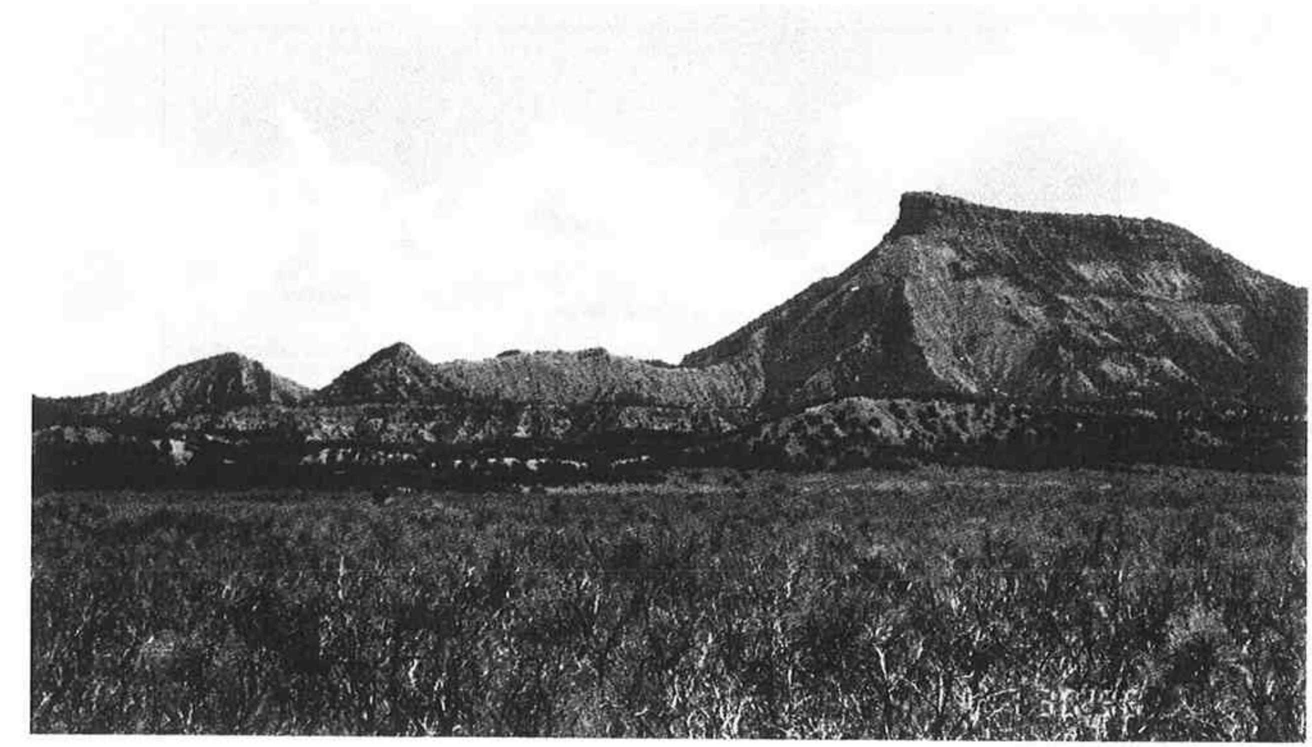

FIGURE 3. Mancos Shale principal reference section as viewed from the northwest. Point Lookout forms the prominent erosional headland at the north end of Mesa Verde National Park (see Fig. 5). Low slopes in the foreground are capped with orange-weathering calcarenite beds of the upper Juana Lopez Member of the Mancos Shale. Behind these slopes and in front of the long erosional ridge extending below Point Lookout is a continuous, horizontal bench marking the contact between the Smoky Hill and Cortez Members of the Mancos Shale (compare with Fig. 18).

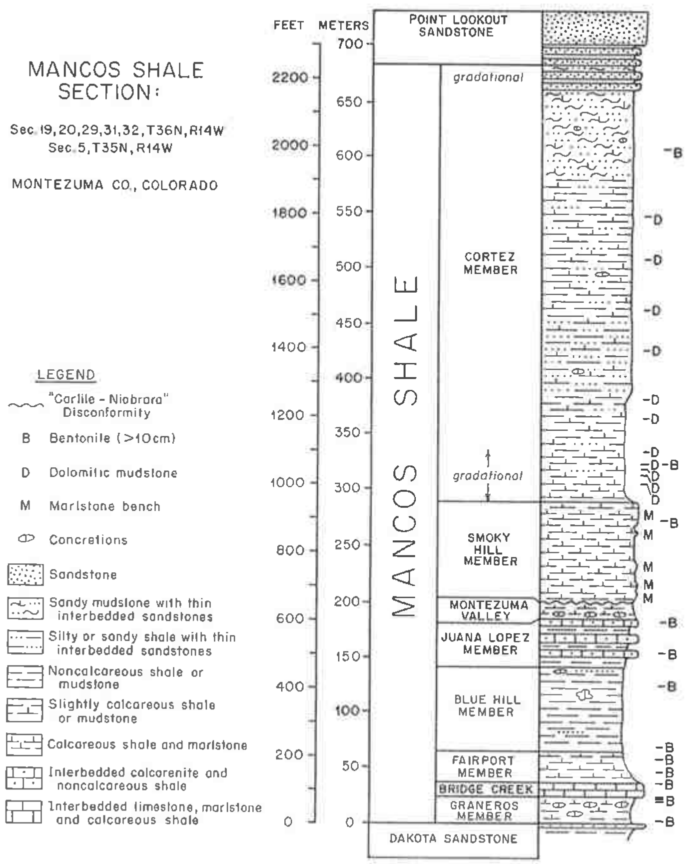

FIGURE 4. Generalized graphic section of the Mancos Shale principal reference section at Mesa Verde. See Figure 2 for location.

METHODS

The Mancos Shale at Mesa Verde was measured, described, and sampled during the summers of 1988 and 1989. Measurement of a complete stratigraphic section was made possible by the occurrence of numerous key beds (e.g., bentonite, limestone, calcarenite, dolomitic mudstone, sandstone) that are scattered throughout the formation (Fig. 4). Bentonite beds are particularly useful in the lower third of the section where the relief is low and stratigraphic subsections are short. We recognized 188 bentonite beds (91 of these are in the lower 220 m of the section); 21 are 5–10 cm in thickness and 14 are greater than 10 cm. In addition, there are numerous (>60) limonite seams, particularly in the Fairport, Montezuma Valley and Smoky Hill Members.

TABLE 1. Comparison of thickness data of Mancos Shale section beneath the sandstone cliffs of Point Lookout at the northern edge of Mesa Verde National Park. Pike (1947) and Wanek (1959) measured the section in feet (values in parentheses). These values have been converted to meters for comparison with this study.

Interval	Pike (1947)	Wanek (1959)	this study
(Principal Reference Section of Mancos Shale beneath Point Lookout, Mesa Verde National Park, Colorado)			
Bridge Creek and Juana Lopez Members	**125 m** (411 ft.)	**146 m** (478.5 ft.)	**160 m** (24-184 m)
Montezuma Valley and Smoky Hill Members	contacts uncertain from data provided	**79 m** (259 ft.)	**105 m** (184-289 m)
Cortez Member	contacts uncertain from data provided	**361 m** (1185 ft.)	**393 m** (289-682 m)
top of Juana Lopez Mbr. to base of massive Point Lookout Ss. cliff	**510 m** (1674 ft.)	indeterminate from data provided	**517 m** (184-701 m)
total thickness of Mancos Shale	**668 m** (2191 ft.*)	**609 m** (1997.5 ft.)	**682 m (701 m*)** (2237 ft.)

*measured to base of massive sandstone cliff at the base of Point Lookout

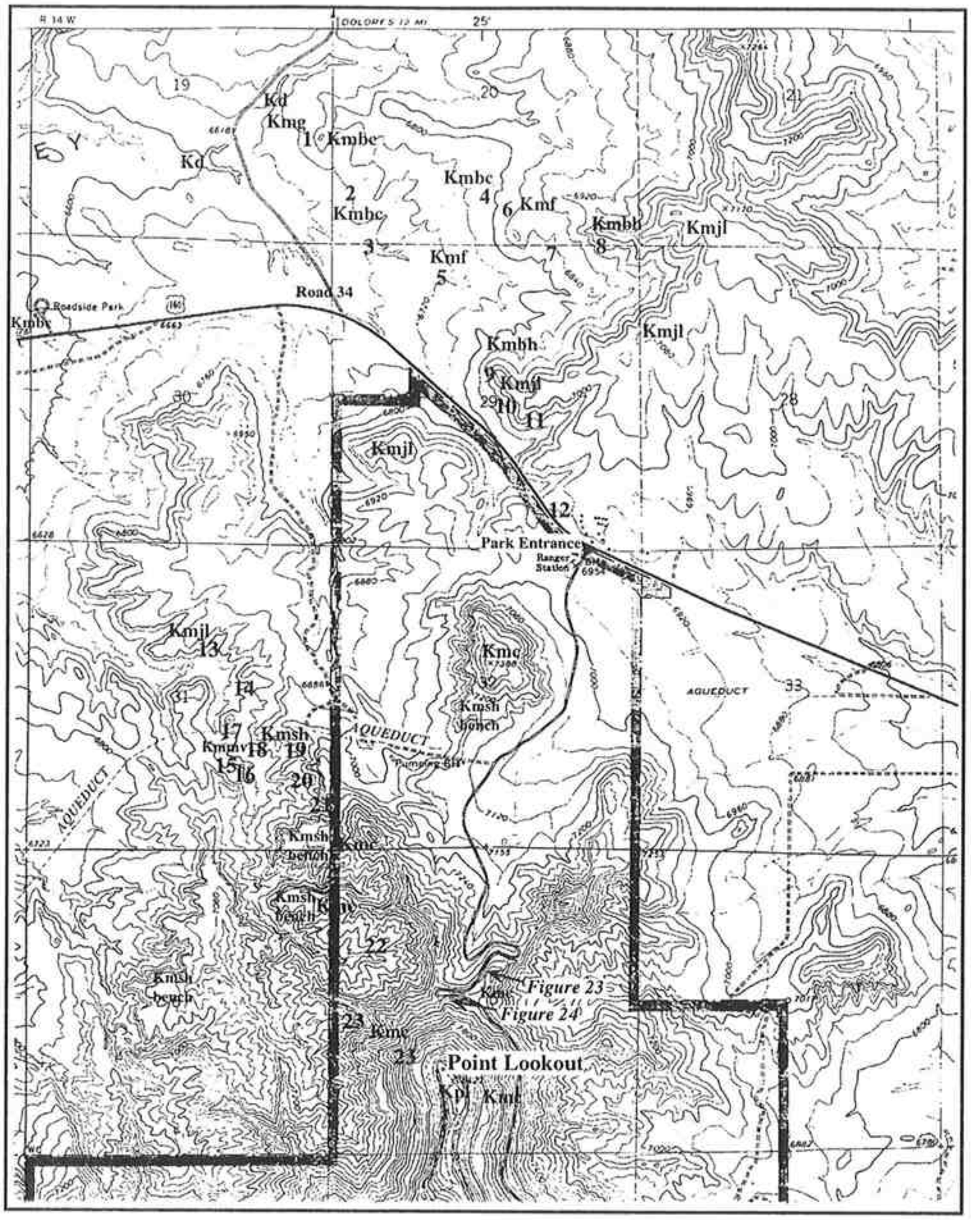

FIGURE 5. Topographic base map of the area at the north end of Mesa Verde National Park, showing the 23 areas that were used to compile the continuous Mancos Shale principal reference (sections 19–21 and 28–33, T36N, R14W, and sections 4–6, T35N, R14W; Point Lookout 7.5' Quadrangle, Colorado). Additional information about each area is presented in Table 2. Kd = Dakota Sandstone, Kmg = Graneros Member of the Mancos Shale, Kmbc = Bridge Creek Limestone Member, Kmf = Fairport Member, Kmbh = Blue Hill Member, Kmjl = Juana Lopez Member, Kmmv = Montezuma Valley Member, Kmsh = Smoky Hill Member, Kmc = Cortez Member, Kpl = Point Lookout Sandstone.

The section was trenched from the top of the Dakota Sandstone to a position well into the transition interval with the overlying Point Lookout Sandstone. The upper 4.4 m of Mancos was not trenched owing to an apron of talus beneath the sandstone cliffs at Point Lookout (see Dunbar et al., this volume, for additional details of the Mancos-Point Lookout transition). Ninety-five trenches were cut in 23 different areas to expose the entire Mancos Shale sequence in a transect extending from sec. 19 and 20, T36N, R14W, north of Mesa Verde National Park, to sec. 5, T35N, R14W at the base of the sandstone cliffs of Point Lookout within the park (Fig. 5; Table 2). Trenches 0.3–0.6 m wide were dug to expose fresh rock prior to description, measurement, and collection, and were stepped in areas of high relief. Large nails with colored flagging were used to mark meter-thick intervals within each trench and to mark positions of lithologic change.

A total of 686 lithostratigraphic units are recognized in 678 m of trenched section, some of which are as little as 1 cm thick (Appendix 1). Key units (e.g., bentonite beds and seams) were used to ensure proper correlation and overlap of sections in adjacent trenches. Multiple units were used as often as possible to correlate between trenches and areas. The longest continuous trenches were possible in areas of high relief, particularly on the shale slopes beneath Point Lookout. The Mancos Shale is fossiliferous through much of its thickness, at least to 647 m above the base of the measured section, and numerous fossils were collected, identified, and cataloged. Macrofossils collected from the overlying Point Lookout Sandstone furnished additional age control. The Research Center at Mesa Verde National Park is the repository for these collections.

Six hundred and sixty-four bulk sediment samples were collected, including at least one sample per meter through the lower 494 m of section. A wider sampling interval was employed above 494 m, where at least one sample was collected for each 2 m of section. In addition to mudrock lithologies, numerous key beds were sampled, including the major bentonites. These samples are currently being analyzed for microfossil content, clay mineralogy and

TABLE 2. Locations of the 23 areas where trenches were dug to measure, describe, and collect the composite Mancos Shale principal reference section at Mesa Verde (refer to Figs. 2, 5).

Area	Section	Township, Range	Lithologic Units	Interval	Member(s) of Mancos Shale	Comments
1	NE1/4, SE1/4, sec. 19	T36N, R14W	MV1-MV57	0-25.6 m	Graneros-basal Bridge Creek	low flank of ridge/knoll capped by limestone beds
2	SW1/4, SW1/4, sec. 20	T36N, R14W	MV49-MV63	24.3-26.5 m	lower Bridge Creek	in arroyo WSW of Area 4
3	NW1/4, NW1/4, sec. 29	T36N, R14W	MV57-MV75	25.5-28.2 m	lower Bridge Creek	in arroyo S of Area 2
4	center of line between SW1/4 and SE1/4, sec. 20	T36N, R14W	MV67-MV107	27.3-38.2 m	middle-upper Bridge Creek	exposed low relief slopes with light and med. light gray bands
5	NE1/4, NW1/4, sec. 29	T36N, R14W	MV107-MV119	38.0-42.4 m	lower Fairport	in arroyo below earthen dam
6	SW1/4, SE1/4, sec. 20	T36N, R14W	MV109-MV150	39.5-59.2 m	much of Fairport	low relief area below tree line; abundant gypsum dust
7	NW1/4, NE1/4, sec. 29	T36N, R14W	MV148-MV171	58.5-71.1 m	upper Fairport-basal Blue Hill	good exposures in deep arroyo
8	NE1/4, NE1/4, sec. 29 and SE1/4, SE1/4, sec. 20	T36N, R14W	MV169-MV222	70.0-139.0 m	much of Blue Hill	steep slope exposure of dark gray to black shale
9	SW1/4, NE1/4, sec. 29	T36N, R14W	MV219-MV226	138.5-142.3 m	Blue Hill/Juana Lopez transition	NW end of ridge capped by calcarenite beds
10	SW1/4, NE1/4, sec. 29	T36N, R14W	MV225-MV258	141.7-162.0 m	lower half of Juana Lopez	along ridge of orange-weathering calcarenite beds
11	NW1/4, SE1/4, sec. 29	T36N, R14W	MV255-MV283	161.2-171.4 m	middle Juana Lopez	ridge of calcarenite beds
12	SW1/4, SE1/4, sec. 29	T36N, R14W	MV278-MV283	170.0-171.4 m	middle Juana Lopez	acoss from MVNP entrance
13	SW1/4, NE1/4, sec. 31	T36N, R14W	MV277-MV293	169.8-182.0 m	upper Juana Lopez	exposures along slope
14	SW1/4, NE1/4, sec. 31	T36N, R14W	MV293-MV310	181.5-186.2 m	uppermost Juana Lopez-basal Montezuma Valley	upper part of slope in wooded area of steep-sided gulleys
15	NW1/4, SE1/4, sec. 31	T36N, R14W	MV307-MV312	185.0-187.5 m	lower Montezuma Valley	in arroyo; south of aqueduct
16	NW1/4, SE1/4, sec. 31	T36N, R14W	MV312-MV324	187.4-194.0 m	lower-middle Montezuma Valley	in arroyo; south of aqueduct
17	NW1/4, SE1/4, sec. 31	T36N, R14W	MV324-MV328	193.9-196.3 m	middle Montezuma Valley	slope of knoll; east of arroyo and along aqueduct
18	NE1/4, SE1/4, sec. 31	T36N, R14W	MV328-MV362	196.3-231.2 m	upper Montezuma Valley-lower Smoky Hill	exposed gray slopes; south of aqueduct
19	NE1/4, SE1/4, sec. 31	T36N, R14W	MV362-MV365, MV369-MV372	231.2-248.2 m 261.0-273.5 m	middle Smoky Hill	lower third of slope and upper fifth of slope
20	SE1/4, SE1/4, sec. 31	T36N, R14W	MV365-MV369	248.2-261.4 m	middle Smoky Hill	mid-slope section
21	SE1/4, SE1/4, sec. 31	T36N, R14W	MV372-MV385	273.2-299.5 m	upper Smoky Hill-basal Cortez	upper gray slopes and cliffs of prominent Smoky Hill bench
22	SW1/4, NW1/4, sec. 5	T35N, R14W	MV380-MV430	297.5-383.2 m	lower Cortez	continuous shale slopes, west side of N-S ridge
23	NW1/4, SW1/4, sec. 5	T35N, R14W	MV430-MV686	382.9-677.7 m	middle-upper Cortez	continuous steep slopes along spur, NW of Point Lookout

selected geochemistry (e.g., Leckie et al., 1991, in press; West and Leckie, in press). Gamma-ray measurements were taken through the entire section using a GRS-101A portable gamma-ray scintillometer.

DAKOTA SANDSTONE

The Dakota Sandstone is well exposed on cuestas east of Cortez, Colorado. Sandstone units exposed opposite the Montezuma County Fairgrounds north of US-160 (NW¼ sec. 27, T36N, R15W) consist of two coarsening upward sequences above a unit containing carbonaceous muddy sandstone. The lower sequence is approximately 9–10 m thick and consists of muddy sandstone to shaly sandstone and is capped by a meter-thick very fine-grained sandstone. The upper sequence is approximately 12–13 m thick and consists of very fine-grained muddy sandstone and fine- to medium-grained sandstone containing some units with low-angle cross stratification and others that are massively bedded or burrowed by *Ophiomorpha*. The cuesta is capped by a meter-thick, resistant, medium-grained sandstone with low-angle cross stratification. These sandstones are at least partially equivalent in age to the Twowells Tongue of the Dakota Sandstone, based on the presence of the ammonite *Calycoceras canitaurinum* in concretions from the Cortez locality. Where present, the Twowells Tongue represents the top of the Dakota Sandstone in the San Juan Basin (e.g., Owen, 1966, 1973: Landis et al. 1973). About 6.5 km to the east and just north of the Mancos Shale reference section, exposures of the Dakota Sandstone crop out along Road 34 (NW¼ and NE¼ sec. 19, T36N, R14W). These outcrops consist of medium- to fine-grained cross-bedded sandstone, muddy sandstone, claystone and two 5–6-m-thick coarsening upwards packages, each of which is capped by clean, medium- to fine-grained, cross-bedded sandstone. The Dakota-Mancos contact is placed at the top of the second package; a 1.1-m-thick clean, fine-grained sandstone exposed north of US-160 and near Road 34 (NE¼ SE¼ sec. 19, T36N, R14W) (Fig. 5). This unit is well indurated and has well-developed cross stratification.

MANCOS SHALE

Introduction

Eight members in the Mancos Shale are recognized below Point Lookout (Fig. 4). In ascending order, they are the Graneros, Bridge Creek Limestone, Fairport, Blue Hill, Juana Lopez , Montezuma Valley, Smoky Hill and Cortez Members. The Montezuma Valley and Cortez Members are new. Type section information is furnished in the following descriptions. The other six members derive their names from lithostratigraphic units of the Colorado Front Range and plains areas of eastern Colorado and western Kansas. This subdivision of the Mancos differs from previous descriptions of the Mesa Verde section as follows (Fig. 6): (1) the Bridge Creek Limestone Member is now used in place of Greenhorn Limestone Member in the San Juan Basin (e.g., Hook and Cobban, 1981; Hook et al., 1983); (2) the lower Carlile member is subdivided into the Fairport and Blue Hill Members based on a sharp lithologic contact; (3) the upper Carlile member is formally named the Montezuma Valley Member of the Mancos Shale; (4) the Niobrara member is now referred to as the Smoky Hill Member on the basis of lithologic similarities with the Smoky Hill Member of the Niobrara Formation and absence of the Fort Hays Limestone Member at Mesa Verde; and (5) the Cortez Shale Member is proposed as a formal name for the upper Mancos Shale member. Descriptions of each member includes information on lithology, fossil content, molluscan biostratigraphy and geophysical log character.

The biostratigraphic zones and subzones used in this report (Fig. 7) are based primarily on the work of Cobban (1951, 1984), Cobban and Reeside (1952), Gill and Cobban (1966), Kauffman (1975), Hattin (1982), Scott et

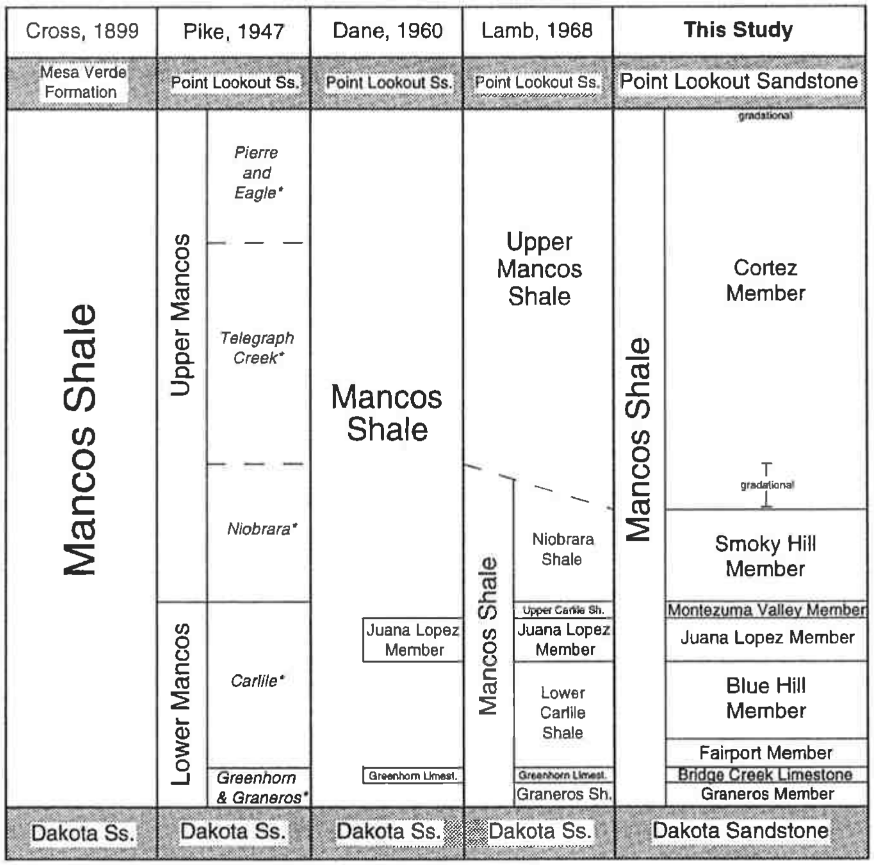

FIGURE 6. History of Mancos Shale stratigraphic nomenclature in the type area, southwestern Colorado.

al. (1986), Cobban et al. (1989) and Kirkland (1990, 1991). The time scale follows Kauffman et al. (1993) and Obradovich (1993). A summary of the chronostratigraphy and molluscan biostratigraphy of the Mancos Shale principal reference section is shown in Figure 8; molluscan taxa are illustrated in a series of figures (Figs. 31–46) at the end of this paper.

Graneros Member

Summary

Interval 0–24.1 m; units MV1–MV47; thickness 24.1 m; lower contact sharp; upper contact sharp.

Lithostratigraphy and geophysical log character

The Graneros Member is a dark-gray sandy mudstone and silty shale in the lower 10 m, and a fossiliferous slightly silty calcareous shale in the upper 14.1 m (Figs. 4, 8). The mudrock and shale is moderately indurated and the calcareous shale is moderately well indurated. Several bentonite beds occur throughout the member; 5–9 cm-thick bentonite beds occur at 4.2 m, 7.3 m, 16.1 m and 17.6 m, and >10-cm-thick bentonite beds occur at 4.0 m (unit MV6), 20.7 m (unit MV36) and 23.2 m (unit MV44). A 36-cm-thick argillaceous sandstone unit occurs at 3.2 m (unit MV2). Large (as much as 42 cm thick, 100 cm across), orange-weathering septarian concretions occur at 8.3 m (unit MV15), and two nearly continuous gray-weathering concretion beds occur at 12.1 m (8 cm thick, unit MV20) and 14.2 m (12 cm thick, unit MV 22). Scattered concretions occur also at 4.3 m, 10.5 m and 21.6 m.

The lower 10 m of section is poorly exposed in low relief gray- to tan-colored slopes. The more calcareous, less sandy upper 14 m of the Graneros Member is better exposed in light-gray slopes that lie beneath ledges formed by limestones of the overlying Bridge Creek Member. Abundant *Pycnodonte newberryi newberryi* are scattered as float on these upper slopes. The measured section of Graneros is exposed east of Road 34 and west of a low light-gray hill in the NE¼ SE¼ sec. 19, T36N, R14W (Fig. 5).

In outcrop, the Graneros Member is characterized by a variable gamma ray signal that is sandwiched between distinctly lower values of the underlying Dakota Sandstone and overlying Bridge Creek Limestone Member. This signal is also observable in subsurface geophysical logs (Fig. 9). Part of the reason for the variable signal through this interval is the presence of several concretion horizons and bentonites. In particular, bentonites at 4.0 m (unit MV6) and 23.1 m (unit MV44) are recorded also on gamma and resistivity logs from nearby wells. The latter bentonite occurs 1 m below the basal limestone bed of the overlying Bridge Creek Member.

Biostratigraphy and age

The Graneros Member is very poorly fossiliferous in the lower 12 m and becomes increasingly fossiliferous upwards to near the top. The upper three mollusk zones of the Western Interior Cenomanian zonal scheme are recognized in the member (Figs. 10, 31).

The base of the member apparently lies within the upper Cenomanian *Metoicoceras mosbyense* Zone. This interpretation is supported by marker-bed correlations across the region (Sageman, 1985). This age assignment is further indicated by an ammonite fauna containing a very large quadrate species of *Calycoceras* (probably *C. canitaurinum*) and a species of *Cunningtoniceras* found in the underlying Dakota Sandstone. *Calycoceras canitaurinum* (Haas) is a zonal index to the basal upper Cenomanian. The Twowells Tongue of the Dakota Sandstone in west-central New Mexico includes both the *C. canitaurinum* and *M. mosbyense* Zones (Cobban, 1977; Cobban et al., 1989; Hook et al., 1983).

The interval of the *Metoicoceras mosbyense* Zone is poorly fossiliferous at this site as at other offshore marine sites in the Western Interior (e.g., Sageman, 1985, 1989). An external mold of a large specimen of *Calycoceras* in the collections of Mesa Verde National Park may be from a horizon of large septarian concretions that lies 8.5 m above the base of the member and is tentatively identified as *Calycoceras obrieni* Young. A monotypic fauna of the epifaunal bivalve *Plicatula* sp. first appears at 12 m and becomes more common up-section to 17 m. A nearly monotypic *Plicatula* sp. fauna is known from this level in the Mancos Shale in the northeastern Black Mesa area in northeastern Arizona and appears to represent an inner shelf environment with reduced benthic oxygen levels (Kirkland, 1990).

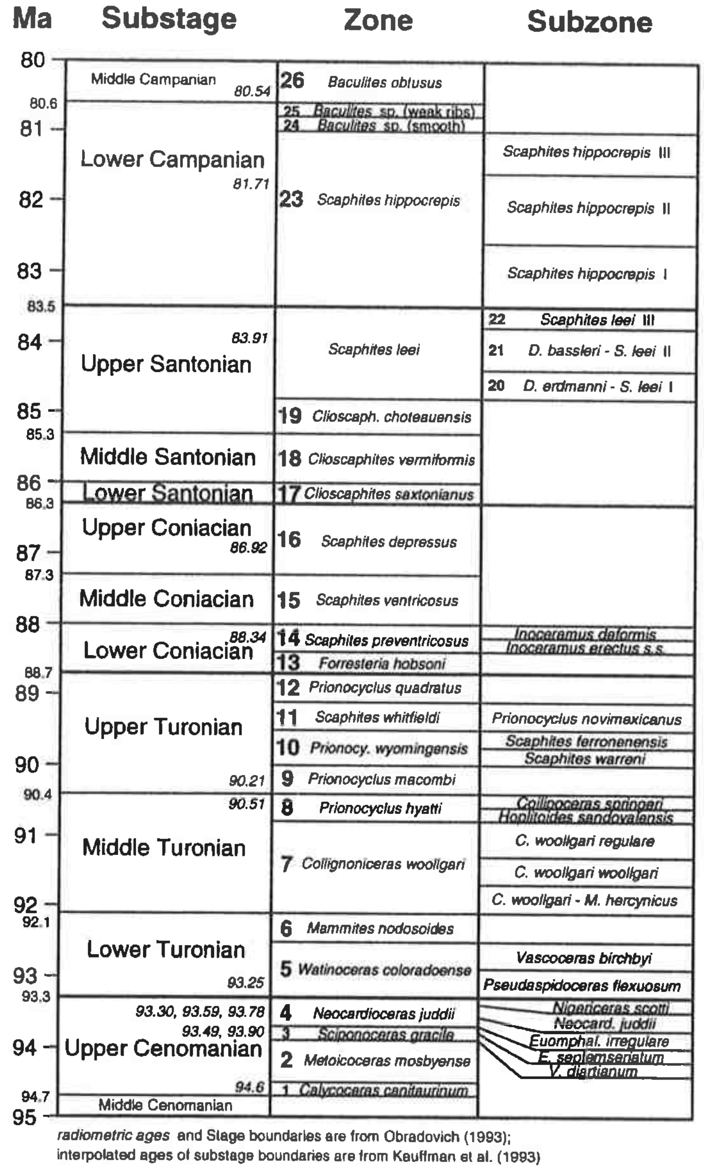

FIGURE 7. Time scale and biostratigraphic zonation of the Mancos Shale principal reference section. Radiometric ages (italics) are from Obradovich (1993). Interpolated ages of substage boundaries are from Kauffman et al. (1993). Refer to text for details of the molluscan biostratigraphy.

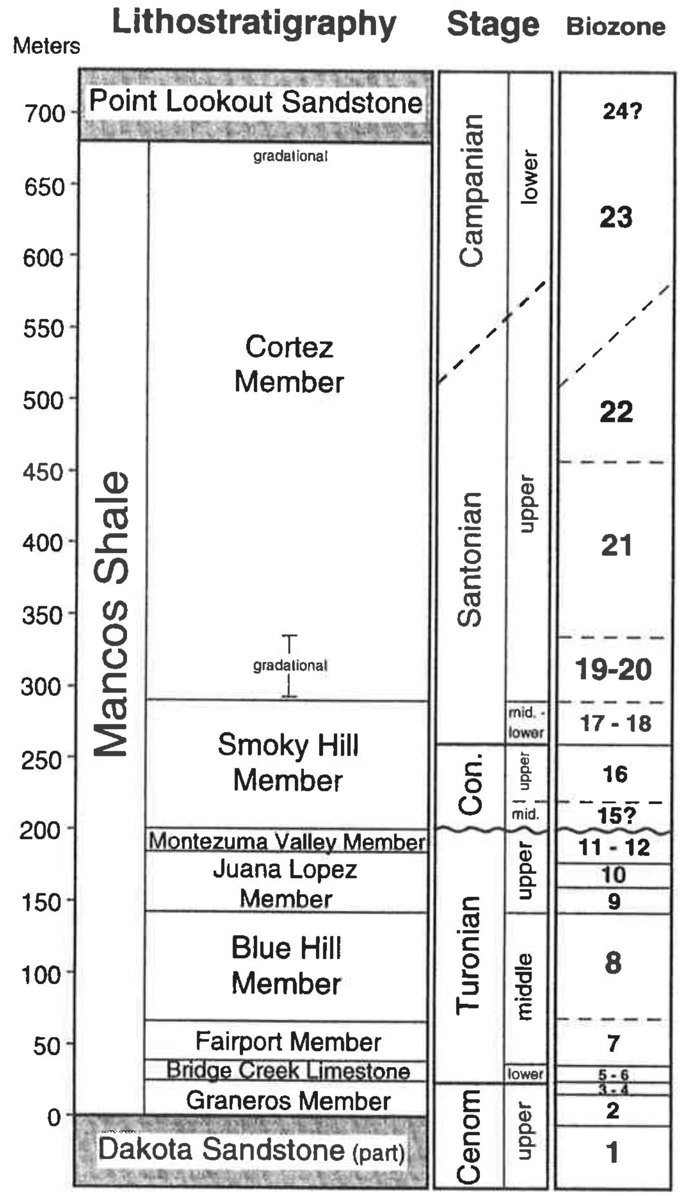

FIGURE 8. Summary of the lithostratigraphy, chronostratigraphy, and biostratigraphy of the Mancos Shale principal reference section at Mesa Verde. Refer to Figure 7 for the names of the numbered biozones.

Faunal diversity increases at 18 m above the base of the Graneros Member, as is typical of the *Sciponoceras gracile* Zone (Kauffman, 1986; Sageman, 1985, 1989). The *S. gracile* Zone extends to approximately 22.2 m. Faunal elements of the zone include rare specimens of the ammonites *S. gracile* (Shumard), *Euomphaloceras septemseriatum* (Cragin), *Metoicoceras geslinianum* (d'Orbigny), and *Allocrioceras annulatum* (Shumard); and the bivalves *Inoceramus pictus* Sowerby, *Pycnodonte newberryi newberryi* (Stanton), *Rhynchostreon acroumbonata* (Kauffman), *Lucina subundata* Hall and Meek, and *Camptonectes* sp.; and the gastropods *Drepanochilus ruidium* (White), *Turritella whitei* Stanton, *Turritella* n.sp. (= *Turritella* n.sp. B of Kirkland, 1996), *Charonia? kanabensis* (Stanton), *Graphidula walcotti* (Stanton), *Eunaticina textilis* Stanton and *Cerithiopsis sohli* Kirkland. Concretions preserving this fauna have been collected along US-160 between Cortez and Mesa Verde, approximately 2.4 km west of the Mancos Shale reference section. This is the most diverse fauna recognized in the Mancos Shale of the region, and is indicative of the *Euomphaloceras septemseriatum* Subzone.

Bentonite marker-bed correlations suggest that the level of the *Vascoceras diartianum* Subzone of other regions may correlate to the interval from approximately 15–17 m above the base of the member. This interpretation is based on (1) our correlation of the bentonite bed at 16 m (unit MV24) with Black Mesa, Arizona, marker-bed BM5 of Kirkland (1991), and with the thin bentonitic clay above Kansas marker-bed HL-1 of Hattin (1975a, 1985), and (2) correlation of the bentonite bed at 17.8 m (unit MV30) with BM6 of Kirkland (1991) and Pueblo, Colorado, Bridge Creek marker-bed PBC-4 of Elder and Kirkland (1985). The bentonite bed at 20.7 m (unit MV36) correlates with BM7 of Kirkland (1991), PBC-5 of Elder and Kirkland (1985), bentonite A of Elder (1987, 1989), southern Utah Tropic-Tununk bentonite marker-bed TT1 of Leithold (1993, 1994) and the bentonite seam below HL-2 of Hattin (1985).

The uppermost Cenomanian *Neocardioceras juddii* Zone is recognized on the basis of *Euomphaloceras irregulare* (Cobban, Hook, and Kennedy), which occurs at 22.5 m. This ammonite is restricted to the basal subzone of *N. juddii* in Arizona and Utah (Kirkland, 1991, 1996). The base of the *N. juddii* Zone is placed at 22.2 m, at the base of a bed of *Pycnodonte newberryi newberryi* shells (unit MV40) that represents a period of sediment bypass. Associated fossils include the ammonites *Sciponoceras gracile* and *Thomasites* sp., and the bivalves *Inoceramus nodai* Matsumoto and Tanaka and *Psilomya concentrica* Stanton. The prominent bentonite (unit MV44)

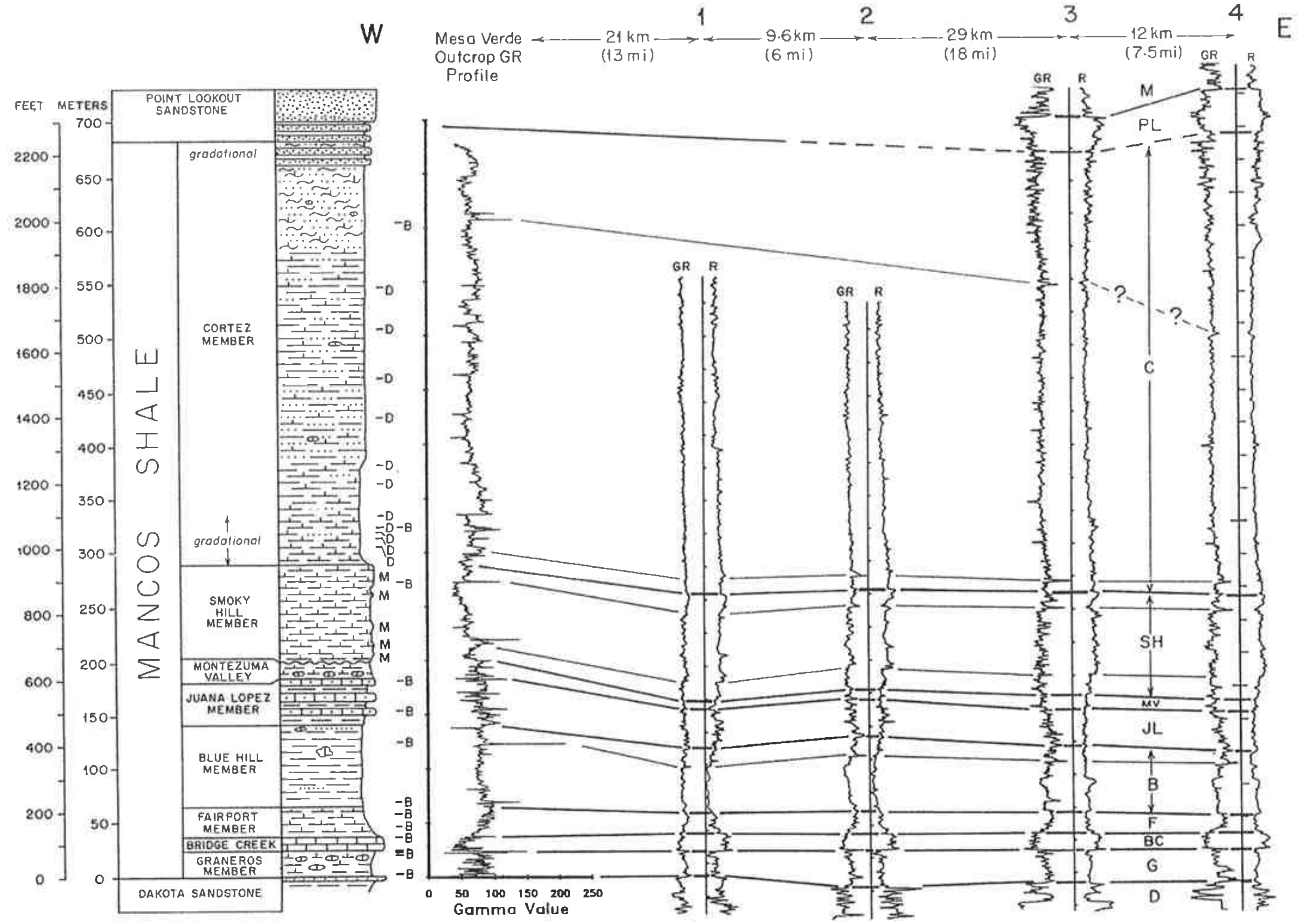

FIGURE 9. Correlation of gamma-ray profile of the Mancos Shale principal reference section with geophysical log profiles from the northern part of the San Juan Basin. See Figure 2 for location and description of boreholes 1-4. GR = gamma-ray, R = resistivity; D = Dakota Sandstone, G = Graneros Member, BC = Bridge Creek Limestone Member, F = Fairport Member, B = Blue Hill Member, JL = Juana Lopez Member, MV = Montezuma Valley Member, SH = Smoky Hill Member, C = Cortez Member, PL = Point Lookout Sandstone, M = Menefee Formation.

lying 23.1 m above the base of the member correlates with the "*Neocard*" bentonite of Eaton and others (1987), marker bed HL-3 of Hattin (1975a), PBC-11 of Elder and Kirkland (1985), BM13 of Kirkland (1990, 1991), bentonite B of Elder (1987, 1989), and TT2 of Leithold (1993, 1994), and is typically associated with common to abundant *Neocardioceras juddii* (Barrois and de Guerne) at other sections. The top of the *N. juddii* Zone is placed at the top of the member at 24.1 m, at the contact between a 24-cm-thick shale bed containing abundant shells of *P. newberryi* (unit MV47) and the basal limestone bed (unit MV48) of the overlying Bridge Creek Limestone Member. The basal Bridge Creek limestone bed contains abundant shells of *P. newberryi umbonata* Kirkland that have a smooth umbonal area. This form of *P. newberryi* is known only from the uppermost Cenomanian and basal Turonian (Elder, 1987, 1989; Kirkland, 1990, 1991, 1996). Condensation and sediment bypass is indicated by these shell beds, and therefore sediments of the *Nigericeras scotti* Subzone (uppermost Cenomanian; Fig. 5) may not have accumulated, or were removed by erosion at this location.

In conclusion, the Graneros Member of the Mancos Shale at Mesa Verde ranges from upper Cenomanian *Metoicoceras mosbyensis* Zone to the Cenomanian/Turonian boundary. Accordingly, the Graneros Member correlates to the middle and upper parts of the Hartland Shale Member and much of the lower Bridge Creek Limestone Member of the Greenhorn Limestone along the Colorado Front Range (Sageman, 1985; Elder and Kirkland, 1985).

Bridge Creek Limestone Member

Summary

Interval 24.1–37.9 m; units MV48–MV105; thickness 13.8 m; lower contact sharp; upper contact sharp.

Lithostratigraphy and geophysical log character

The Bridge Creek Limestone Member contains interbedded limestone and calcareous shale in the lower 3.7 m (24.1–27.8 m); and interbedded calcarenite, shaly limestone or platy marlstone and calcareous shale in the upper 10.1 m (27.8–37.9 m) (Fig. 3). The shale has subparallel parting and is moderately well indurated. The unweathered shale is light olive gray to medium olive gray in the lower part of the member where interbedded with limestone, becoming dark olive gray in the upper part where interbedded with marlstone. The basal limestone bed (unit MV48) is 22 cm thick where the section was measured and is not quite as hard and resistant as the overlying limestones. These latter limestone beds are as little as 6 cm thick and others are as much as 23 cm thick. The thickness of the individual limestone beds varies across the area. For example, a limestone bed with a calcarenitic upper surface (unit MV57) caps low light-gray hills in the area north and east of Cortez, Colorado, and varies in thickness between 18–23 cm (Fig. 11). Above the uppermost limestone (unit MV71) is a meter (27.8–28.7 m) of thin beds (4–11 cm thick) of calcarenite and interbedded calcareous shale, followed by a meter

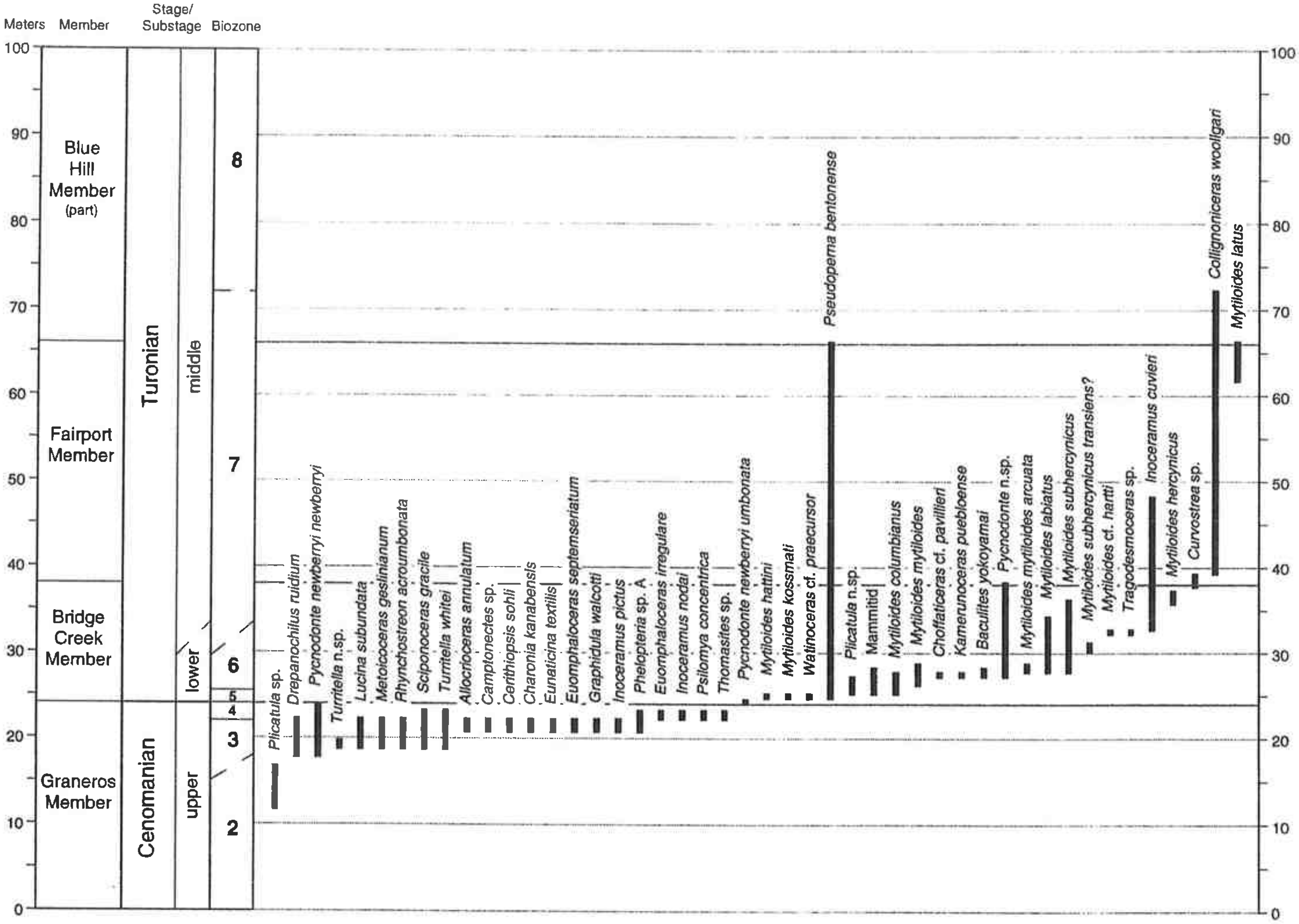

FIGURE 10. Stratigraphic ranges of selected mollusks and biozones of the lower 100 m of Mancos Shale principal reference section (Graneros to lower Blue Hill Members). Refer to Figure 7 for the names of the numbered biozones.

(28.7–29.5 m) of interbedded shaly limestone and calcareous shale. An 11-cm-thick calcarenite bed at 28.2 m (unit MV75) is ripple-bedded and contains scour features, load structures, and abundant broken and whole inoceramid bivalve shells on the upper bedding surface. Interbedded platy marlstone and calcareous shale dominate the remainder of the member (29.5–37.9 m) (Fig. 12). The marlstone is gradational with the calcareous shale. The limestone beds are typically bioturbated and the calcareous shale is, in general weakly bioturbated. Several of the marlstone beds have calcarenitic upper surfaces, including the uppermost unit of the member (unit MV105), which is 24 cm thick. The Bridge Creek-Fairport Member boundary is placed at the highest marlstone bed. The Bridge Creek is fossiliferous throughout.

Relatively thick bentonite beds occur in the interval of interbedded limestones and calcareous shale, whereas very thin (<1 cm) bentonite and limonite seams occur throughout the upper three-quarters of the member. A 19-cm-thick bentonite bed occurs at 24.3 m (unit MV49) and a 9-cm-thick bentonite lies at 27.8 m (unit MV72).

The interval of interbedded limestone and calcareous shale in the lower part of the Bridge Creek Member caps low light-gray hills in Montezuma Valley north of Mesa Verde National Park. The upper part of the member crops out as low-relief light-gray slopes on which are scattered slabs of platy marlstone (Fig. 12). Numerous short trenched intervals were needed to assemble a composite section of the Bridge Creek Member, including the southwest side of a low gray hill in the NE¼ SE¼ sec. 19, T36N, R14W, an arroyo in the SW¼ SW¼ sec. 20, and an arroyo in the NW¼ NW¼ sec. 29 (Fig. 5).

The Bridge Creek Member is characterized by low gamma-ray values owing to the dominance of limestone, marlstone and hard calcareous shale. In geophysical logs of nearby wells, the basal limestone produces a strong resistivity kick directly above a strong gamma-ray kick that represents the upper bentonite of the underlying Graneros Member (Fig. 9). The Bridge Creek Member is an excellent geophysical log marker across the San Juan Basin (Molenaar, 1977; Molenaar and Baird, 1989).

Biostratigraphy and age

The Bridge Creek Limestone Member contains ammonites and inoceramid bivalves that enable us to recognize three biozones (Figs. 10, 31, 32). The encrusting oyster, *Pseudoperna bentonense* (Logan) is ubiquitous in the member and apparently utilized ammonite and inoceramid shells as substrates.

The lowermost Turonian *Watinoceras coloradoense* Zone is considered to range from the shell bed of *Pycnodonte newberryi umbonata* Kirkland at the base of the member at (unit MV48) up to the first occurrence of a mammitid ammonite at 25.3 m (unit MV55). Overlying the basal limestone is a 19-cm-thick bentonite bed (unit MV49), which we correlate with HL-4 of Hattin (1975a), PBC-17 of Elder and Kirkland (1985), BM15 of Kirkland (1991), bentonite C of Elder (1987, 1989) and TT3 of Leithold (1993, 1994). Limestone unit MV51 at 24.9 m contains *Watinoceras* cf.

FIGURE 11. Interbedded limestone (units MV57, MV60, and MV63) and calcareous shale in the lower part of the Bridge Creek Limestone Member exposed in Area 2 (see Fig. 5; Appendix 1). Limestone unit MV57 caps the small knoll in Area 1.

FIGURE 12. Alternating bands of lighter colored platey marlstone and darker-colored calcareous shale units in the upper part of the Bridge Creek Limestone Member (units MV93–MV105) exposed in low-relief gray slopes in Area 4 (Fig. 5; Table 2).

praecursor Wright and Kennedy, *Mytiloides hattini* Elder, and *Pseudoperna bentonense* (Logan), the first of which is indicative of the *Pseudospidoceras flexuosum* Subzone (Cobban, 1984, 1988).

Marker-bed correlations suggest that the overlying *Vascoceras (Greenhornoceras) birchbyi* Subzone (*Watinoceras coloradoense* Zone) should be represented in the interval of the Bridge Creek Member. These correlations include (1) a 3-cm-thick bentonite bed (unit MV53) at 25.2 m that may be equivalent to HL-5 of Hattin (1985), PBC-20 of Elder and Kirkland (1985), BM17 of Kirkland (1991), bentonite D of Elder (1987, 1989), and TT4 of Leithold (1993, 1994), and (2) a 6-cm-thick limestone bed (unit MV55) at 25.3 m that may be equivalent to JT-1 of Hattin (1971, 1985), PBC-21 of Elder and Kirkland (1985) and BM19 of Kirkland (1991). However, fossils diagnostic of this subzone were not found in this interval. In fact, although regional marker-bed correlation suggests that limestone unit MV55 correlates to the *V. birchbyi* bed at Pueblo (Rock Canyon), Colorado, included in the *W. coloradoense* Zone, common mammitid ammonites in unit MV55 imply that at Mesa Verde the *Mammites nodosoides* Zone begins at this level. This suggests that unit MV55 correlates to limestone bed JT-3 of Hattin (1971, 1985) and PBC-23 of Elder and Kirkland (1985) and is underlain by a disconformity. A disconformity removing approximately ten limestone-shale cycles of the Bridge Creek Member has been observed at about this level on the north flank of the San Juan Basin near Pagosa Springs, Colorado (Elder, 1991). Alternatively, mammitids may occur in older strata in this area.

Mammitids indicative of the *Mammites nodosoides* Zone occur in the interval from 25.3 m (unit MV55) to 27.8 m (unit MV71) and appear to include both *M. nodosoides* (Schluter) and *Morrowites wingi* (Morrow). Cobban and Hook (1983) established the genus *Morrowites*, which overlaps the temporal range of *Mammites* and is superficially very similar, being distinguished by the nature of the early whorls and suture. Unit MV67 at 27.4 m is the most fossiliferous limestone bed in the Bridge Creek Member and preserves other ammonite species, including *Kamerunoceras puebloense* (Cobban and Scott), *Choffaticeras papillieri* (Pervinquiere) and *Baculites yokoyamai* Tokunaga and Shimizu. The presence of *K. puebloense* together with the fact that this is the sixth limestone bed in the section beginning at unit MV55 (assuming it correlates to marker-bed JT-1) suggests that this bed may correlate to JT-6 of Hattin (1971, 1985), which contains a diverse molluscan fauna at Pueblo (Cobban and Scott, 1972; Cobban, 1985, 1988). However, the sequence of beds from units MV67 through MV72 (limestone, calcarenite, thin bentonite, chalky shale, limestone and thick bentonite) is identical to the sequence at Pueblo from marker-beds PBC-29 through PBC-32 (Elder and Kirkland, 1985), indicating that limestone units MV67 and MV71 correlate to limestone marker beds JT-9 and JT-10 (Hattin, 1971, 1985), respectively. This correlation is further supported by the same sequence of beds in a section of the Bridge Creek Member near Pagosa Springs (Elder, 1991). This analysis also further supports the correlation of limestone unit MV55 to limestone marker bed JT-3 rather than to JT-1 (discussed above).

Inoceramids of the genus *Mytiloides* are common and evolved rapidly during the early Turonian, and although discredited as a biostratigraphically useful group by some researchers (e.g., Badillet and Sornay, 1980), many Cretaceous paleontologists have found the genus to be highly useful in biostratigraphy (Seitz, 1934; Kauffman, 1975, 1976a, b, 1977a, b; Kauffman et al., 1977; Keller, 1982; Elder and Kirkland, 1985; Kirkland, 1990, 1991, 1996). *Mytiloides hattini* Elder and *Mytiloides kossmati* (Heinz) (= *Mytiloides opalensis* sensu Kauffman and Seitz) occur in the basal Turonian. *Mytiloides columbianus* (Heinz) occurs from 25.4 m (unit MV57) to 27.4 m (unit MV67), and early forms of *M. mytiloides* (Mantell) occur commonly from 26.4 m (unit MV63) to 28.2 m (unit MV75) in the *Mammites nodosoides* Zone. An orange-weathering and widely traceable calcarenite bed at 28.2 m (unit MV75) and the limestone bed below (unit MV71) both contain *M. mytiloides* and a late form of the species, *M. mytiloides arcuata* (Seitz). Identifiable specimens of *M. labiatus* (Schlotheim) and *M. subhercynicus* (Seitz) also first occur at 27.7 m (unit MV71), and rare juvenile specimens of the ammonite *Tragodesmoceras* sp. are found with these inoceramids at 32.7 m (unit MV89). The middle Turonian *Inoceramus cuvieri* Sowerby first occurs at 33.4 m (unit MV90) and indicates that the most probable level for the top of the lower Turonian

Mammites nodosoides Zone and the base of the middle Turonian *Collignoniceras woollgari* Zone lies between 27.7 m and 33.4 m (Kauffman, 1977b: Elder and Kirkland, 1985; Kirkland, 1991). *Mytiloides hercynicus* (Petracheck) was recovered from 36.0 m (unit MV98). This latter occurrence suggests that the uppermost part of the Bridge Creek lies within the *C. woollgari woollgari-M. hercynicus* Subzone of the *C. woollgari* Zone (Kirkland, 1990, 1991, 1996), although *C. woollgari* was not found in the Bridge Creek Member at Mesa Verde.

In summary, the faunal data and marker-bed correlations indicate that the Bridge Creek Limestone Member contains a relatively continuous stratigraphic record extending from the basal Turonian *Pseudaspidoceras flexuosum* Subzone of the *Watinoceras coloradoense* Zone to the basal middle Turonian *Collignoniceras woollgari woollgari-Mytiloides hercynicus* Subzone of the *C. woollgari* Zone. The *W. coloradoense* Zone is condensed and a disconformity was delimited in the lower Turonian *Mammites nodosoides* Zone.

Fairport Member

Summary

Interval 37.9–66.1 m; units MV106–MV163; thickness 28.2 m; lower contact sharp; upper contact sharp.

Lithostratigraphy and geophysical log character

The Fairport Member consists of fossiliferous calcareous shale containing numerous limonite seams, bentonite seams, and bentonite beds (Fig. 4). Carbonate content decreases sharply upward through the member although contact with the overlying Blue Hill Member is sharp. Several marly shale intervals occur in the lower 3 m of the member (37.9–41.1 m) and thin calcarenitic stringers occur in an interval above (42.4–47.4 m). The shale is moderately to moderately well indurated and has subparallel to parallel parting. Unweathered colors of the shale include medium gray, and light olive gray to dark olive gray. Forty-five limonite seams (most <1 cm) and 11 thin bentonite beds (<5 cm) are recorded within the Fairport Member (Fig. 13). Bentonite beds from 5–9 cm thick occur at 43.1 m, 51.1 m, 56.5 m and 64.9 m, and bentonite beds >10 cm thick occur at 38.1 m (unit MV107), 48.3 m (unit MV134) and 58.5 m (unit MV148). The Fairport-Blue Hill Member boundary is placed at the sharp contact between slightly calcareous shale and noncalcareous shale. Evidence of seafloor erosion is suggested by the presence of calcisilt streaks defining the lamination in the upper 5 m of the Fairport and a lag of broken juvenile ammonite shells and oysters along a bedding plane in the basal meter of the Blue Hill Member.

The Fairport Member is poorly exposed in low-relief, light- to medium-gray slopes that rise topographically above the Bridge Creek Member. Numerous short sections were utilized in an area of low-relief gray slopes in the center of the SW¼ and SE¼ line, sec. 20, T36N, R14W, and in an arroyo below an earthen dam in the NE¼ NW¼ sec. 29 (Fig. 5).

The gamma-ray values observed in outcrop and on logs from nearby boreholes show a basal part that is transitional with the underlying Bridge Creek Limestone Member followed by steadily increasing values (Fig. 9). This upward trend probably is due to the combined effects of upward-decreasing carbonate content of the member and the presence of numerous thin bentonite beds and limonite seams throughout the member. By comparison, the overlying Blue Hill Member is largely devoid of bentonites and limonite seams, resulting in lower gamma-ray values. The subsurface gamma-ray log contact between the Fairport and Blue Hill Members is placed at the change from increasing gamma-ray values to decreasing values.

Biostratigraphy and age

Fossils, although common in the Fairport Member, are of low diversity and consist almost exclusively *Collignoniceras woollgari* (Mantell), *Baculites yokoyamai* Tokunaga and Shimizu, *Inoceramus cuvieri*, and *Pseudoperna bentonense*. This fauna occurs from 39.5 m to the top of the member at 66.1 m and indicates that the entire Fairport lies within the middle Turonian *C. woollgari* Zone (Figs. 10, 33).

The basis for dividing the *Collignoniceras woollgari* Zone into subzones is recognition of two distinct subspecies, which are best differentiated in specimens that represent middle to late growth stages (Cobban and Hook, 1979). All specimens encountered in the Mesa Verde reference section are juveniles so we cannot divide the Fairport Member into subzones on the basis of ammonites. However, the inoceramid *Mytiloides latus* sensu Hattin (1962, 1975b) occurs in the upper 4 m of the member. In the Black Mesa Basin, this taxon is associated with the basal part of the *C. woollgari regulare* (Haas) Subzone (Kirkland, 1991, 1996).

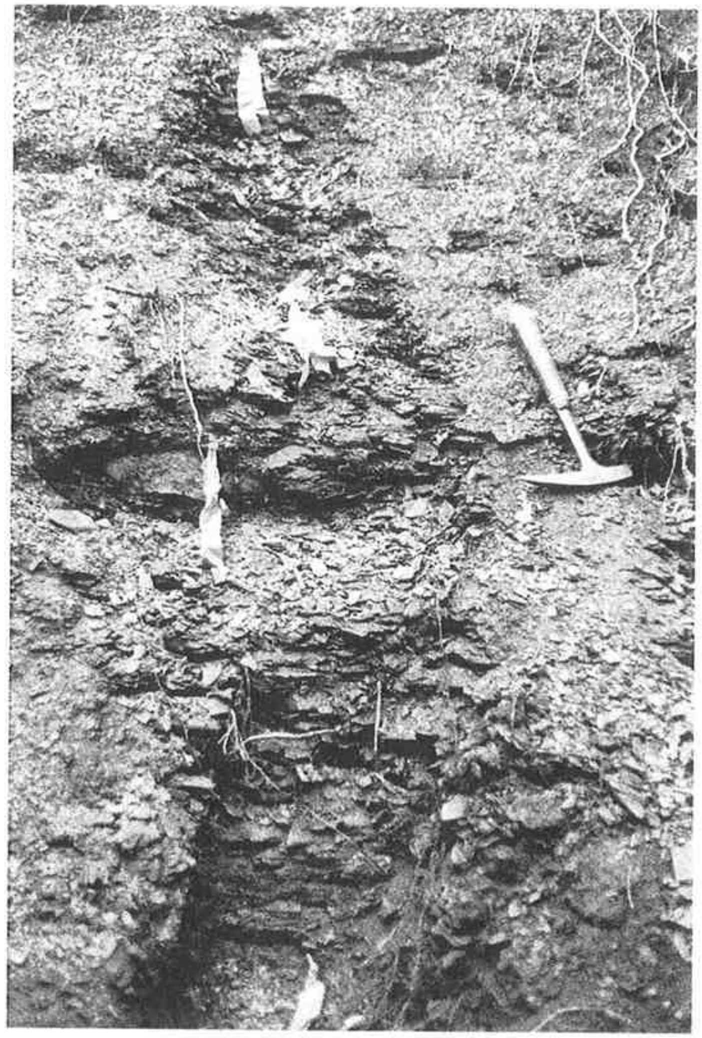

FIGURE 13. Close view of a 1.5-m-thick interval of calcareous shale in the upper part of the Fairport Member. Flag at the bottom of the trench marks a 15-cm-thick bentonite bed (unit MV148). The upper three flags mark a concretion horizon (unit MV150) and two thin bentonite seams (units MV152 and MV154). This part of the section was trenched in Area 7 (Fig. 5; Table 2).

A regional disconformity at the Fairport-Blue Hill Member boundary is suggested by the abrupt lithologic change from calcareous to noncalcareous shale (Glenister and Kauffman, 1985; Merewether and Cobban, 1986). Much of the *Collignoniceras woollgari regulare* Subzone may be missing in this area due to erosion or non-deposition. Absence of age-diagnostic fossils in the basal Blue Hill Member precludes us from determining the magnitude of this suspected disconformity.

Blue Hill Member

Summary

Interval 66.1–141.6 m; units MV164–MV223; thickness 75.5 m; lower contact sharp; upper contact sharp.

Lithostratigraphy and geophysical log character

The Blue Hill Member is a dark-olive-gray to olive-black, noncalcareous, poorly fossiliferous shale to silty shale that contains widely scattered concretions (Fig. 4). The number of bentonite beds and limonite seams decreases sharply at the Fairport/Blue Hill contact. The shale is moderately to moderately well indurated and has parallel to subparallel parting surfaces. The lower 15.5 m of the member (66.1–81.6 m) comprises shale, widely scattered concretions, and a few bentonite beds. Above this is a 4.2-m-thick interval (81.6–85.8 m) of shale that contains an 8-cm-thick sandy concretion bed with cone-in-cone structures (unit MV175), and numerous thin (1-4 cm) siltstone beds, siltstone lenses, and silt laminae. The siltstone beds have scoured bases and multidirectional tool marks. The remainder of the member (85.8–141.6 m) consists of slightly silty to silty shale with occasional thin (1–4 cm thick) siltstone beds and silt laminae, scattered concretion horizons and several bentonite beds. Thin bentonites at 73.8 m and 79.3 m fill depressions along shale-on-shale scour surfaces. Yellow-weathering jarosite occurs on shale bedding planes and along joints, a characteristic also observed at the type locality of the Blue Hill Member of the Carlile Shale in Kansas (Hattin, 1962). In addition, a metallic sheen is also observed on some fracture surfaces.

Large, irregular (bulbous-shaped), orange-weathering septarian concretions (Fig. 14), some in excess of one meter in diameter, are present at approximately 116 m and 118 m (unit MV194). Concretions with similar character and stratigraphic position occur in the upper Blue Hill Member, Carlile Shale, at Pueblo (Rock Canyon), Colorado (Glenister and Kauffman, 1985) and in Kansas (Hattin, 1962). Coarse silt/very fine-grained sandstone gutter casts are associated with the upper bulbous septarian concretion horizon at Mesa Verde. The gutter casts are oriented N15°W to N20°W. Other smaller septarian concretionary beds occur at 131.2 m (12 cm thick, unit MV206) and 138.1 m (37 cm thick, unit MV218). Bentonite beds with a thickness of 5 to 9 cm occur at 71.0 m, 79.3 m, 95.1 m and 118.5 m. Bentonite beds >10 cm thick occur at 70.0 m (unit MV169), 113.8 m (unit MV193) and 123.6 m (21 cm thick, unit MV199). A 46-cm-thick interval of brownish-gray silty mudstone at 121.4 m (unit MV197) yielded the only macrofossils in the middle and upper parts of the Blue Hill Member. Interval 136.8–137.8 m contains five thin beds (1–4 cm thick) of very fine-grained sandstone with wavy upper and lower contacts and low-angle cross stratification that we interpret as distal equivalents of the Semilla or Codell sandstones.

The lowermost part of the Blue Hill Member was measured in an arroyo in the SW¼ SE¼ sec. 20, T36N, R14W, above the light-gray slopes developed on the Fairport Member. The bulk of the member is exposed on low to fairly steep dark-gray to black slopes beneath resistant beds of the overlying Juana Lopez Member in the NW¼ and NE¼ NE¼ sec 29 and SE¼ SE¼ sec. 20 (Fig. 5).

Gamma-ray trends of the Blue Hill Member show decreasing values through the lower third of the member followed by steady or slightly increasing values through the upper third (Fig. 9). A strong, positive gamma-ray kick in the upper quarter of the Blue Hill corresponds with a 21-cm-thick bentonite at 123.6 m (unit MV199) in the Mesa Verde section. This bentonite can be traced widely on geophysical logs from wells in the northern San Juan Basin (e.g., Molenaar and Baird, 1989). The thin Semilla or Codell-equivalent sandstone beds of the Mesa Verde outcrop section could not be distinctly detected on the logs from nearby boreholes.

Biostratigraphy and age

Most workers in the Western Interior place the top of the *Collignoniceras woollgari* Zone at the top of the Fairport. No fossils are known from the lower part of the Blue Hill Member in the central Western Interior and the oldest examples of *Prionocyclus hyatti* (Stanton) first occur in the middle part of the Blue Hill Shale in Kansas (Hattin, 1962). Biostratigraphic relationships between sections at Black Mesa, Arizona and the central Western Interior strongly suggest that the *C. woollgari regulare* Subzone is present in the lower Blue Hill (Kirkland, 1991, 1996). In fact, toward the eastern margin of the Western Interior Basin in northeastern Nebraska, *C. woollgari regulare* is present near the top of the member (Hattin, 1975b). The Blue Hill Member at Mesa Verde does little to clarify this biostratigraphic problem as the member is nearly devoid of invertebrate fossils. However, rare specimens of *C. woollgari* and marine reptile bones were found in a concretion from the basal part of the member (lower part of unit MV172; approximately 72 m) (Fig. 10).

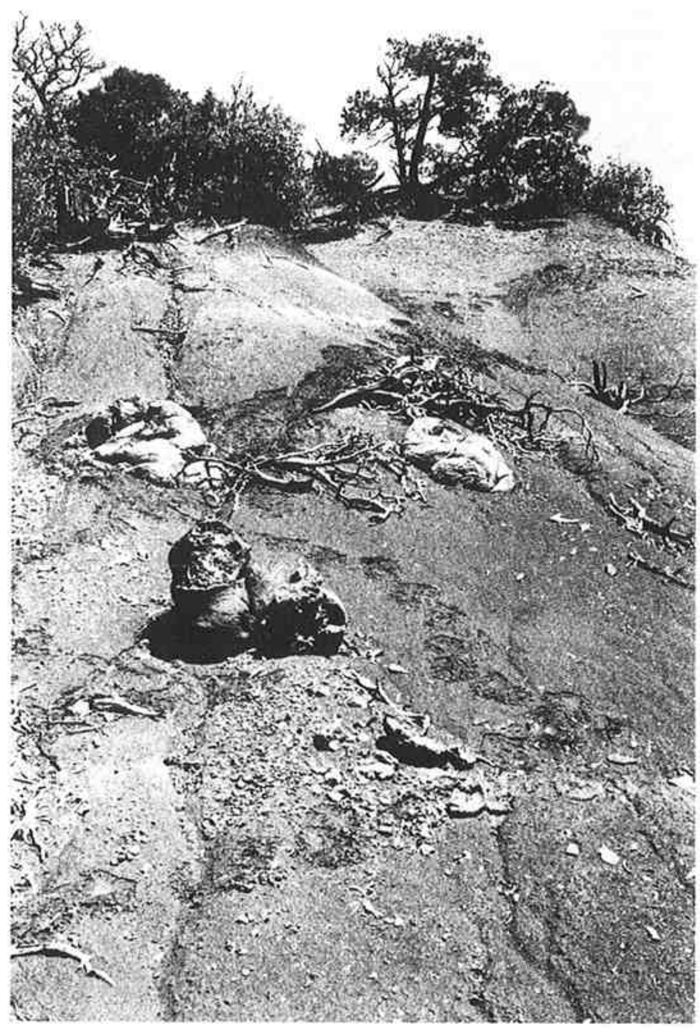

FIGURE 14. Upper part of the Blue Hill Member containing large bulbous septarian concretions (unit MV194). Much of the Blue Hill Member is exposed on a relatively steep hill in Area 8 (Fig. 5; Table 2).

The only other fossiliferous unit in the Blue Hill Member is a 46-cm-thick silty mudstone (unit MV197) that lies 121.4 m above the base of the Mesa Verde reference section (Figs. 15, 33). This bed contains a diverse fauna including *Prionocyclus hyatti* (Stanton), *Inoceramus costellatus* Woods, *I.* cf. *flaccidus* White, *I.* cf. *howelli* White, *Breviarca* sp., *Nucula coloradoensis* Stanton, *Yoldia* sp., *Syncyclonema* sp., *Camptonectes* sp., oyster, *Pleurocardia pauperculum* (Meek), *Cyclorisma orbiculata* (Hall and Meek), *Corbula kanabensis* Stanton, *Turritella* sp., *Levicerithium* cf. *timberanum* Stephenson, *Eoacteon* sp., and *Gyrotropis* sp. This fauna suggests a shallow marine environment and is assigned to the *Prionocyclus hyatti* Zone (subzone assignment is indeterminate). On the basis of these fossils and those found at the base of the overlying Juana Lopez Member, we assume that the *P. hyatti* Zone ranges up to the top of the Blue Hill Member (Fig. 15).

Juana Lopez Member

Summary

Interval 141.6–184.2 m; units MV224–MV304; thickness 42.6 m; lower contact sharp; upper contact sharp.

Lithostratigraphy and geophysical log character

The Juana Lopez Member is a dark, noncalcareous, slightly silty to silty shale that contains numerous beds of orange-weathering calcarenite (Fig. 4). The shale of the Juana Lopez is moderately well indurated, has subparallel parting, and is generally olive black in color, but becomes brown, dusky yellow brown, and gray where silty. Silt laminae define stratification in some intervals. Other shaly intervals contain calcarenite lenses or thin beds of calcarenite (<1 cm thick). Limonite staining and jarosite occur along some fractures and parting surfaces.

The base of the Juana Lopez is recognized by the first occurrence of calcarenite above typical beds of the Blue Hill Member (Dane et al., 1966; Hook and Cobban, 1980; MacLachlan, 1981). At Mesa Verde, this is a 6-cm-thick sandy calcarenite bed (unit MV224) containing abundant fish bones and shark teeth. A half-meter above this lies a 5-cm-thick, lenticular, coquina-like calcarenite bed (unit MV226) containing a *Prionocyclus macombi* fauna that may have filled cutter casts on the seafloor. Calcarenite beds are rare in the lower 9.4 m (141.6–151.0 m) of the member. Even though the Juana Lopez is dominated by noncalcareous shale, four prominent bench-forming calcarenitic intervals are recognized, the uppermost of which contains the thickest beds of calcarenite. These intervals are characterized by interbedded calcarenite and noncalcareous shale. The intervening shale intervals also contain numerous thin beds or laminae of calcarenite; most are <1 cm in thickness but several are as much as 4 cm thick. The calcarenite beds consist primarily of well-cemented bioclastic debris, including the shells of foraminifers, inoceramid shell debris (calcite "prisms" from the prismatic layer of the shell), broken and abraded shells of ammonites and oysters, and phosphatic debris including fish bones and teeth. Detrital quartz sand and silt may also be a minor component of the calcarenite (Dane et al., 1966). Many of the calcarenite beds have basal scour surfaces and sole marks, and often contain low angle cross-stratification and rippled upper surfaces. In addition, many of these beds yield excellent molluscan fossils. The lowest calcarenitic interval extends from 151.0 to 156.8 m (units MV232–MV246) in the Mesa Verde section. The most prominent individual calcarenite bed is 18 cm thick. Several concretionary beds also occur in this interval. The second calcarenitic interval extends from 162.7 m to 164.1 m (units MV260–MV266), and the thickest calcarenite bed is 16 cm. The third calcarenitic interval extends from 170.6 to 171.4 m (units MV279–MV283). The thickest calcarenite bed in this interval is 29 cm. Capping the Juana Lopez Member is the fourth and most prominent of the calcarenitic intervals (Fig. 16), which extends from 181.5 to 184.2 m (units MV293–MV304). Included within this interval are two thick calcarenite beds, unit MV293 (59 cm) and unit MV301 (78 cm).

Concretion horizons are scattered throughout the Juana Lopez. Two concretionary beds are associated with bentonite beds at 155.3 m (20 cm thick, unit MV240) and at 167.3 m (30 cm thick, unit MV273), and two are associated with calcarenite beds at 151.1 m (30 cm thick, unit MV232) and at 178.5 m (9 cm thick, unit MV291). Other noteworthy concretion beds occur at 147.9 m (6 cm thick, unit MV228), 161.9 m (8 cm thick, unit MV258), and 174.3 m (8 cm thick, unit MV287). Bentonites in the Juana Lopez with thicknesses of 5 to 9 cm occur at 149.9 m, 167.2 m, 169.8 m and 184.1 m. Bentonites with thicknesses >10 cm occur at 155.2 m (a multiple bentonite, 33 cm thick, unit MV240) and at 182.9 m (13 cm thick, unit MV297).

The Juana Lopez Member caps low, orange hills north of Mesa Verde National Park. Numerous short trenched sections were used to measure the thickness of the Juana Lopez, including sections both north and south of US-160. The contact with the underlying Blue Hill Member was described in the SW¼ NE¼ sec. 29, T36N, R14W, at the northwestern end of a prominent northwest-trending ridge of uppermost Blue Hill and lower to middle Juana Lopez strata (Fig. 5). The ridge lies to the north of US-160, west of the entrance road to Mesa Verde National Park, and extends parallel to the highway. The third calcarenitic interval (170.6 to 171.4 m, units MV279–MV283) caps this ridge. Three additional areas along the south-

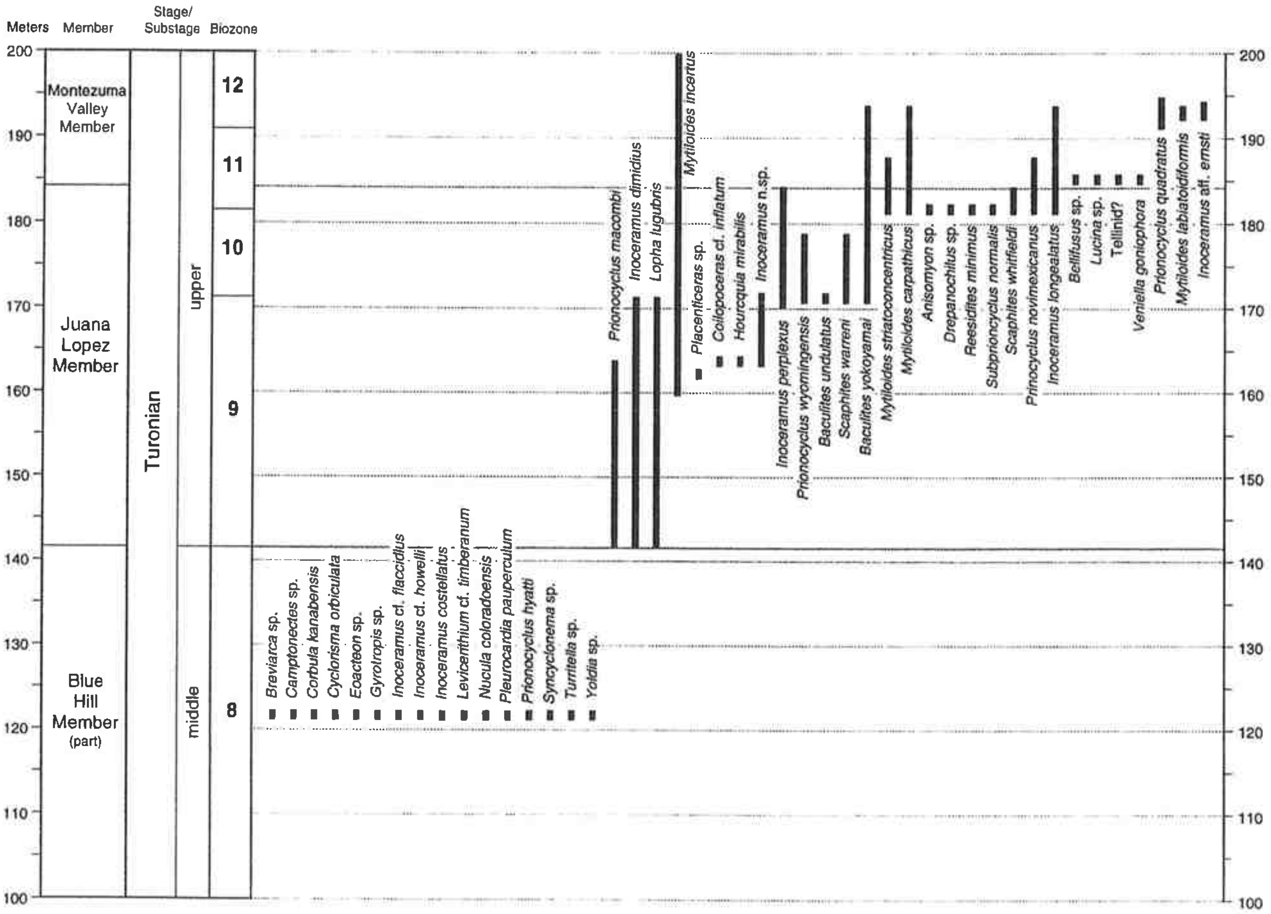

FIGURE 15. Stratigraphic ranges of selected mollusks and biozones of the interval from 100 to 200 m of Mancos Shale principal reference section (upper Blue Hill to Montezuma Valley Members). Refer to Figure 7 for the names of the numbered biozones.

west-facing slopes of this ridge were used to assemble the composite section: SW¼ NE¼ sec. 29; NW¼ SE¼ sec. 29; and at the boundary between the SW¼ and SE¼ SE¼ sec. 29. Two additional areas south of US-160 were used to define the uppermost part of the Juana Lopez Member: SW¼ NE¼ sec. 31, and NW¼ SE¼ sec. 31.

The Juana Lopez Member is characterized by strongly fluctuating gamma-ray values in outcrop and logs of nearby boreholes, and by strong resistivity kicks on the borehole logs (Fig. 9). The resistivity values are greatest in the upper two-thirds of the member in correspondence with the increasing abundance and thickness of calcarenite beds in outcrop. On borehole gamma-ray and resistivity logs the top of the Juana Lopez Member is placed at the top of a resistivity bench that lies directly below a strong gamma-ray kick. The uppermost calcarenitic interval in the Mesa Verde outcrop section (181.5–184.2 m), which defines the top of the Juana Lopez, contains a 13-cm-thick bentonite bed (unit MV 297). However, we believe the well-cemented calcarenite beds are responsible for the resistivity bench observed in the nearby well logs, while the several bentonite beds in the basal 2 m of the overlying Montezuma Valley Member are responsible for the strong gamma-ray kick above the observed resistivity bench.

Biostratigraphy and age

The Juana Lopez Member contains well-preserved ammonites, inoceramid bivalves, and oysters that permit the recognition of three upper Turonian ammonite biozones (Figs. 15, 33–37). A slight disconformity at the base of the member is suggested by a concentration of fish debris, shark teeth and possible cutter casts. The lower upper Turonian *Prionocyclus macombi* Zone is first recognized at 142.2 m (unit MV226) by the occurrence of *P. macombi* Meek, *Baculites* sp., *Inoceramus dimidius* White, and the encrusting oyster *Lopha lugubris* (Conrad). These fossils are recognized up-section in the shale, with particularly good material preserved at 155.0 m (unit MV239, within the lowest calcarenitic interval) and in the second calcarenitic interval at 164 m (units MV264, MV266), where *L. lugubris* occurs with the ammonites *Hourcquia mirabilis* Collignon and *Coilopoceras* cf. *inflatum* Cobban and Hook, and *Inoceramus* n. sp.

Inoceramus perplexus Whitfield first appears at 170.0 m (unit MV278) followed by the first appearance of *Prionocyclus wyomingensis* Meek at 170.7 m (unit MV280). A bench-forming calcarenite bed at 171.2 m (unit MV283, third calcarenitic interval) contains a diverse fauna indicative of the *P. wyomingensis* Zone, and includes the ammonites *P. wyomingensis*, *Scaphites warreni* Meek and Hayden, *Baculites undulatus* d'Orbigny, and *B. yokoyamai*, the inoceramids *I. perplexus* and *I. dimidius*, and the oyster *Lopha lugubris* (Conrad). This is the highest occurrence of *L. lugubris* and *I. dimidius* in this section. Impressions in the overlying shale indicate that this zone ranges up-section.

The *Scaphites whitfieldi* Zone is readily recognized on the basis of abundant specimens of *S. whitfieldi* Cobban in the bench-forming calcarenite beds in the upper 2.7 m of the member (units MV293-MV301). Scattered concretions at the base of this interval contain very well-preserved specimens of ammonites *S. whitfieldi*, *Prionocyclus novimexicanus* (Marcou), *Baculites yokoyamai*, *Reesidites minimus* Hayasaka and Fukada and *Subprionocyclus normalis* (Anderson): the inoceramid bivalves *Inoceramus perplexus*, *I. longealatus* Troeger, *Mytiloides striatoconcentricus* (Guebel), and *M. carpathicus* (Simionescu); and the gastropods *Drepanochilus* sp. and *Anisomyon* sp. Until now, *S. normalis* had not been recognized in the Western Interior (e.g., Wright, 1979). The *S. whitfieldi* Zone extends upward into the lower part of the overlying Montezuma Valley Member. In summary, the Juana Lopez Member at Mesa Verde extends from the lower upper Turonian *Prionocyclus macombi* Zone into the upper Turonian *Scaphites whitfieldi* Zone.

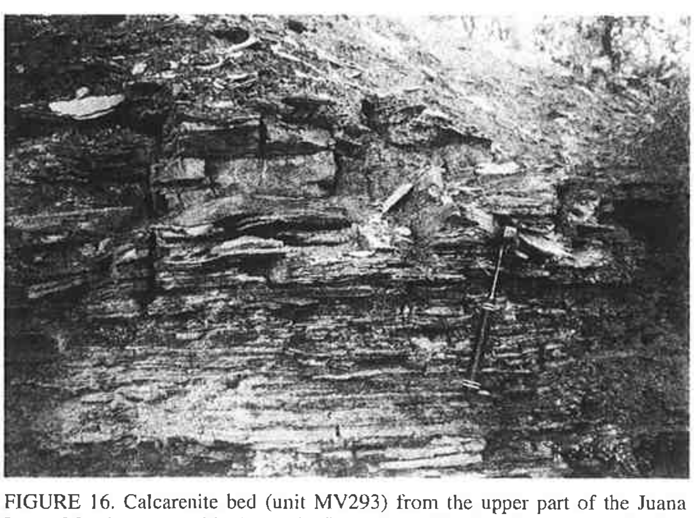

FIGURE 16. Calcarenite bed (unit MV293) from the upper part of the Juana Lopez Member exposed in Area 14 (Fig. 5; Table 2). Note the ripple lamination in the center of the bed.

Montezuma Valley Member

Summary

Interval 184.2–200.4 m; units MV305–MV329; thickness 16.2 m; lower contact sharp; upper contact sharp.

Lithostratigraphy and geophysical log character

The Montezuma Valley Member consists of slightly silty to slightly sandy calcareous shale that contains numerous septarian concretions (Fig. 4). The shale is moderately well indurated with subparallel to parallel parting, and it varies in color from gray at the base to medium dark gray, olive gray, and dark olive gray through the remainder of the unit. The shale of the Montezuma Valley contains disseminated carbonaceous plant material and is fossiliferous with inoceramid bivalves and baculites. Three informal units can be distinguished. The interval from 184.2 to 187.4 m (units MV305–MV311) is a slightly silty, weakly calcareous shale containing several thin calcarenite beds and calcarenite lenses. The shale becomes distinctly more calcareous in the interval containing numerous septarian concretions between 187.4 and 194.7 m (units MV312–MV326) (Fig. 17). A swarm of limonite seams also occurs within this interval (189.6–190.1 m). The uppermost concretion bed occurs at 196.5 m. The concretions range from 5 cm to as much as 20 cm in thickness, and several preserve large ammonites. A horizon of abundant current-oriented baculites occurs at 188 m (unit MV313). The upper part of the Montezuma Valley Member consists of slightly sandy (very fine- to fine-grained) calcareous shale. The Montezuma Valley Member contains several bentonite beds, including an 8-cm-thick bed at 186.1 (unit MV310) m and a 10-cm-thick bed at 193.9 m (unit MV324).

The Montezuma Valley Member is exposed on slopes and in arroyos beneath the more resistant marlstones and calcareous shales of the overlying Smoky Hill Shale Member. The type section of the Montezuma Valley Member is exposed on both sides of the Mesa Verde National Park aqueduct and along an unimproved service road in SE¼ sec. 31, T36N, R14W (Fig. 5). Five short trench sections were used to assemble a composite section of the member. The contact with the underlying Juana Lopez Member was described north of the aqueduct and service road in NW¼ SE¼ sec. 31. The bulk of the Montezuma Valley Member is exposed in a major arroyo about 0.25 km south of the service road along the boundary between SW¼ and SE¼ SE¼ sec. 31. Contact with the overlying Smoky Hill Member was described near the base of a west-facing slope just south of the service road along the boundary between NW¼ and NE¼ SE¼ sec. 31.

Gamma-ray values recorded through the Montezuma Valley Member outcrop section are variable due to the numerous concretion beds in the lower two-thirds of the member. However, the amplitude of the variation is not as large as observed in the underlying Juana Lopez Member. On gamma-ray and resistivity logs from nearby boreholes, the Montezuma Valley Member can be recognized as the interval between the distinctive high-amplitude Juana Lopez geophysical log signature and the lower gamma-ray/higher resistivity values of the calcareous shales and marlstones of the lower Smoky Hill (Fig. 9).

Biostratigraphy and age

The Montezuma Valley Member contains common ammonites and inoceramid bivalves, that are preserved both as compressions in shale and variably preserved specimens in septarian concretions. *Scaphites whitfieldi, Prionocyclus novimexicanus, Baculites yokoyamai, Inoceramus perplexus, I. longealatus*, and *Mytiloides carpathicus* occur through the lower half of the member, indicating the *Scaphites whitfieldi* Zone. Large prionocyclids (as much as 45 cm in diameter) with weak lateral tubercles occur sporadically in septarian concretions near the middle of the member (191–195 m) and are probably assignable to *Prionocyclus quadratus* Cobban, which defines the uppermost Turonian ammonite zone. These occur with *Mytiloides labiatoidiformis* (Troeger), *M. incertus* (Jimbo) and *Inoceramus* aff. *ernsti* Heinz. Fossils are scarce in the upper part of the member, but those present are in agreement with a latest Turonian age. The member thus ranges from within the upper Turonian *Scaphites whitfieldi* Zone upward into the uppermost Turonian *Prionocyclus quadratus* Zone (Figs. 15, 36, 37, 38). Lower Coniacian rocks, and perhaps also uppermost Turonian and lower middle Coniacian rocks, are missing in the sharp shale-on-shale disconformity between the Montezuma Valley Member and the overlying Smoky Hill Member.

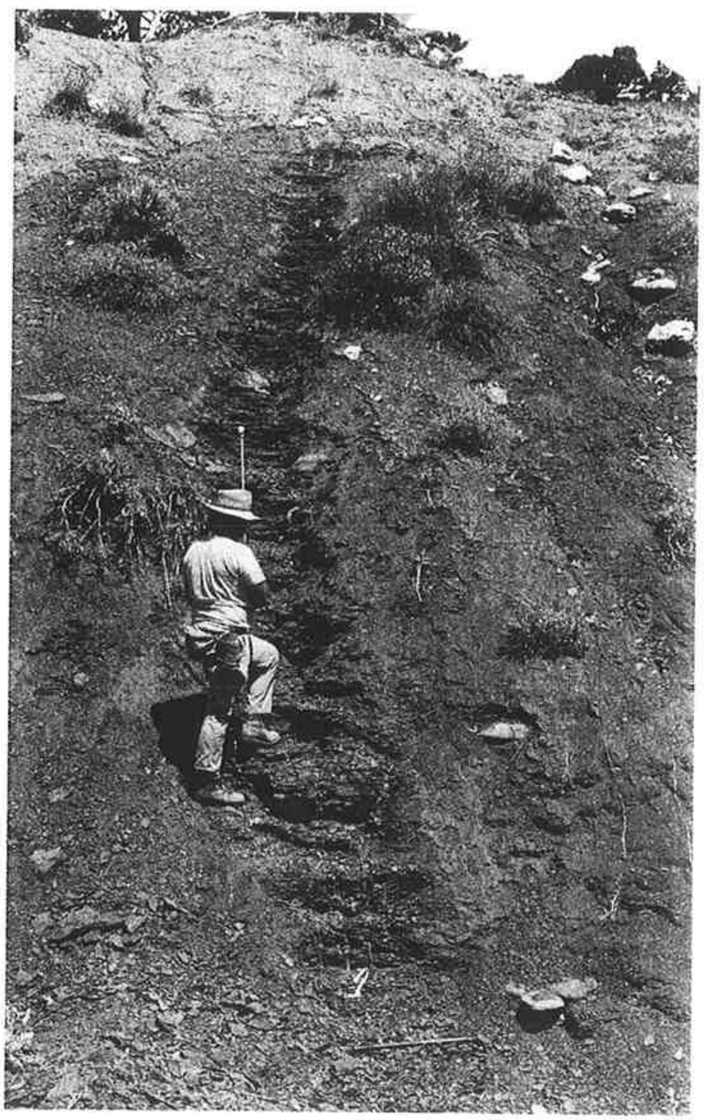

FIGURE 17. Middle part of the Montezuma Valley Member exposed in an arroyo in Area 16 (Fig. 5; Appendix 1). The trench that Jim Kirkland is working in contains a 6.5-m-thick interval of calcareous shale with numerous septarian concretions (unit MV312 at base of trench near hoe-pick, unit MV323 at the top of the trench).

Smoky Hill Member

Summary

Interval 200.4–289.0 m; units MV330–MV376; thickness 88.6 m; lower contact sharp; upper contact gradational.

Lithostratigraphy and geophysical log character

The Smoky Hill Member consists of dark-gray, well-laminated, foraminifer-rich calcareous shale, foraminifer-rich calcareous mudstone, and medium-gray foraminiferal marlstone (Fig. 4). The member is fossiliferous throughout and calcarenitic in places. Limonite seams are numerous, particularly in the upper 13 m of the member. Bentonite beds are rare, and most are <5 cm thick. The dominant lithology is calcareous shale. The calcareous shale and marlstone have platy weathering, in contrast with the calcareous mudstone beds, which show knobby weathering. Fecal pellet laminae occur commonly through the member and fecal pellets are abundant on many calcareous shale, calcareous mudstone, and marlstone bedding surfaces. Calcareous mudstone is best represented in the lower part of the member, particularly in the interval from 204.6 to 213.4 m.

The marlstone units are more resistant than the calcareous shale and calcareous mudstone, and weather to a light gray. Benches are developed on marlstone beds in intervals 202.3–204.6 m (unit MV332), 213.4–215.7 m (unit MV341), 219.6–219.8 m (unit MV347), 266.2–273.2 m (unit MV371) and 276.0–289.0 m (units MV374–MV376). The two thick upper marlstone intervals form steep outcrop faces (Fig. 18). The second from the top is capped by a 23-cm-thick bentonite (unit MV372). The upper marlstone interval is 13 m thick and forms a prominent bench around the northernmost edge of Mesa Verde National Park. Two calcarenitic intervals are observed: 231.2–233.9 m (unit MV363) and 260.3–261.4 m (units MV367–MV369). The upper interval forms a distinctive mid-slope bench.

The lower contact of the Smoky Hill Member corresponds with a widespread disconformity (Fig. 8) separating Carlile rocks below from Niobrara rocks above (Pike, 1947; Dane, 1960; Lamb, 1968; Molenaar, 1977, 1983; Dyman et al., 1993). In this section, the Carlile-Niobrara disconformity is represented by a sharp shale-on-shale contact that is unrecognizable without trenching. The calcareous shales above (light olive gray) and below the disconformity (dark olive gray) are similar except for a subtle color difference and the presence of disseminated glauconite, biotite, and fine-grain quartz sand in the basal 2–3 m of the Smoky Hill Member. Isolated medium to coarse grains of quartz sand also occur above the disconformity at Mesa Verde. The lighter color, absence of disseminated carbonaceous plant material, and the presence of glauconite and more abundant foraminifera dis-

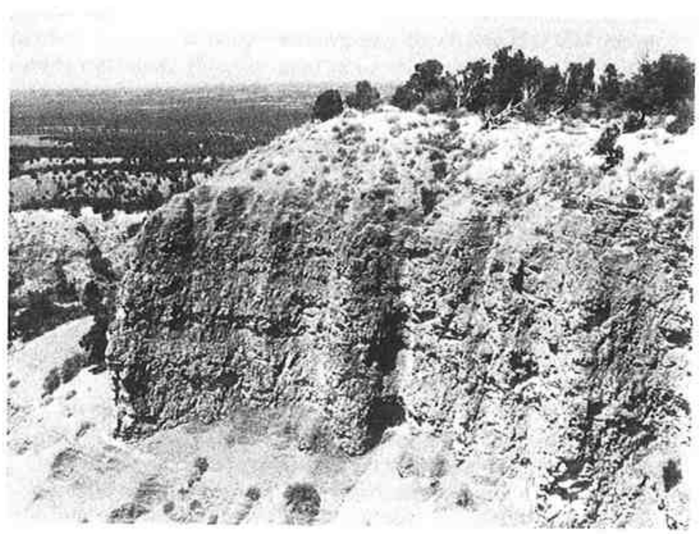

FIGURE 18. Prominent bench formed by calcareous shale and marlstone in the upper part of the Smoky Hill Member. The break in slope above the cliff marks the contact between the Smoky Hill and the overlying Cortez Member. A 23-cm-thick bentonite bed (unit MV372) forms a white band in the slope below the cliff. The relief on the cliff face is approximately 15 m.

tinguish the Smoky Hill from the underlying Montezuma Valley Member.

The upper contact of the Smoky Hill Member is placed at the top of a prominent marlstone bench (289.0 m; Fig. 18). Contact between the Smoky Hill and the overlying Cortez Member is gradational. Similar lithologies, namely calcareous shales, constitute the bulk of the lower 46.5 m (289.0–335.5 m) of the Cortez Member. The decision to place the Smoky Hill-Cortez contact at 289.0 m is based on mappability of the prominent marlstone bench and distinctive geophysical log character, as discussed below. In addition, the Cortez Member is distinguished from the Smoky Hill Member by numerous well-cemented dolomitic mudstone beds and numerous thin sandstone beds. The lowest of the dolomitic mudstone beds occurs at 307 m and the lowest sandstone bed lies at 321.6 m.

The Smoky Hill Member forms steep, medium- to light-gray slopes on the northern edge of Mesa Verde National Park. Uppermost parts of the member are benched and form nearly vertical cliffs of sharp, platy marlstone. The disconformable contact with the underlying Montezuma Valley Member was described near the base of a west-facing slope just south of the aqueduct service road along the boundary of NW¼ and NE¼ SE¼ sec. 31, T36N, R14W, and contact with the overlying Cortez Member was described in the SE¼ SE¼ sec. 31 (Fig. 5). Additional trenches used in compiling the composite Smoky Hill section were dug in the NE¼ SE¼ sec. 31.

The marlstone and calcarenite benches that characterize surface exposures are expressed distinctively in geophysical log profiles of the member. One such bench in the basal part of the member facilitates recognition of the disconformable Montezuma Valley-Smoky Hill contact in nearby geophysical subsurface logs (Fig. 9). Gamma-ray values increase slightly and gradually in the upper 16 m of the Smoky Hill Member, above a 23-cm-thick bentonite bed at 273.2 m (unit MV372). We attribute the increasing gamma-ray values to numerous limonite seams (thin remnants of volcanic ash?) in the upper part of the Smoky Hill Member at Mesa Verde. The contact with the overlying Cortez Member is placed at the top of the uppermost bench-forming Smoky Hill marlstone unit. The relative resistance pattern observed in outcrop is perfectly mimicked in subsurface resistivity logs. In addition, bentonite MV372 is distinguished on the logs by a strong gamma-ray and low resistivity kick. This results in a very distinctive geophysical log profile for the uppermost part of the Smoky Hill Member, and can be easily traced in the subsurface (e.g., Molenaar and Baird, 1989).

Biostratigraphy and age

The amount of time represented by the disconformity at the base of the Smoky Hill Member can be estimated on the basis of fossils recorded in the underlying Montezuma Valley Member and by stratigraphically lowermost age-determinant fossils within the Smoky Hill. *Inoceramus (Platyceramus) stantoni* (Sokolow) first occurs 2.3 m above the base of the member (202.7 m; unit MV332), and poorly preserved specimens of the genus *Inoceramus (Volviceramus)* appear at 219.4 m (unit MV347). *Scaphites depressus* Reeside first appears at 223 m (unit MV353) together with *Inoceramus (Magadiceramus) subquadratus* (Schlueter), thus indicating the upper Coniacian *Scaphites depressus* Zone. *Inoceramus (P.) stantoni* occurs in the lower shale unit of the Smoky Hill in the area near Pueblo, Colorado (Scott and Cobban, 1964; Scott et al., 1986). The interval between the base of the Smoky Hill Member and the first occurrence of *S. depressus* (200.4-223 m) may represent the middle Coniacian *Scaphites ventricosus* Zone. The unconformity at the base of this member thus omits the interval from within the uppermost Turonian *Prionocyclus quadratus* Zone through the lower Coniacian and into the middle Coniacian *S. ventricosus* Zone, or perhaps even into the lower upper Coniacian *S. depressus* Zone (Figs. 19, 38–40).

The *Scaphites depressus* Zone can be recognized through the interval extending from 223 to 266 m (unit MV353–MV370). This zone is the most fossiliferous interval in the member and contains the ammonites *S. depressus*, *Baculites codyensis* Reeside (includes forms referable to *B. asper* Morton), *Protexanites bourgeoisi* (d'Orbigny) [= *P. shoshonensis* (Meek)], and *Phlycticrioceras trinodosus* (= *P. oregonense* Reeside), the inoceramid bivalves *Inoceramus (P.) stantoni*, *I. (Magadiceramus) subquadratus*, and *I. (Volviceramus) grandis* (Conrad), the encrusting oyster *Pseudoperna congesta* (Conrad), the epifaunal bivalves *Phelopteria* sp. and *Modiolus* n. sp., the deep infaunal generalist *Lucina* sp., and the brachiopods *Discinisca* sp. and *Lingula* sp. The inoceramids *I. (M.) subquadratus* and *I. (V.) grandis* last occur at 266 m (unit MV370), suggesting that the top of the Coniacian may occur at approximately this level.

The upper 22.5 m of the Smoky Hill Member (266.5–289 m) contains common *Platyceramus platinus* (Logan), *Pseudoperna congesta*, and rare *Phelopteria*. We collected no ammonites that can be used to precisely date these strata, but a fauna indicative of a Santonian age occurs 8.5 m above the top of the Smoky Hill, at 297.5 m (unit MV381). In addition, the lower upper Santonian zonal ammonite marker species *Clioscaphites choteauensis* is present at 307 m (unit MV389). These relationships suggest that the upper Smoky Hill includes the lower Santonian *Clioscaphites saxitonianus* Zone and middle Santonian *Clioscaphites vermiformis* Zone, and may include the basal part of the upper Santonian *Clioscaphites choteauensis* Zone. *Clioscaphites choteauensis* and associated taxa occur with *Uintacrinus socialis* Grinnell in central Kansas (Hattin, 1982) and in the Grand Valley of western Colorado. In Europe, the upper Santonian is divided into two zones based on pelagic crinoids with *Uintacrinus* at the base and *Marsupites* at the top (Rawson et al., 1978; Hancock, personal commun., 1989). However, no specimens of *C. choteauensis* or *Uintacrinus* were found in the upper Smoky Hill Member at Mesa Verde.

In summary, the lower and middle Santonian is represented by upper bluff-forming units (266.5–289.0 m) of the Smoky Hill Member in this area, with the entire member spanning the upper middle Coniacian through middle Santonian.

Cortez Member

Summary

Interval 289.0–682.0 m; units MV377–MV686 (677.7 m); thickness 393.0 m; lower contact gradational; upper contact gradational.

Lithostratigraphy and geophysical log character

The Cortez Member consists of two coarsening upwards sequences that make up most of the shaly slopes exposed beneath the northern rim of Mesa Verde (Fig. 4). The lower part of the Cortez Member consists of calcareous shale at the base overlain by silty calcareous shale containing an increasing abundance of thin (1–4 cm thick) very fine- to fine-grained sandstones in the middle of the unit (389.6–451.7 m). The upper part represents a second overall coarsening upwards package with silty to sandy shale and sandy mudstone overlain by interbedded very fine- to fine-grained sandstone, argillaceous sandstone, and sandy mudstone in the transition with the overlying Point Lookout Sandstone. A distinctive feature of the Cortez Member are the numerous beds or discontinuous pod-like concretions of dolomitic mudstone. Cole et al. (in press) described similar beds from the Prairie Canyon Member of the Mancos Shale in western Colorado as "rusty weathering, sandy, ankeritic dolomite." X-ray diffraction analysis of six of the beds from the Prairie Canyon Member reveal that the primary carbonate mineral is ferroan dolomite (Cole et al., in press).

The Cortez Member is subdivided into six informal units, each of which is gradational with the corresponding suprajacent unit. The lowest of these informal units is 46.7 m thick (289.0–335.7 m; units MV377–MV418) and is composed of olive-gray foraminifer-bearing calcareous shale and slightly silty calcareous shale that contain numerous limonite seams and thin bentonite beds. The shale is moderately well indurated, well stratified, and contains fecal pellet laminae and scattered fish scales. Most of the shale has subparallel to parallel parting. Five very well-indurated, orange-weathering dolomitic mudstone beds are present at 307 m (unit MV389), 313.6 m (unit MV397), 320 m (unit MV401), 324.2 m (unit MV411) and 335.5 m (unit MV418). These distinctive units are from 10 to 22 cm in thickness, medium gray to medium light gray in color, and well stratified with parallel parting and irregular fracture. Some of the beds are sparingly fossiliferous, and all five stand out prominently on the shale slopes. A 21-cm-thick, discontinuous, oyster-inoceramid biostrome (unit MV381) lies at 297.6 m (Fig. 20). Relatively thin (8–23 cm in thickness) foraminiferal marlstone beds occur at 322.6 m (unit MV409), 324.7 m (unit MV413) and 325.8 m (unit MV415).

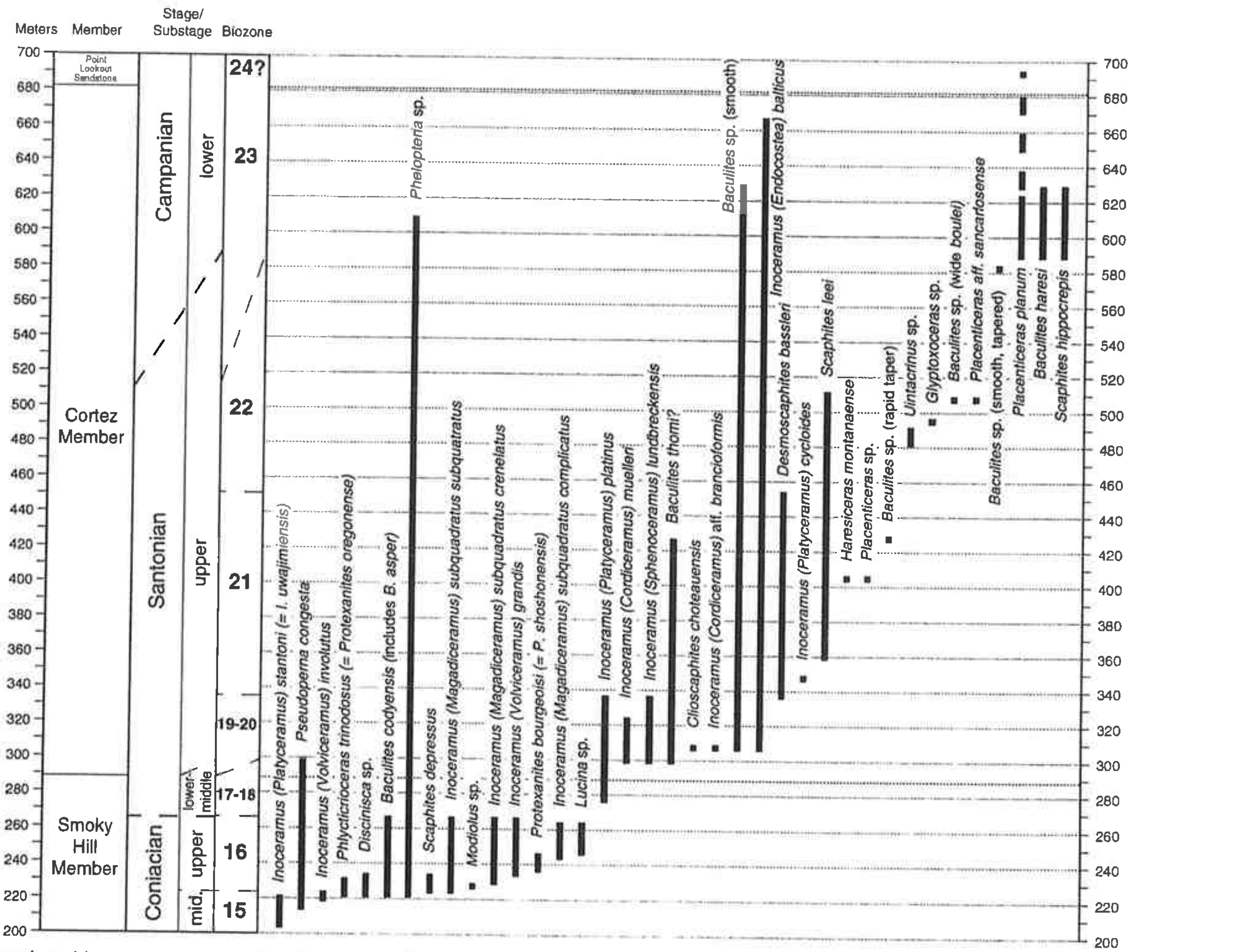

FIGURE 19. Stratigraphic ranges of selected mollusks and biozones of the interval from 200 to 700 m of Mancos Shale principal reference section (Smoky Hill and Cortez Members). Refer to Figure 7 for the names of the numbered biozones.

A bentonite bed approximately 95 cm thick is present at 325 m (unit MV414), and forms a distinctive whitish band in the gray shale slope (Fig. 21). The lower contact of this bentonite is sharp but the upper contact is gradational through a 20–30 cm interval. A thin sandstone bed (unit MV405) occurs at 321.6 m. This bed is 2–3 cm thick and is composed of wavy ripple bedded, very fine-grained sandstone. This informal interval of the Cortez Member is lithologically similar to the underlying Smoky Hill Member but can be distinguished by absence of thick bench-forming marlstone units, by presence of prominent dolomitic mudstone beds, and by presence of the lowest sandstone bed of the regressive upper Mancos sequence.

The second informal unit of the Cortez Member is 53.9 m thick (335.7–389.6 m, units MV419–MV435) and is composed of dark-olive-gray slightly calcareous silty shale. The shale is moderately well to well indurated, well stratified, and contains laminae of silt and fecal pellets. Subparallel to parallel parting with plant material and fish scales on the parting surfaces is common. No bentonite beds, and only one limonite seam, occur in this interval. Very thin beds (mostly <0.5 cm), starved ripples, and laminae of coarse siltstone to very fine-grained sandstone occur more commonly upward toward the top of the interval. In addition, the interval contains several 2–4-cm-thick very fine-grained sandstone beds with scour-fill bases, ripple laminations, and shale partings. Two very well indurated dolomitic mudstones are present at 365.7 m (14 cm thick, unit MV425) and 383.0 m (31 cm thick, unit MV430) (Fig. 22). This interval differs from the one below in being less calcareous, more silty, and marked by presence of numerous thin siltstones/sandstones, fewer dolomitic mudstones, and absence of bentonites.

More common and thicker sandstone beds are present in the 62.1 m interval from 389.6–451.7 m (units MV436–MV477) (Fig. 23). This informal unit of the Cortez Member is composed of slightly calcareous sandy shale and interbedded sandstone. Bentonite beds and limonite seams are absent. The shale is dusky yellowish-brown to olive-gray in color, moderately well to well indurated, and well stratified. The shale contains disseminated plant debris along the partings, and laminae or lenses of very fine-grained sandstone. Sandstone also occurs in thin beds between 0.5 and 9 cm thick, although most beds are in the range of 0.5–2.0 cm. The sandstone is yellow gray to light gray in color and weathers grayish orange. It is well

FIGURE 20. Basal Cortez Member with a discontinuous 21-cm-thick oyster-inoceramid biostrome (unit MV381). This distinctive unit occurs on low relief slopes above the bench formed by the upper marlstone of the Smoky Hill Member (see Fig. 5).

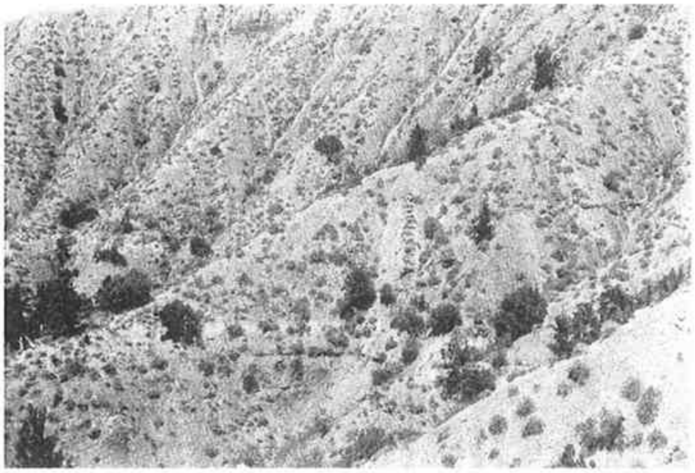

FIGURE 21. Lower part of the Cortez Member (upper part of informal unit 1 and basal part of unit 2). Note trench in the middle of the photograph (with person for scale). Below the trench are several thin marlstone beds (units MV409-MV413) overlain by a 95-cm-thick bentonite bed (unit MV414) that forms a distinctive whitish band in the shale slope. At the top of the trench is a 22-cm-thick dolomitic mudstone bed (unit MV418). This part of the section is exposed in the lower part of Area 22 (see Fig. 5; Table 2).

indurated, ripple laminated, and commonly has scour-fill bases. The thicker sandstone beds (>2 cm) contain shale partings or thin shale drapes over the ripple crests. A 26-cm-thick dolomitic mudstone bed is present at 427.6 m (unit MV464) and a large lenticular dolomitic(?) concretionary mudstone, approximately 45 cm thick and 150 cm across, is present at 406.2 m. This informal interval differs from the one below by its greater abundance of thin interbedded sandstone.

The fourth informal unit of the Cortez Member contains significantly fewer thin sandstone beds. This interval is 131.9 m thick and extends from 451.7 to 583.6 m above the Dakota Sandstone (units MV478–MV615). The unit is composed primarily of slightly calcareous, silty to sandy shale containing thin very fine-grained sandstone beds, thin grayish red-weathering, concretionary horizons, and a few thin (<10 cm) bentonite beds. Three prominent dolomitic mudstone beds are present in this interval. A discontinuous bed as much as 49 cm thick lies at 464.2 m (unit MV495) and is exposed along the Mesa Verde National Park entrance road (Fig. 24); another discontinuous bed as much as 22 cm thick lies at 509 m (unit MV551) and is also exposed along the entrance road, and an apparently continuous bed ranging in thickness from 3 to 20 cm lies at 546.2 m (unit MV604). Units MV495 and MV551 occur as long pods, 6–10 m in length, with 2–4 m between pods. Unit MV604 is the uppermost of eleven dolomitic mudstone beds in the Cortez Member. There is a suggestion of three coarsening upwards cycles in the lower part of this informal unit (451.7–534.4 m) based on the abundance of thin interbedded sandstone. Overall, the shale becomes sandier above 534.4 m. The interval from 456.6–481.0 m contains nine 3–11 cm-thick beds of silty to sandy brown to yellowish-brown calcareous shale. Twenty-eight beds of slightly silty, concretionary calcareous shale are present in the interval from 483.5–540.0 m. These beds range in thickness between 2 and 16 cm, although many are about 3–4 cm thick. Most are grayish red to pale-red to grayish orange-pink in color, and some are fossiliferous (Fig. 25). Four additional pinkish red, concretionary calcareous shale beds occur in the interval from 540.0–591.7 m.

The interval from 583.6–660.2 m (units MV616-MV658) is the fifth informal unit of the Cortez Member, and is composed of slightly calcareous sandy mudstone and sandy shale with thin interbedded sandstone and sparse small micritic limestone concretions (Fig. 26). These concretions occur throughout the 76.6-m-thick unit; many weather grayish red, and thus resemble those of the underlying informal unit. The concretions are ovate to subspherical in shape, typically 2–5 cm thick, and 5–7 cm in diameter. They occur in isolated and widely spaced, to distinctly closely spaced horizons. A 35-cm-thick bentonite is present at 607.2 m (unit MV633), and several thin (<5 cm) bentonite beds occur in this interval. Sand content increases generally toward the top of the unit, as does the abundance of argillaceous sandstone and interbedded sandy mudstone.

The uppermost interval of the Mancos Shale, and sixth informal unit of the Cortez Member, extends from 660.2–682.0 m (units MV659-MV686). This unit is composed of interbedded very fine- to fine-grained sandstone, argillaceous sandstone, and sandy mudstone (Fig. 27). The individual sandstone beds increase in thickness from 15 cm at the base of the 21.8 m interval to 60 cm near the top. This interval represents the transition with the overlying Point Lookout Sandstone. We trenched the section to a horizon 677.7 m above the Dakota Sandstone (unit MV686, a 60-cm-thick, clean, fine-grained sandstone bed). Above this level, an apron of talus beneath the sandstone cliffs of Point Lookout prevented complete exposure, although numerous prominent sandstone beds, from 29 cm to 200 cm in thickness, crop out through the cover. The mudrock-dominated portion of the transition is assigned to the uppermost Mancos Shale, and the sandstone-dominated portion to the Point Lookout Sandstone (Dunbar et al., this volume). The Mancos-Point Lookout contact is placed where sandstone thickness exceeds mudrock thickness over an interval greater than 2

FIGURE 22. Lower part of the Cortez Member (upper part of informal unit 2 and basal part of unit 3). Interval of slightly calcareous silty shale with numerous laminae or very thin beds of coarse siltstone/very fine-grained sandstone. The resistant bed at the base of the trench is a 31-cm-thick dolomitic mudstone (unit MV430). The trench extends from 383 m to 392 m in the Mancos Shale reference section (lower part of Area 23; Fig. 5; Table 2).

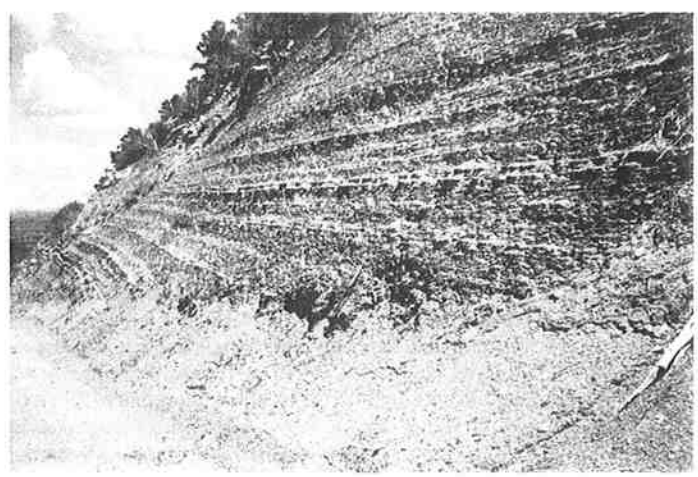

FIGURE 23. Middle part of the Cortez Member (informal unit 3) containing numerous thin beds of coarse siltstone/very fine-grained sandstone. Note hoe-pick for scale. This exposure is along the winding entrance road into Mesa Verde National Park (below Point Lookout; see Fig. 5).

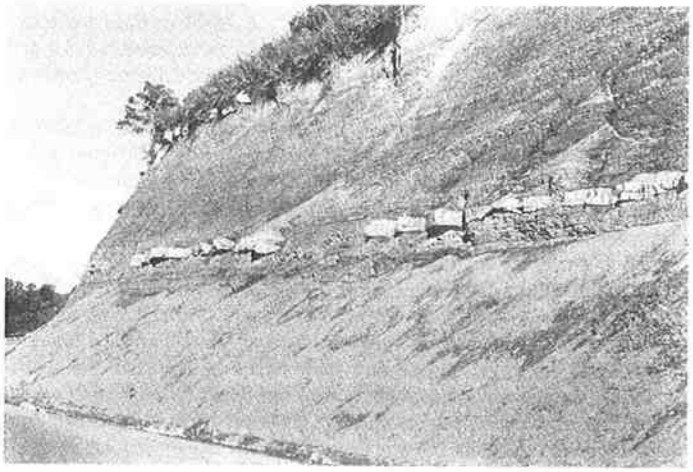

FIGURE 24. Middle part of the Cortez Member (lower part of informal unit 4) containing 49-cm-thick discontinuous dolomitic mudstone bed (unit MV495) exposed at hairpin turn along the entrance road into Mesa Verde National Park (below Point Lookout; see Fig. 5).

m, and where the sandstone beds are clean (not argillaceous) and form hard, resistant beds with interbedded mudrocks (Dunbar et al., this volume). Many of the argillaceous sandstone beds are thoroughly bioturbated and generally lack depositional sedimentary structures. They also tend to be less well indurated and are therefore less prominent than the cleaner sandstone beds. The thicker, more massive beds of argillaceous sandstone (>50 cm) contain ball-and-pillow structures. In the lower part of this informal unit, the muddy sandstone beds thicken upwards in repetitive cycles. The cleaner sandstone beds are calcareous and the grains are well sorted, very fine to fine grained, and manifest a general coarsening upward trend through the unit. They are light gray to medium light gray in color and weather to a yellowish gray, pale yellowish brown or light olive gray. The sandstone beds are well indurated and well stratified, exhibiting planar to low-angle cross stratification or hummocky cross stratification. Burrows and disseminated plant debris are common on parting surfaces. The sandy shale in this interval is slightly calcareous, and the sparse thin beds or laminae of paper shale are noncalcareous.

The type section of the Cortez Member is in the western half of sec. 5, T35N, R14W (Fig. 5). The Cortez Member makes up the bulk of the steep

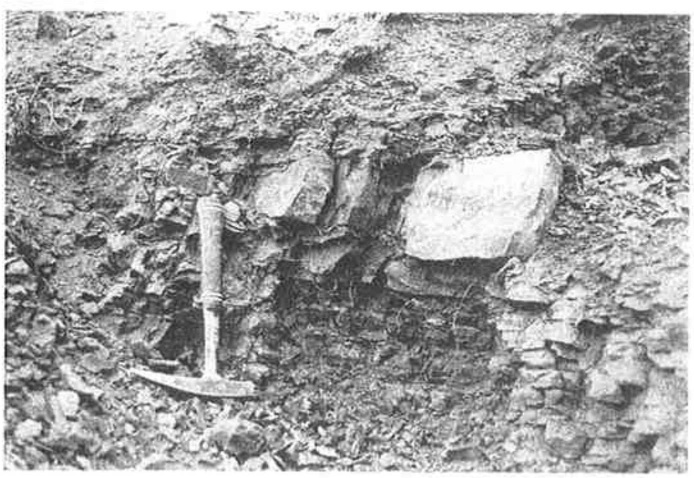

FIGURE 25. Middle part of the Cortez Member (informal unit 4) containing slightly calcareous, slightly silty shale. Grayish red-weathering concretion (unit MV525) overlies shale containing pinkish or grayish red, knobby weathering (concretionary?) intervals typical of this part of the Cortez Member.

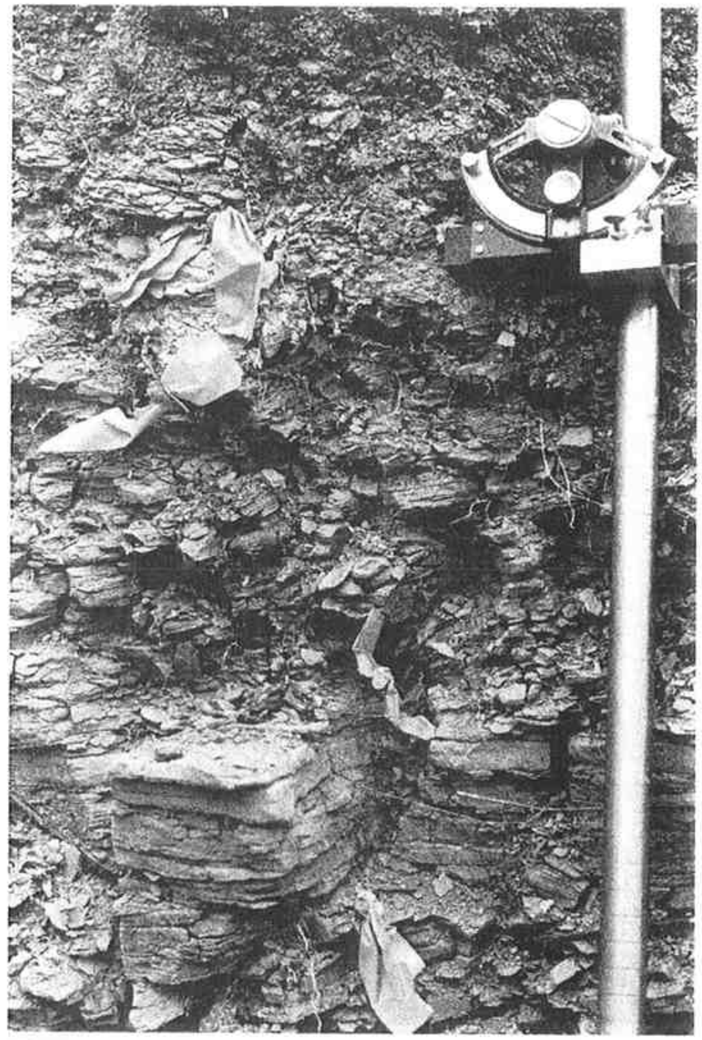

FIGURE 26. Middle part of the Cortez Member (upper part of informal unit 4). Note 7-cm-thick shaly, very fine-grained sandstone bed (unit MV575) and 6-cm-thick bentonite bed (unit MV577) at position of Abney level.

gray slopes below the Point Lookout Sandstone. Contact with the underlying Smoky Hill Member was described on the basis of an exposure in the SE¼ SE¼ sec. 31, T36N, R14W. The contact with the overlying Point Lookout Sandstone was described beneath the cliffs of Point Lookout in the NE¼ SW¼ sec. 5, T36N, R14W. Most of the Cortez Member was described on the basis of 10 trenches in the SW¼ NW¼ sec. 5, T36N, R14W, and 21 trenches in the NW¼ SW¼ sec. 5, T36N, R14W.

The gamma-ray profile generated on the outcrop shows variability that reflects the six informal units (Fig. 9). The sharp low gamma kicks are from the numerous hard dolomitic mudstone beds and concretion horizons observed in the field. Unfortunately, few of these hard beds or the six informal units discussed above can be recognized with great confidence on the logs from nearby wells. Comparison of the Mesa Verde outcrop gamma-ray profile with borehole logs from farther east in the northern San Juan Basin (Molenaar and Baird, 1989) shows several intervals of likely correlation within the Cortez Member (Fig. 6). For example, a 35-cm-thick bentonite at 607.2 m in the Mesa Verde section (unit MV633) can be traced eastward by its distinctive positive gamma-ray kick, and several of the dolomitic mudstones may correspond with strong resistivity kicks on the subsurface logs.

Biostratigraphy and age

The Cortez Member is sparsely fossiliferous. The best preserved material is associated with concretionary units. Fossils also occur in the intervening shale but are generally poorly preserved and widely scattered. The

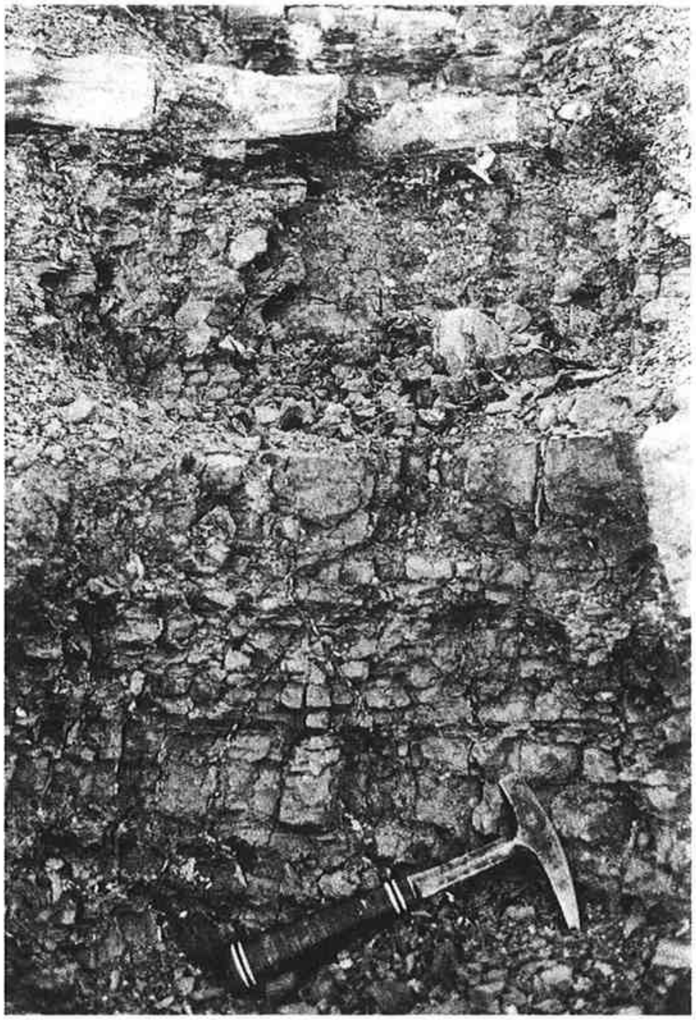

FIGURE 27. Upper part of the Cortez Member (informal unit 6). Interval of very fine-grained argillaceous sandstone and mudstone. Note 10-cm-thick very fine-grained sandstone bed with hummocky cross-stratification in upper part of photograph (unit MV671).

sporadic distribution of fossils in this member makes precise zonal division impractical at this time (Figs. 8, 19, 40–46).

The lower foraminifer-bearing calcareous shale interval (289–335.7 m) may be included largely within the upper Santonian *Clioscaphites choteauensis* Zone on the basis of contained ammonites and inoceramids. These include the ammonites *C. choteauensis* Cobban, *Baculites thomi*? Reeside and *Baculites* sp. (smooth); the inoceramids *I. (Platyceramus) platinus, I. (Sphenoceramus) lundbreckensis* Mclearn, *I. (Endocostea) balticus* (Bohm), *I. (Cordiceramus) muelleri* Petrascheck, and *I. (C.) brancioformis* Seitz; and the encrusting oyster *Pseudoperna congesta*. A dolomitic mudstone at the top of this interval (335.5 m, unit MV418) contains *Desmoscaphites bassleri* Reeside, the nominal species of that subzone of the *Scaphites leei* Zone (Cobban, 1951; Hattin, 1982), suggesting that the *D. erdmanni* Subzone is also included in the underlying calcareous shale.

The lower silty shale interval (335.7–389.6 m) is within the upper Santonian *Desmoscaphites bassleri* Subzone. Fossils are rare but include the ammonites *D. bassleri* Cobban, *Scaphites leei* Reeside, and *Baculites* sp. (smooth), as well as scattered specimens of *Inoceramus (Platyceramus) cycloides* (Wegner). The middle sandy interval (389.6–451.7 m) also lies in the *D. bassleri* Subzone. Fossils also are sparse in this interval. A concretionary unit at approximately 405 m (unit MV441) contains the ammonites *S. leei* Reeside, *Haresiceras montanaense* (Reeside), *Baculites* sp. (smooth), and *Placenticeras* sp., and the bivalves *I. (Endocostea) balticus* and *Phelopteria* sp. In addition, *Baculites thomi*? was recorded at 425.6 m (unit MV460) and *D. bassleri* and *Baculites* sp. (smooth) were recorded in a dolomitic mudstone at 427.5 m (unit MV464).

The highest occurrence of the genus *Desmoscaphites* is recorded at 454 m (unit MV478), 2 m above the base of the middle silty shale interval (451.7-583.6 m). *Scaphites leei* occurs as scattered isolated specimens in the lower 60 m of this interval. Cobban (1969) recognized three forms of *S. leei*, namely I, II and III. The recovered material at Mesa Verde is too sparse and poorly preserved for specific assignment. *Desmoscaphites* is reported to occur throughout the range of *S. leei*, but has not been recognized in the upper part of the *S. leei* Zone at Mesa Verde. Scott et al. (1986) recognized the *S. leei* III Zone above the *Desmoscaphites bassleri* Zone. Thus, the lower 60 m (451–511 m) of the middle silty shale unit may represent the *S. leei* III Subzone of the upper Santonian *S. leei* Zone (Figs. 7, 19). Fossils are sparse in this interval but include *Baculites* sp. (smooth) throughout, pelagic crinoids (*Uintacrinus* sp.) in the interval from 481 to 491 m, *Glyptoxoceras* sp. at 494 m, and *Placenticeras* aff. *sancarloense* Hyatt at 509 m (unit MV551). In the upper 72 m (511-583 m) of the middle silty shale unit we recorded only a few widely scattered specimens of *Baculites* sp. (smooth), *Placenticeras* sp., *I. (Endocostea) balticus,* and *Phelopteria* sp.

The base of Campanian is placed between 511.0 m (unit MV555) and 588.4 m (unit MV619) in the stratigraphic gap between the highest occurrence of *Scaphites leei* and the lowest occurrence of *S. hippocrepis* (DeKay) (Fig. 19). The presence of *Placenticeras* aff. *sancarloense* at 509 m suggests that the base of the Campanian may lie as low as this level. Scott et al. (1986) placed the Santonian/Campanian boundary between the zones of *S. hippocrepis* I and *S. hippocrepis* II. Kauffman (1975) placed it between *S. leei* II and *S. leei* III. Here, we follow Hattin (1982), among others, and place the Santonian/Campanian boundary between *S. leei* III and *S. hippocrepis* I. In Europe, *S. hippocrepis* occurs in the basal Campanian.

Isolated specimens of *S. hippocrepis* were collected from 588.4 m (unit MV619), 610.1 m (unit MV636), and 629.1 m (unit MV649) within the upper sandy shale unit (583.6–660.2 m). The material is too sparse and poorly preserved to distinguish the individual forms I, II and III of Cobban (1969), and therefore we can recognize only a broad lower Campanian zone of *S. hippocrepis* for this interval. Other fossils are present in the lower 64 m (583–647 m) of the upper sandy shale unit and include widely scattered specimens of the ammonites *Placenticeras planum* Hyatt, *Baculites* sp. (smooth), and *B. haresi* Reeside, the bivalves *Inoceramus (Endocostea) balticus* and *Phelopteria* sp, and very rarely the encrusting worm, *Serpula* sp. An upper age constraint is difficult to put on the Cortez Member in its type area because the overlying Point Lookout Sandstone contains few fossils. However, *B. haresi, P. planum?*, and *I. (E.) balticus* have been identified within the overlying Point Lookout Sandstone. These fossils may indicate a continuation of the *S. hippocrepis* Zone into the Point Lookout Sandstone in this area. However, a cautionary note is needed because it is possible that the smooth baculite identified as *B. haresi* could represent the smooth species of *Baculites* from the next higher zone (Reeside, 1927; Gill and Cobban, 1966).

The sparse fossils found within the Cortez Member indicate the strata span the upper Santonian *Clioscaphites choteauensis* Zone through the lowermost Campanian *Scaphites hippocrepis* Zone.

DISCUSSION AND REGIONAL CORRELATIONS

Colorado Front Range stratigraphic nomenclature works well at the Mesa Verde section of the Mancos Shale (Fig. 28). Along the southern part of the Front Range and eastward into Kansas, the Graneros Shale comprises transgressive marine muds that overlie the marginal marine sands of the Dakota Sandstone (Hattin, 1965; Kauffman, 1985). In the San Juan Basin, the Graneros Member is defined as that part of the Mancos Shale that lies above the highest member of the Dakota Sandstone and below the Bridge Creek Limestone Member (or Greenhorn Limestone Member of authors) (Molenaar, 1977). Stratigraphically, the Graneros Member becomes less sandy and silty, and more calcareous and fossiliferous upward in response to increasing distance from shore and improving marine conditions as the unit was being deposited during late Cenomanian time. At

Mesa Verde, the Graneros Member is time-equivalent to the upper part of the Hartland Shale and basal part of the Bridge Creek Limestone Members of the Greenhorn Formation at Rock Canyon, Colorado (Elder, 1985; Elder and Kirkland, 1985; Sageman, 1985). A prominent bentonite bed (unit MV44) near the top of the member correlates with the uppermost Cenomanian marker beds HL-3 of Hattin (1975a), PBC-11 of Elder and Kirkland (1985), bentonite B of Elder (1987, 1988, 1989), BM13 of Kirkland (1991, 1996), and TT2 of Leithold (1993, 1994). The Bridge Creek Limestone Member of the Mancos Shale represents peak transgression of the Western Interior Sea during early Turonian time (T-1 of Molenaar, 1983). The basal limestone bed of the Mesa Verde reference section (unit MV48) is correlated with marker-bed PBC-16 (Elder and Kirkland, 1985) from the lower part of the Bridge Creek Limestone Member at Rock Canyon, west of Pueblo, Colorado. A 19-cm-thick bentonite bed (unit MV49) that overlies the basal limestone bed, is correlated with HL-4 (Hattin, 1975a, 1985) in the uppermost part of Hartland Shale Member in central Kansas, PBC-17 (Elder and Kirkland, 1985) from Rock Canyon, bentonite C (Elder, 1987, 1988, 1989) from the Colorado Plateau and Front Range, BM15 (Kirkland, 1991) from the lower shale member of the Mancos Shale in the Black Mesa Basin of northeastern Arizona, and TT3 (Leithold, 1993, 1994) from the Tropic Shale and Tununk Member of the Mancos Shale of southern Utah.

Not all thirteen limestone beds of the Jetmore Member of the Greenhorn Formation of central Kansas (Hattin, 1975a, 1985) (= middle part of Bridge Creek Limestone Member at Rock Canyon; Elder and Kirkland, 1985) are present in the Mesa Verde section. The upper Graneros and lower Bridge Creek Members accumulated at an average sedimentation rate of 4.5–8 m/Ma reflecting condensation of the uppermost Cenomanian part of the section and a diastem in the lower Turonian (Fig. 29). Individual marker beds of the Pfeifer Member of central Kansas (Hattin, 1975A, 1985) or upper part of the Bridge Creek Limestone Member of Rock Canyon (Elder and Kirkland, 1985) cannot be accurately identified in the Mesa Verde section. However, the distribution and thickness of marlstone and bentonite beds closely mimics the stratigraphy at Rock Canyon (Elder and Kirkland, 1985) suggesting that the upper part of the Bridge Creek Member at Mesa Verde (29–38 m above base of section) is complete relative to the section at Rock Canyon. The Bridge Creek Member at Mesa Verde is equivalent to part of the Rio Salado Tongue of the Mancos Shale in west-central New Mexico (Molenaar, 1983; Hook et al., 1983; Fig. 28). The Bridge Creek is an excellent marker on electric logs from wells in the San Juan Basin (Molenaar, 1977; Molenaar and Baird, 1989).

The Fairport Member of the Mancos Shale contains abundant thin bentonite beds and limonite seams that furnish stark lithologic contrast with the darker, noncalcareous shales of the overlying Blue Hill Member. Together, the Fairport and Blue Hill Members record a stepped regression of the Western Interior Sea during middle Turonian time (R-1 of Molenaar, 1983). An interval of condensation and/or surface of erosion may separate these two units (Fig. 29). The Fairport Member at Mesa Verde is equivalent to the lower part of the lower shale unit of the Mancos in the eastern and northeastern San Juan Basin (Fassett, 1974; Landis et al., 1974), and the Fairport Member of the Carlile Shale along the Colorado Front Range (e.g., Kauffman, Pratt et al., 1985). The Fairport is partly equivalent to the middle shale and Hopi Sandy Member of the Mancos in the Black Mesa Basin (Kirkland, 1990, 1991, 1996) and to the lower part of the Tres Hermanos Formation of west-central New Mexico (Molenaar, 1983; Cobban and Hook, 1984; Hook et al., 1983).

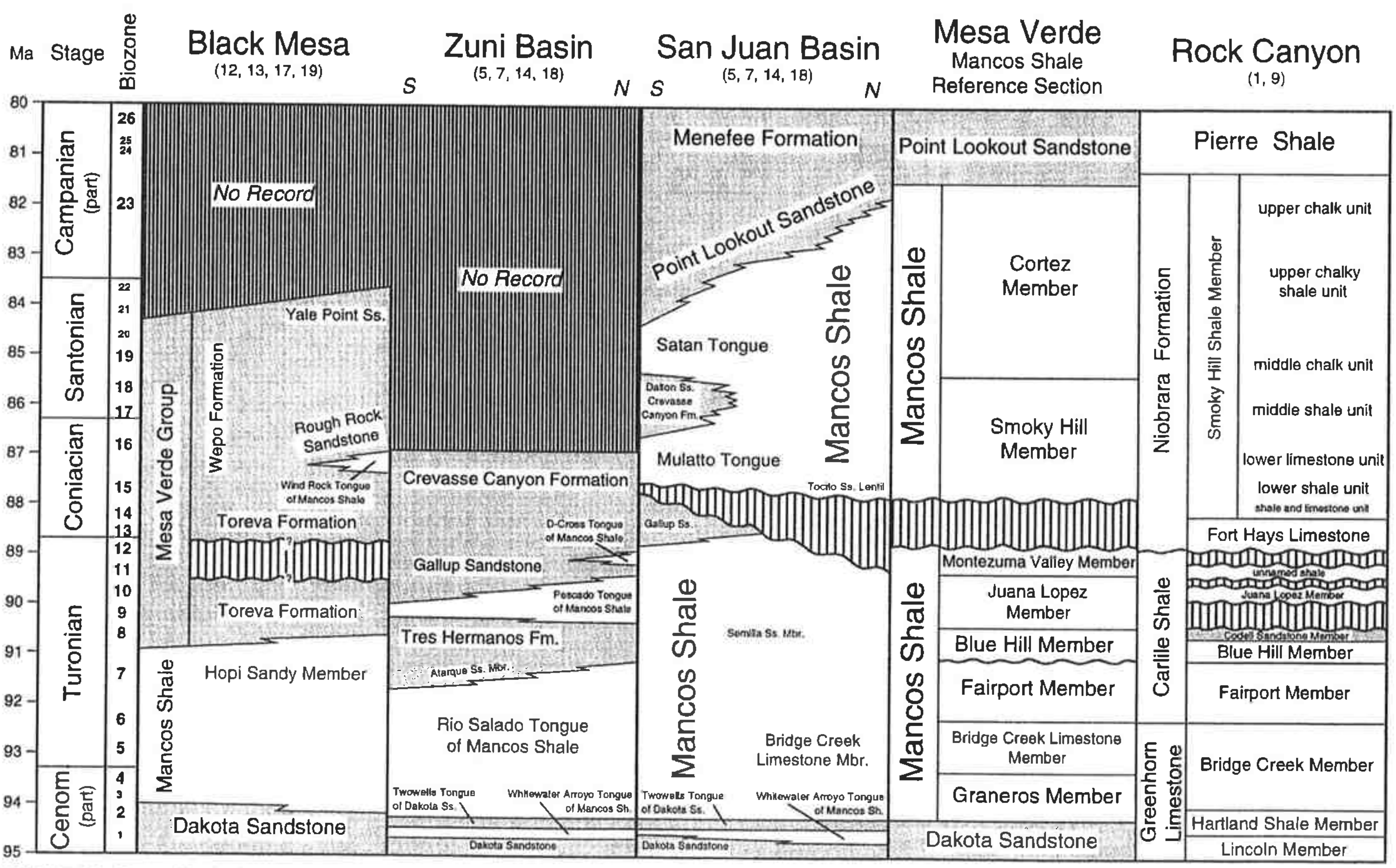

FIGURE 28. Generalized time-stratigraphic cross-section illustrating relationships between the Mancos Shale section at Mesa Verde (northern part of San Juan Basin) and sections to the southwest and northeast. For localities refer to Figure 1.1 = Scott and Cobban, 1964; 2 = Fassett, 1974; 3 = King, 1974; 4 = Landis et al., 1974; 5 = Molenaar, 1974, 1977, 1983; 6 = Peterson and Kirk, 1977; 7 = Hook et al., 1983; 8 = Cobban and Hook, 1984; 9 = Kauffman, Pratt, et al., 1985; 10 = Merewether and Cobban, 1986; 11 = Scott et al., 1986 12 = Eaton et al., 1987; 13 = Franczyk, 1988; 14 = Cobban and Hook, 1989; 15 = Eaton, 1990; 16 = Eaton, 1991; 17 = Kirkland, 1991, 1996; 18 = Dyman et al., 1993; 19 = Elder and Kirkland, 1993.

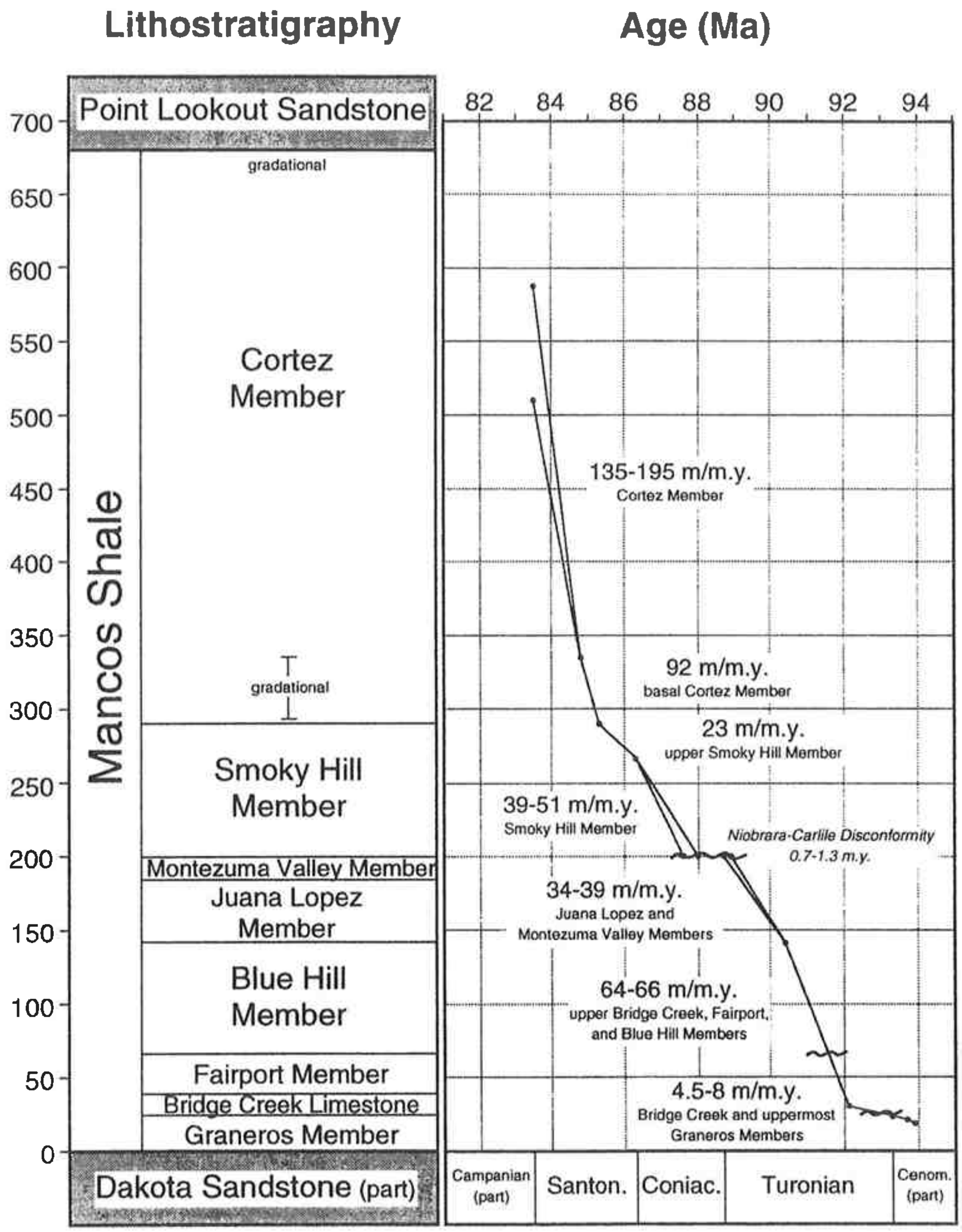

FIGURE 29. Estimates of sedimentation rate through the principal reference section of the Mancos Shale at Mesa Verde. Several intervals show a range of values due to uncertainties in the placement of biozone boundaries (see Figs. 7, 8, 10, 15, 19).

The Blue Hill Member of the Mancos Shale at Mesa Verde is a distinctive, widespread dark-gray to olive-black, noncalcareous shale facies (Hattin, 1962) that is equivalent to the upper part of the lower shale unit of the Mancos in the eastern and northeastern San Juan Basin (Fassett, 1974; Landis et al., 1974) and the Blue Hill and Codell Sandstone Members of the Carlile Shale along the Front Range (Kauffman, Pratt et al., 1985). The Blue Hill is equivalent to the upper shale member of the Mancos in the Black Mesa Basin (Kirkland, 1990, 1991) and the middle? and upper parts of the Tres Hermanos Formation of west-central New Mexico (Molenaar, 1983; Hook et al., 1983; Cobban and Hook, 1984). A 1-m-thick interval (136.8–137.8 m) of shale containing thin beds of sandstone that lies near the top of the Blue Hill Member may represent the distal equivalents of the Semilla Sandstone Member of the Mancos Shale in the eastern San Juan Basin (Dane et al., 1968), Codell Sandstone Member of the Carlile Shale along the Colorado Front Range (Kauffman, Pratt et al., 1985), lower sandstone member of the Toreva Formation in the Black Mesa Basin (Franczyk, 1988), and the lower part of the Ferron Sandstone Member of the Mancos Shale in east-central Utah (Peterson and Kirk, 1977; Merewether and Cobban, 1986) (Figs. 28, 30). The upper Bridge Creek, Fairport and Blue Hill interval accumulated at an average rate of 64–66 m/Ma (Fig. 29).

The Juana Lopez Member of the Mancos Shale represents a transgressive phase during late Turonian time (T-2 of Molenaar, 1983). The base of the Juana Lopez is recognized by the lowermost of numerous calcarenite beds that characterize the section directly above the Blue Hill (Dane et al., 1966; Hook and Cobban, 1980; MacLachlan, 1981). As observed in the type area by Dane et al. (1966) and Hook and Cobban (1980), the thickest beds of calcarenite occur near the top of the Juana Lopez Member. We observed a similar trend at Mesa Verde. Hook and Cobban (1980) also noted that the shale overlying the Juana Lopez at the type section is calcareous and silty at the base, and the silt content decreasing upwards. The same gradation was observed in the basal part of the overlying Montezuma Valley Member in the Mesa Verde section. The Juana Lopez is a lithologically distinctive and laterally persistent member of the Mancos Shale in

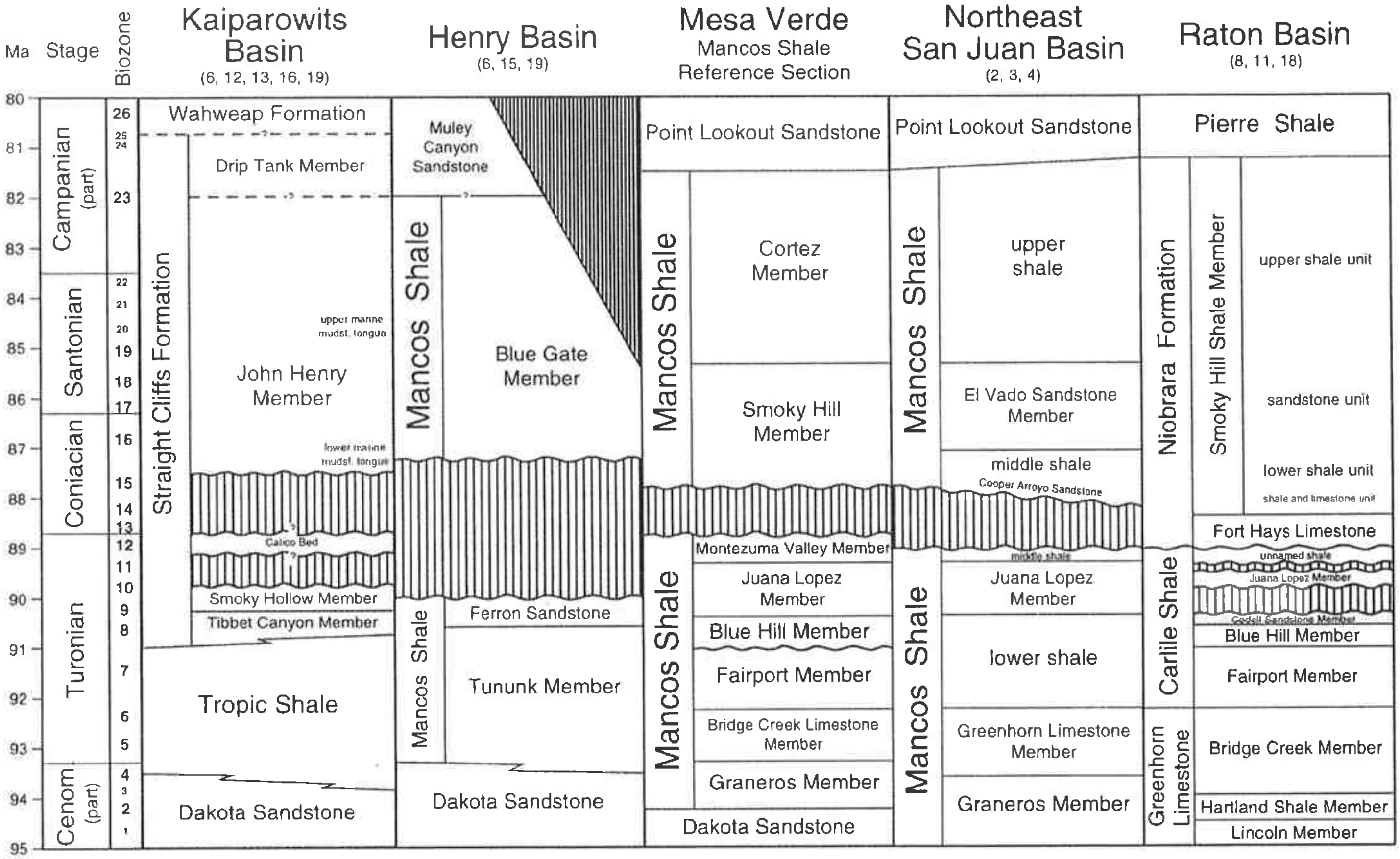

FIGURE 30. Generalized time-stratigraphic cross-section illustrating relationships between the Mancos Shale section at Mesa Verde (northern part of San Juan Basin) and sections to the west and east. For localities refer to Figure 1.

western and southwestern Colorado, eastern Utah, and northwestern New Mexico, and of the Carlile Shale in central and southeastern Colorado and northeastern New Mexico (Dane et al., 1966; Molenaar and Cobban, 1991; Dyman et al., 1993). The lower Juana Lopez may be partly correlative to the uppermost Tres Hermanos Formation at the reference section of the latter unit in the southern San Juan Basin, based on the presence of *Prionocyclus macombi* (Hook et al., 1983). Much of the Juana Lopez correlates to the transgressive Pescado Tongue and lower part of the D-Cross Tongue of the Mancos Shale of west-central New Mexico (southwestern San Juan Basin-Zuni Uplift-Zuni Basin; Hook et al., 1983; Molenaar, 1983; Molenaar in Baars et al., 1988; Cobban and Hook, 1989; Dyman et al., 1993).

The newly proposed Montezuma Valley Member is widely distributed across the northern San Juan Basin, where it has not been cut out by erosion (e.g., Dane, 1960; Molenaar, 1983). Named and unnamed correlative strata can be traced across much of the San Juan Basin and beyond, particularly to the east and northeast (Figs. 28, 30; Dyman et al., 1993). Kirkland (unpublished) has recognized the Montezuma Valley Member as far north as the Grand Valley of west-central Colorado where it is also separated from the Smoky Hill Member by a distinct disconformity. In central Colorado, strata correlative to the Montezuma Valley Member have been referred to as the Sage Breaks equivalent member of the Carlile Shale (Fisher et al., 1985). The Montezuma Valley correlates with a stepped regressive sequence in the southwestern part of the San Juan Basin (R-2 of Molenaar, 1983). The concretion-rich lower half of the unit probably correlates with the transgressive upper part of the D-Cross Tongue of the Mancos Shale along the southwestern edge of the San Juan Basin and Zuni uplift area of west-central New Mexico, whereas the upper part of the Montezuma Valley Member correlates with the uppermost part of the D-Cross Tongue and the regressive Gallup Sandstone (Molenaar, 1974, 1977, 1983; Hook et al., 1983; Cobban and Hook, 1984). In the eastern part of the San Juan Basin, the Montezuma Valley Member is equivalent to the lower part of the middle shale unit of the Mancos, beneath the widespread "Carlile-Niobrara" disconformity (Fassett, 1974; Landis et al., 1974). The Montezuma Valley and underlying Juana Lopez Members accumulated at an average rate of 34–39 m/Ma (Fig. 29).

Landis et al. (1974) observed that the thickness of the lower part of the middle shale unit between the Juana Lopez Member and a thin, medium- to coarse-grained glauconitic sandstone, the Cooper Arroyo Sandstone Member of the Mancos Shale, is probably 24.3–30.4 m. We suggest that this interval is equivalent to the Montezuma Valley Member at Mesa Verde (16.2 m). King (1974) proposed that the contact between the lower part of the middle shale unit and the Cooper Arroyo Sandstone Member in the eastern part of the San Juan Basin represents the "Carlile-Niobrara" disconformity. The Montezuma Valley Member also correlates with an unnamed calcareous shale member of the Carlile Shale in the Raton Basin (Cobban and Hook, 1984; Scott et al., 1986) and with the condensed Sage Breaks Shale equivalent at Rock Canyon anticline south of the Colorado Front Range (Fisher et al., 1985; Kauffman, Pratt et al., 1985).

The Montezuma Valley Member is overlain by the Smoky Hill Member. The contact between these two units is a sharp shale-on-shale disconformity at Mesa Verde. Disseminated glauconite grains and medium quartz sand occur in the basal meter of the Smoky Hill, although no discrete sandstone bodies were observed. Molenaar (1974) noted that in areas of the San Juan Basin where the basal Niobrara transgressive sandstones are absent, sand and glauconite typically occur in the basal few feet of the upper Mancos Shale. These disseminated grains may be the muddy equivalent of the transgressive Tocito Sandstone Lentil in the western and southwestern parts of the San Juan Basin, and the Cooper Arroyo Member of the Mancos Shale in the northeastern part of the San Juan Basin. This surface represents the "Carlile-Niobrara" disconformity that is widely recognized in the northern part of the San Juan Basin (Dane, 1960; Lamb, 1968;

Thompson, 1972; Molenaar, 1973, 1974, 1977, 1983; King, 1974; Dyman et al., 1993).

At Mesa Verde, the Smoky Hill Member is composed of hard calcareous shales and marlstones. Lithologically, it is very similar to the Smoky Hill Member of the Niobrara Chalk of western Kansas (Hattin, 1982) and the Smoky Hill Shale Member of the Niobrara Formation along the Colorado Front Range (Scott and Cobban, 1964; Kauffman, Pratt et al., 1985). Lithologies equivalent to the Fort Hays Limestone Member of the Niobrara are absent at Mesa Verde, although the upper part of the Montezuma Valley Member is probably temporally equivalent to the lower part of the Fort Hays Limestone Member in the Raton Basin (Scott et al., 1986; Dyman et al., 1993). The Smoky Hill Member at Mesa Verde correlates with the upper part of the lower shale, lower limestone, and middle shale units of the Smoky Hill along the Front Range (Scott and Cobban, 1964). The "Carlile-Niobrara" disconformity probably spans the uppermost Turonian (*Prionocyclus quadratus* Zone) to upper middle Coniacian (upper *Scaphites ventricosus* Zone) in the Mesa Verde reference section. The duration of the hiatus is estimated to be 0.7–1.3 Ma (Fig. 29).

The lower part of the Smoky Hill Member at Mesa Verde correlates with the transgressive Mulatto Tongue of the Mancos Shale along the southwestern side of the San Juan Basin and Zuni Basin of west-central New Mexico (T-3 of Molenaar, 1983). The average rate of sedimentation for this part of the Smoky Hill was 39–51 m/Ma, depending on the age of the strata above the "Carlile-Niobrara" disconformity. The prominent bench-forming marlstone that caps the Smoky Hill Member at Mesa Verde correlates with the regressive Dalton Sandstone Member of the Crevasse Canyon Formation (R-3 of Molenaar, 1983) (Fig. 28). The latter interval accumulated at a rate of approximately 23 m/Ma (Fig. 29).

The Smoky Hill Member of the Mancos at Mesa Verde also correlates with the upper part of the middle shale unit of the Mancos Shale (including the Cooper Arroyo Sandstone Member), El Vado Sandstone Member, and basal part of the upper shale unit of the Mancos in the eastern San Juan Basin (Fassett, 1974; King, 1974; Landis et al., 1974). The sandy unit of the Smoky Hill Shale Member of the Niobrara Formation in the Raton Basin (Scott et al., 1986) correlates with the upper part of the Smoky Hill Member at Mesa Verde. The El Vado Sandstone in the eastern San Juan Basin occurs in the same stratigraphic position as the sandy unit in the Raton Basin (Fig. 30). Both the El Vado Sandstone and sandy unit correlate with regressive deposits (R-3 of Molenaar, 1983). The presence of thick sandy units in the eastern San Juan Basin and Raton Basin, and the paucity of sand in equivalent strata at Mesa Verde on the northern rim of the San Juan Basin and along the Colorado Front Range suggest the existence of a paleohigh in north-central New Mexico during Late Cretaceous time (e.g., Fassett, 1976). The middle Turonian Semilla Sandstone and mid-Campanian La Ventana tongue of the Cliff House Sandstone, both of which are developed in the eastern part of the San Juan Basin, also furnish evidence for a sediment source (i.e., paleohigh) to the east or southeast of Mesa Verde (Dane et al., 1968; Fuchs-Parker, 1977).

The newly named Cortez Member of the Mancos Shale is a thick, widespread unit (Figs. 28, 30) and much of it represents a time of overall regression in the Western Interior Basin (R-4 of Molenaar, 1983). The six informal units of the Cortez Member may prove to be related to changes in rates of regression and to reversals in overall regression of the sea, with the lower three subunits representing one coarsening upwards sequence and the upper three subunits representing a second. The sandy interval in the middle of the Cortez Member may record the same regressive interval responsible for the Emery Sandstone Member of the Mancos Shale, which splits the Blue Gate Member into lower and upper units in eastern Utah (Dyman et al., 1993; Elder and Kirkland, 1993a, b; Cole et al., in press). The Cortez accumulated at a high rate of sedimentation, approximately 135–195 m/Ma, depending on the placement of the Santonian/Campanian boundary (Fig. 29).

The Cortez Member correlates with the middle chalk, upper chalky shale, and upper chalk units of the Smoky Hill Shale Member, Niobrara Formation, along the Colorado Front Range (Scott and Cobban, 1964; Kauffman, Pratt et al., 1985). The lowest informal unit of the Cortez Member is transitional with the underlying Smoky Hill Member and it correlates with the middle chalk unit of the Smoky Hill Shale Member of the Niobrara Formation, and with the transgressive Satan Tongue of the Mancos Shale (T-4 of Molenaar, 1983; Dyman et al., 1993).

The Cortez Member at Mesa Verde (393 m thick) is equivalent to much of the 364.8-m-thick upper shale unit of the Mancos Shale in the eastern part of San Juan Basin (Fassett, 1974; Landis et al., 1974). Landis et al. (1974) noted the occurrence of a discontinuous silty oyster-coquina, several inches thick that lies at or near the base of the upper shale unit. We also recorded a very distinctive oyster-inoceramid biostrome (unit MV381), 21 cm thick, near the base of the Cortez Member at Mesa Verde. The biostrome could not be traced for as much as a kilometer, but the presence of several thin oyster-rich horizons can be shown to represent the equivalent stratigraphic level based on bentonite correlation. These oyster-rich beds and bedding planes may be equivalent to the oyster-coquina described by Landis et al. (1974), and they may represent a time of transgression and sediment bypass in the basin.

Most of the upper shale unit of the Smoky Hill Shale Member, Niobrara Formation, in the Raton Basin is equivalent to the Cortez Member. One of the characteristics of the Cortez Member at Mesa Verde is the occurrence of eleven well-indurated, orange-weathering dolomitic mudstone beds, some of which are fossiliferous. The upper shale unit of the Raton Basin contains as many as ten hard, dense, orange-weathering limestone beds (Scott et al., 1986). The dolomitic mudstones of the Cortez Member may be equivalent to limestone beds in the upper shale unit of the Raton Basin. Similar dolomitic beds and concretions also occur in the Mancos Shale of eastern Utah and western Colorado. These hard carbonate beds tend to cap coarsening upwards packages in the Prairie Canyon Member of the Mancos and have been interpreted as transgressive pulses at the end of progradational intervals (Cole, et al., in press).

SUMMARY

A principal reference section for the Mancos Shale is located at the northern edge of Mesa Verde National Park. This section is an important lithostratigraphic and biostratigraphic control point for correlation of strata between the western margin of the Cretaceous Western Interior Basin, and the central and eastern parts of the basin. We have demonstrated that it is possible to correlate the Colorado Front Range stratigraphy westward into the thick sequences of marine shale and mudrock, and to recognize Fairport, Blue Hill and Smoky Hill lithofacies within the Mancos Shale. We have formally named and described two new members of the Mancos Shale, the Montezuma Valley Member and the Cortez Member, both of which can be recognized beyond the northern San Juan Basin. The Mesa Verde section is fossiliferous through much of its thickness. A molluscan biostratigraphy has been established and several stratigraphic breaks are noted. The uppermost Cenomanian-lower Turonian part of the sequence is condensed and a diastem is detected in lower Turonian strata of the Bridge Creek Limestone Member. Another diastem is suspected within the middle Turonian, between the Fairport and Blue Hill Members. All of the lower Coniacian and part of the middle Coniacian section is missing at the contact between the Montezuma Valley and Smoky Hill Members ("Carlile-Niobrara" disconformity). The Santonian/Campanian boundary cannot be accurately placed at this writing owing to the paucity of fossils in the upper part of the Cortez Member. The generation of an outcrop gamma-ray profile has permitted us to correlate the principal reference section of the Mancos Shale with the subsurface section of the northern part of the San Juan Basin, including the recognition of prominent bentonite beds.

ACKNOWLEDGMENTS

This project would not have been possible without the hard work and good humor of David Finkelstein, "Sooz" Kirkland, Richard Cashman, Christie Farnham, Constance Hayden-Scott, Huaibao Liu, George "Skip" Price, John Roy, Peter Vaz, Oona West and Richard Yuretich. We express our sincere appreciation to the helpful people of Mesa Verde National Park and ARA Leizure Services, Inc., for making our stay at Mesa Verde (1988, 1989) enjoyable and productive. In particular, we thank Mary Griffitts, Jack Smith and Linda Towle of the Mesa Verde Research Center, and park rangers Jim Lynch and Dave Dyson. A very special thanks is extended to Mr. Stanley Hindmarsh for access to parts of the section. C.M. ('K')

Molenaar (USGS-Denver) provided invaluable assistance in the form of numerous discussions about Colorado Plateau stratigraphy and correlation, and in providing access to subsurface geophysical logs. Elana Leithold assisted with supplementary field checking through the Bridge Creek, Fairport and Blue Hill Members. Neil Tibert assisted with road log preparation and final computer drafting of the graphic section. We would also like to acknowledge helpful discussions with William Cobban (USGS-Denver), Rex Cole (Mesa State College), Donald Hattin (Indiana Univ.), Erle Kauffman (Univ. of Colorado, now Indiana Univ.), Marge MacLachlan (USGS-Denver), Robyn Wright Dunbar (Rice Univ.) and Rob Zech (USGS-Denver). The paper has greatly benefited from the reviews of Don Hattin, 'K' Molenaar, Frank Ethridge and John Hobson. We thank Marie Litterer for drafting assistance and Carl Carlson for computer drafting of the graphic section. Acknowledgment is made to the donors of The Petroleum Research Fund, administered by the American Chemical Society, for field and laboratory research support to R.M.L. Additional support for field work was provided by the University of Massachusetts (Faculty Research Grant to R.M.L.), Amoco Production Company (Denver), NSF Grant No. EAR-8904608 to R.M.L. and R. Yuretich, and NSF Grant No. EAR-9219113 to R.M.L. and E. Leithold. This paper is dedicated to 'K' Molenaar; he was an inspiration and teacher to a younger generation of Cretaceous stratigraphers.

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CAPTIONS FOR FIGURES 31–46

(Figure number in upper right corner of each figure)

FIGURE 31. Mollusks from the Graneros Member (**A–M**) and Bridge Creek Limestone Member (**N–U**) of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A,** *Metoicoceras geslinianum* (d'Orbigny), MEVE 74299, 22 m, unit MV39. **B-D,** *Rhynchostreon acroumbonata* (Kauffman); **B,** MEVE 74300, 22 m, unit MV39, x2; **C, D,** MEVE 74301, 21 m, unit MV39, left and dorsal views. **E,** *Phelopteria* sp., MEVE 74302, 22 m, unit MV39, x2. **F,** *Inoceramus pictus* Sowerby, MEVE 74303, 22 m, unit MV39, left valve. **G,** *Lucina subundata* Hall and Meek, MEVE 74304, 22 m, unit MV39, x2. **H,** *Corbula kanabensis* (Stanton), MEVE 74305, 22 m, unit MV39, x2. **I,** *Psilomya concentrica* Stanton, MEVE 74306, 23 m, unit MV41. **J, K,** *Allocrioceras annulatum* (Shumard), MEVE 74307, 22 m, unit MV39, ventral and side views. **L,** *Sciponoceras gracile* (Shumard), MEVE 74308, 22 m, unit MV39. **M,** *Turritella* n. sp., MEVE 65849, 19 m, unit MV33, x2. **N,** *Plicatula* n. sp., MEVE 65844, 25.3 m, unit MV55. x2. **O, P,** *Mytiloides hattini* Elder, 24.9 m, unit MV51; **O,** MEVE 74309; **P,** MEVE 74310. **Q,** *Watinoceras* cf. *praecursor* Wright and Kennedy, MEVE 74311, 24.9 m, unit MV51. **R-T,** *Pseudoperna bentonensis* (Logan); **R,** MEVE 74312, 27.7 m, unit MV71; **S,** MEVE 74313, 37 m, unit MV103; **T,** MEVE 74314, 24.9 m, unit MV51. **U,** Mammitid ammonite, MEVE 74315, 25.25 m, unit MV55.

FIGURE 32. Inoceramids and ammonite from the Bridge Creek Limestone Member of the Mancos Shale; except **Q**, which is from the Fairport Member. Specimens are natural size unless otherwise indicated. **A–C,** *Mytiloides columbianus* (Heinz), 27.4 m, unit MV67; **A,** MEVE 74316; **B,** MEVE 74317; **C,** MEVE 74318. **D–F,** *Mytiloides mytiloides mytiloides* (Mantell), 27.4 m, unit MV67; **D,** MEVE 74319; **E,** MEVE 74320; **F,** MEVE 74321. **G,** *Mytiloides mytiloides arcuata* (Seitz), MEVE 74322, 27.75 m, unit MV71. **H, I,** *Mytiloides labiatus* (Schlotheim), 27.75 m, unit MV71; **H,** MEVE 74323; **I,** MEVE 74324. **J, K,** *Mytiloides subhercynicus* (Seitz); **J,** MEVE 74325, 30.5 m, unit MV85; **K,** MEVE 74326, 27.75 m, unit MV71. **L,** *Kamerunoceras puebloense* (Cobban & Scott), MEVE 74327, 27.4 m, unit MV67b. **M,** *Mytiloides* cf. *hartti* (Hessel), MEVE 74328, 32.6 m, unit MV89, x2. **N–P,** *Pycnodonte* n. sp.; **N, O,** MEVE 74329, 37 m, unit MV103, left valve, top and posterior views, x2; **P,** MEVE 74330, 37.8 m, unit MV105, right valve. **Q–S,** *Inoceramus cuvieri* Sowerby; **Q,** MEVE 74331, Fairport Member, 40.3 m, unit MV112; **R, S,** MEVE 74332, 37 m, unit MV103, latex pull of external mold and composite mold.

FIGURE 33. Ammonites and bivalves from the Fairport (**A–G**), Blue Hill (**H–N**) and lower part of the Juana Lopez Members (**O–BB**) of the Mancos Shale. **A–F,** *Collignoniceras woollgari* (Mantell); **A,** MEVE 74333, 40.7 m, unit MV114; **B,** MEVE 74334, 57.4 m, unit MV147; **C,** MEVE 65846, 40.3 m, unit MV112; **D,** MEVE 74335, 59.6 m, unit MV153; **E,** MEVE 74336, 57.4 m, unit MV147; **F,** MEVE 74337, 57.4 m, unit MV147. **G,** *Mytiloides latus* (Sowerby), MEVE 74338, 62.6 m, unit MV157. **H,** *Prionocyclus hyatti* (Stanton), MEVE 74339, 121.6 m, unit MV197, x2. **I,** *Cyclorisma orbiculata* (Hall and Meek), MEVE 74340, 121.6 m, unit MV197. **J,** *Cardium* sp., MEVE 74341, 121.6 m, unit MV197, x2. **K–M,** *Breviarca* sp., 121.6 m, unit MV197, x2; **K,** MEVE 74342; **L,** MEVE 74343; **M,** MEVE 74344. **N,** *Inoceramus costellatus* Woods, MEVE 74345, 121.6 m, unit MV197. **O–Q, BB,** *Prionocyclus macombi* Meek; **O,** MEVE 74346, 155.2 m, unit MV240; **P,** MEVE 74347, 155.2 m, unit MV240; **Q,** MEVE 74348, 155 m, unit MV239; **BB,** MEVE 74356, unit MV266. **R–U,** *Lopha lugubris* (Conrad), **R,** MEVE 74349, 153.2 m, unit MV234; **S,** MEVE 74350, 153.2 m, unit MV234; **T,** MEVE 74351, unit MV266; **U,** MEVE 74352, unit MV266. **V, W,** *Coilopoceras* cf. *inflatum* Cobban and Hook, MEVE 60677, 164 m, unit MV266, side and ventral views. **X–AA,** *Inoceramus dimidius* White; **X, Y,** MEVE 74353, 155.2 m, unit MV240, right and posterior views; **Z,** MEVE 74354, 155 m, unit MV239; **AA,** MEVE 74355, unit MV283.

FIGURE 34. Ammonite and inoceramid bivalves characteristic of the Juana Lopez Member of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A,** *Prionocyclus macombi* Meek, MEVE 74357, 164 m, unit MV266, x0.67. **B–J,** *Inoceramus* n. sp.; ridge between Areas 10 & 11; **B, C,** MEVE 65843, dorsal and left views; **D,** MEVE 74358; **E,** MEVE 74359; **F, G,** MEVE 74360, anterior and right views; **H–J,** MEVE 74361, anterior, left, and dorsal views. **K–N,** *Inoceramus dimidius* White, ridge between Areas 10 & 11; **K, L,** MEVE 74362, left and anterior views; **M, N,** MEVE 74363, left and posterior views. **O–R,** *Inoceramus perplexus* Whitfield, 181.6 m, unit MV293; **O,** MEVE 74364; **P,** MEVE 74365; **Q, R,** MEVE 74366, left and dorsal views.

FIGURE 35. Ammonites characteristic of the upper part of the Juana Lopez Member of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A–E,** *Scaphites warreni* Meek & Hayden, Area 11; **A, B,** MEVE 74367, macroconch, side and front views; **C, D,** MEVE 74368, microconch, side and front views; **E,** MEVE 74369, microconch and macroconch on slab. **F–H,** *Baculites undulatus* d'Orbigny, 171.2 m, unit MV283; **F,** MEVE 74370; **G,** MEVE 74371; **H,** MEVE 74372. **I–K,** *Subprionocyclus normalis* (Anderson), 181.6 m, unit MV293; **I, J,** MEVE 74373, side and front views; **K,** MEVE 74374. **L–N,** *Reesidites minimus* (Hayasaka & Fukada), 181.6 m, unit MV293, **L, M,** MEVE 74375, side and ventral view; **N,** MEVE 74376. **O–S,** *Prionocyclus wyomingensis* Meek; **O, P,** MEVE 74377, Area 12, side and apertural views; **Q, R,** MEVE 74378, 171.2 m, unit MV283, side and ventral view; **S,** MEVE 74379, Area 13.

FIGURE 36. Ammonites and inoceramid bivalves of the upper part of the Juana Lopez (**E–G, M–P**) and Montezuma Valley Members (**A–D, H–L, Q–U**) of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A–D,** *Scaphites whitfieldi* Cobban; **A, B,** MEVE 74380, 181.6 m, unit MV293, side and apertural view; **C, D,** MEVE 74381, Area 14, side and apertural view. **E–G,** *Inoceramus longealatus* Tröger, 181.6 m, unit MV293; **E,** MEVE 74382; **F,** MEVE 74383; **G,** MEVE 74384. **H–L,** *Mytiloides striatoconcentricus* (Gümbel); **H, I,** MEVE 74385, Area 14, right and posterior views; **J.** MEVE 74386, Area 14; **K.** MEVE 74387, Area 14; **L,** MEVE 74388, 185 m, unit MV307. **M–P,** *Baculites yokoyamai* Tokunaga & Shimizu; **M, P,** MEVE 74389, 181.6 m, unit MV293, end and side; **N,** MEVE 74390, Area 13, *P. wyomingensis* zone?, unwhitened; **O,** MEVE 74391, 181.6 m, unit MV293. **Q–U,** *Prionocyclus novimexicanus* (Marcou), 181.6 m, unit MV293; **Q, R,** MEVE 74392, side and apertural views; **S, T,** MEVE 74393, apertural and side views, x0.67; **U,** MEVE 74394.

FIGURE 37. Bivalves characteristic of the upper part of the Juana Lopez (**P**) and Montezuma Valley Members (**A–O, Q**) of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A, B,** *Mytiloides carpathicus* (Simionescu); **A,** MEVE 74395, 193 m, unit MV322; **B,** MEVE 74396, 181.6 m, unit MV293. **C–G,** *Inoceramus* aff. *ernsti* Heinz, 194 m, unit MV325; **C, D,** MEVE 74397, anterior and left views; **E,** MEVE 74398; **F,** MEVE 74399; **G,** MEVE 74400. **H,** *Veniella goniophora* Meek, MEVE 74401, 185 m, unit MV307, x2. **I–K,** Tellinid?, 185 m, unit MV307; **I,** MEVE 74402, x2; **J,** MEVE 74403, x2, **K,** MEVE 74404, x2. **L, M,** *Mytiloides* aff. *labiatoidiformis* (Tröger); **L,** MEVE 74405, 193 m, unit MV322; **M,** MEVE 74406, 194 m, unit MV325. **N–Q,** *Mytiloides incertus* (Jimbo); **N,** MEVE 74407, 191 m, unit MV319; **O,** MEVE 74408, 185 m, unit MV307; **P.** MEVE 74409, 159.9 m, unit MV249; **Q,** MEVE 74410, 196.5 m, unit MV329.

FIGURE 38. Ammonites and bivalves from the Montezuma Valley Member (**A**), the Smoky Hill Member (**B–E**) and the lower part of the Cortez Member (**G–I**) of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A.** *Prionocyclus quadratus* Cobban, MEVE 74411, 194 m, unit MV326, x0.67. **B–D,** *Inoceramus (Platyceramus) stantoni* Sokolow; **B,** MEVE 74412, 10 m above Area 18; **C,** MEVE 74413, 219.5 m, unit MV347; **D,** MEVE 74414, 10 m above Area 18. **E, F,** *Baculites codyensis* Reeside; **E,** MEVE 74415, 266 m, unit MV370; **F,** MEVE 74416, 222 m, unit MV352. **G–I,** *Pseudoperna congesta* (Conrad); **G,** MEVE 74417, 289 m, unit MV381; **H.** MEVE 74418, 289 m, unit MV381; **I,** MEVE 74419, 299 m, unit MV384.

FIGURE 39. Bivalves and ammonites characteristic of the lower to middle parts of the Smoky Hill Member of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A**, **E**, *Inoceramus (Volviceramus) grandis* Conrad; **A**, MEVE 74420, Area 18; **E**, MEVE 74423, 265 m, unit MV370, x0.5. **B**, *Phylcticrioceras trinodosum* (Geinitz), MEVE 74421, 221 m, unit MV351. **C**, *Inoceramus (Volviceramus) involutus* Sowerby, MEVE 74422, 219.5 m, unit MV347. **D**, *Modiolus* n. sp., MEVE 65848, 225 m, unit MV357. **F**, **G**, *Protexanites (Protexanites) bourgeoisianus* (d'Orbigny); **F**, MEVE 74424, 246 m, unit MV364, x2; **G**, MEVE 74425, 237 m, unit MV364. **H–J**, *Inoceramus (Magadiceramus) subquadratus subquadratus* Schlüter; **H**, MEVE 74426, 229 m, unit MV361; **I**, MEVE 65842, 252 m, unit MV365; **J**, MEVE 74427, 227 m, unit MV359. **K**, *Scaphites depressus* Reeside, MEVE 74428, 224 m, unit MV357.

FIGURE 40. Inoceramid bivalves from the Smoky Hill Member (**A–D**, **F**) and the lower part of the Cortez Member (**E**) of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A**, *Inoceramus (Magadiceramus) subquadratus subquadratus* Schlüter, MEVE 74429, 254 m, unit MV366. **B**, **C**, *Inoceramus (Magadiceramus) subquadratus crenelatus* Seitz, 233 m, unit MV366; **B**, MEVE 74430; **C**, MEVE 74431. **D**, **F**, *Inoceramus (Magadiceramus) subquadratus complicatus* Heine; **D**, MEVE 51259, Area 18; **F**, MEVE 74432, 264 m, unit MV370. **E**, *Inoceramus (Platyceramus) platinus* Logan, MEVE 74433, 335 m, unit MV418, x0.67.

FIGURE 41. Inoceramid bivalves and ammonites from the lower part of the Cortez Member of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A**, **B**, *Inoceramus (Platyceramus) platinus* Logan, 335 m, unit MV418; **A**, MEVE 74434, endocostate form; **B**, MEVE 74435. **C**, *Clioscaphites choteauensis* Cobban, MEVE 74436, 307 m, unit MV389, latex pull. **D**, *Baculites thomi* Reeside, MEVE 74437, 298.5 m, unit MV384. **E**, **F**, *Inoceramus (Cordiceramus) mülleri mülleri* Petrascheck, MEVE 74438, 307 m, unit MV389, dorsal and side views.

FIGURE 42. Inoceramid bivalves from the Cortez Member of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A**, *Inoceramus (Cordiceramus) mülleri mülleri* Petrascheck, MEVE 74439, 307 m, unit MV389, x0.67. **B**, **F**, *Inoceramus (Cordiceramus) mülleri germanicus* Heinz; **B**, MEVE 74440, 298.5 m, unit MV384; **F**, MEVE 74443, 307 m, unit MV389. **C–E**, *Inoceramus (Endocostea) balticus* Böhm; **C**, **D**, MEVE 74441, 624 m, unit MV648, side and dorsal views. **E**, MEVE 74442, 637 m, unit MV650.

FIGURE 43. Inoceramid bivalves and ammonite from the lower to middle part of the Cortez Member of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A**, **D**, **F**, *Inoceramus (Sphenoceramus) lundbreckensis* McLearn, 335 m, unit MV418; **A**, MEVE 74444; **D**, MEVE 74447; **F**, MEVE 74449. **B**, **E**, *Inoceramus (Platyceramus) cycloides* Wegner, 348 m, unit MV421; **B**, MEVE 74445; **E**, MEVE 74448. **C**, *Scaphites leei* Reeside, MEVE 74446, 358 m, unit MV428, x2.

FIGURE 44. Inoceramid bivalves, ammonites and crinoid from the lower to middle part of the Cortez Member of the Mancos Shale. Specimens are natural size unless otherwise indicated. **A**, **F**, *Inoceramus (Cordiceramus)* aff. *brancoiformis* Seitz, 307 m, unit MV389; **A**, MEVE 74450, x 0.67; **F**, MEVE 74455. **B–D**, *Desmoscaphites bassleri* Reeside, 335 m, unit MV418; **B**, MEVE 74451; **C**, MEVE 74452; **D**, MEVE 74453, latex pull. **E**, *Inoceramus (Endocostea) balticus* Böhm, MEVE 74454, 307 m, unit MV389. **G**, *Haresiceras* cf. *montanaense* (Reeside), MEVE 74456, 405 m, unit MV441, oblique view. **H**, *Uintacrinus* sp., MEVE 65845, 481 m, unit MV502.

FIGURE 45. Ammonites from the middle part of the Cortez Member of the Mancos Shale. Specimens are natural size. **A**, *Placenticeras* aff. *sancarlosense* Hyatt, MEVE 51936, 509 m, unit MV551, latex pull. **B**, *Baculites* sp. (smooth, rapid taper), MEVE 74457, 584 m, unit MV617.

FIGURE 46. Ammonites from the upper part of the Cortez Member of the Mancos Shale (*Scaphites hippocrepis* zone) (**A–L**) and the Point Lookout Sandstone (**L**, **M**). Specimens are natural size unless otherwise indicated. **A–C**, **M**, *Placenticeras planum* Hyatt, **A**, MEVE 74458, 624 m, unit MV648; **B**, **C**, MEVE 74459, 624 m, unit MV648, side and ventral views; **M**, MEVE 51835, sandstone float block, x0.5. **D**, **G–K**, *Baculites haresi* Reeside; **D**, **I**, MEVE 74460, 624 m, unit MV648; **G**, MEVE 74463, 610 m, unit MV636; **H**, MEVE 74464, 587 m, unit MV618, side and end view; **J**, **K**, MEVE 74465, 624 m, unit MV648, side and ventral view. **E**, **F**, *Scaphites hippocrepis* (Dekay); E, MEVE 74461, 588.5 m, unit MV619, ventral view, x2; **F**, MEVE 74462, 629 m, unit MV649. **L**, *Baculites* sp., MEVE 51839, sandstone float block.

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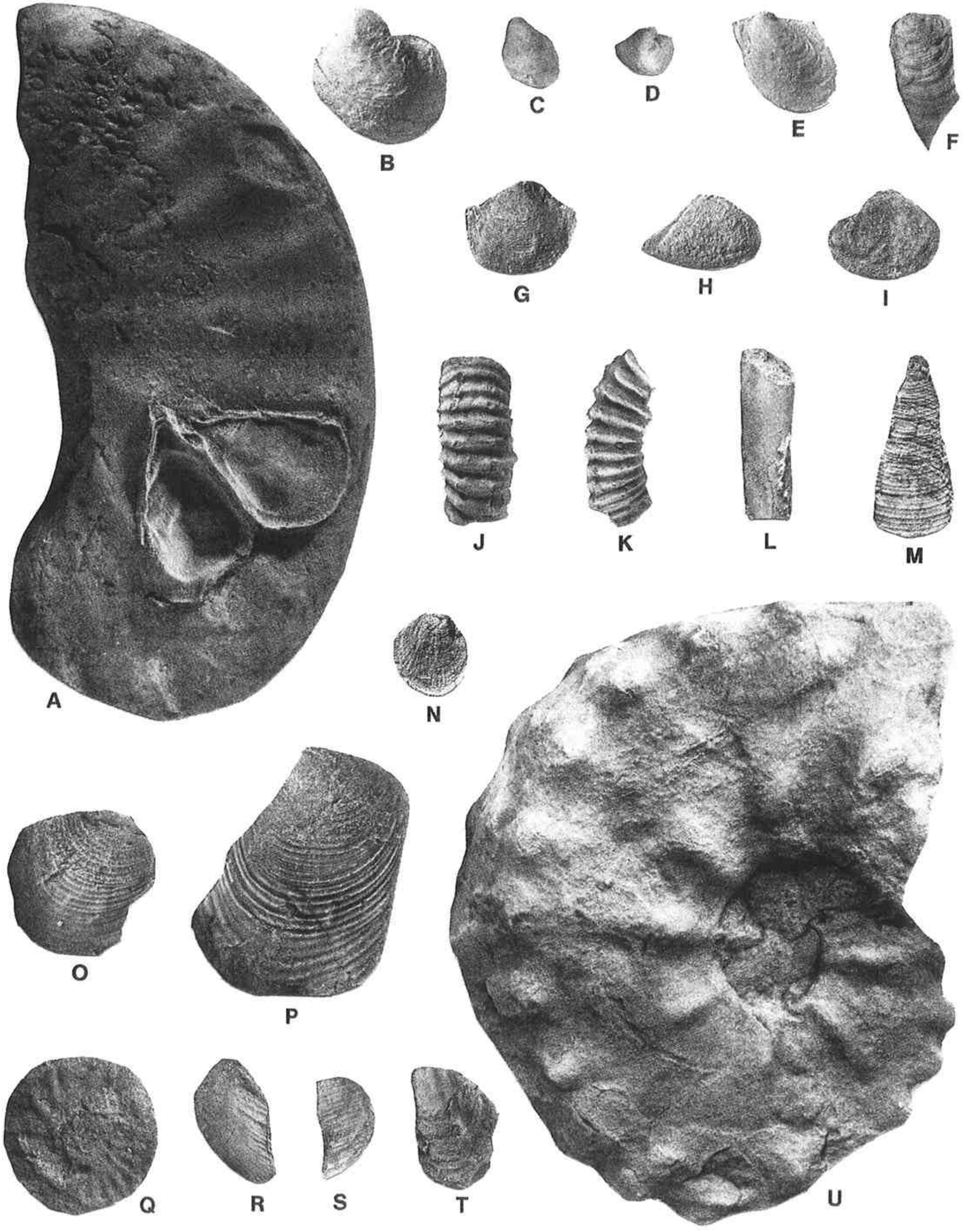

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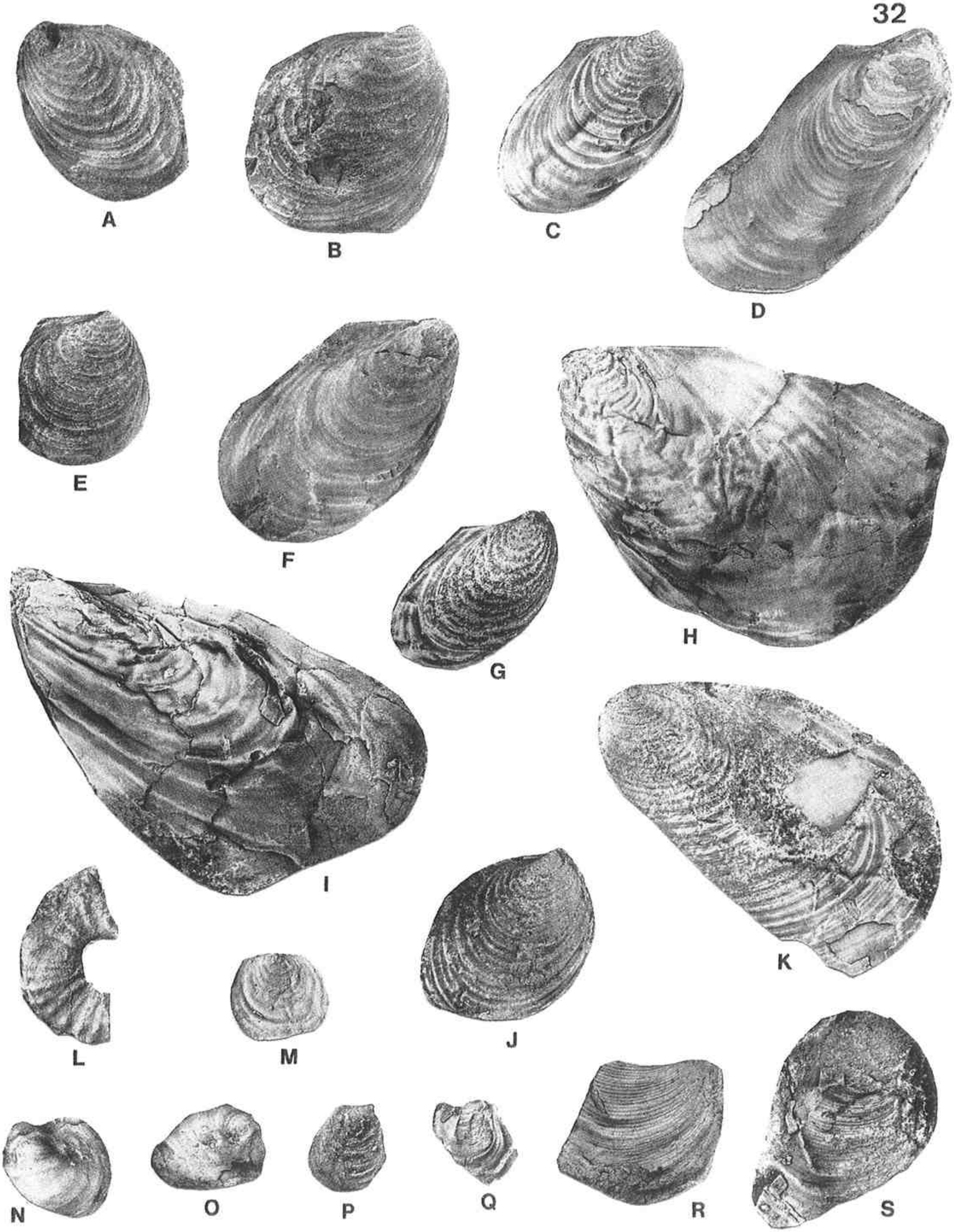

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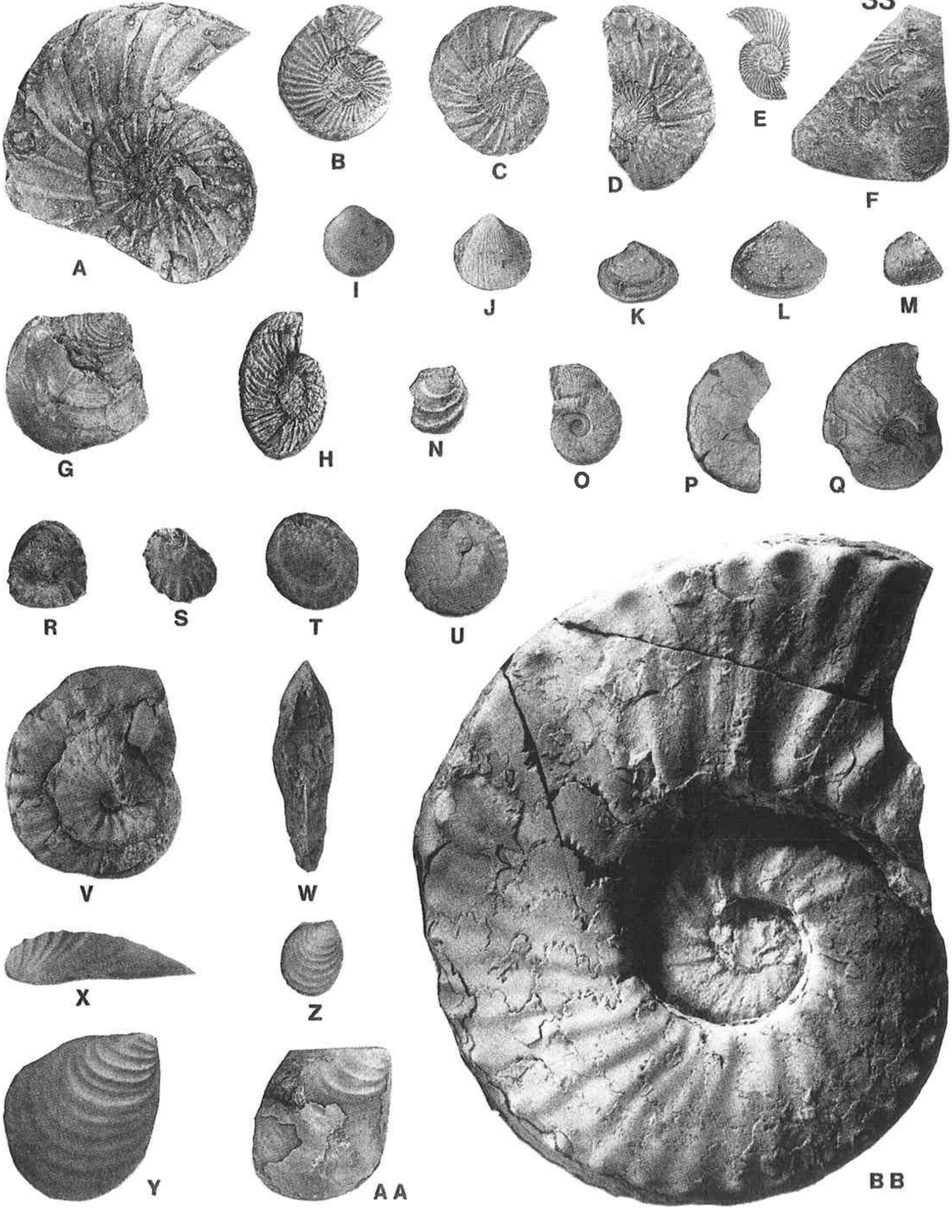

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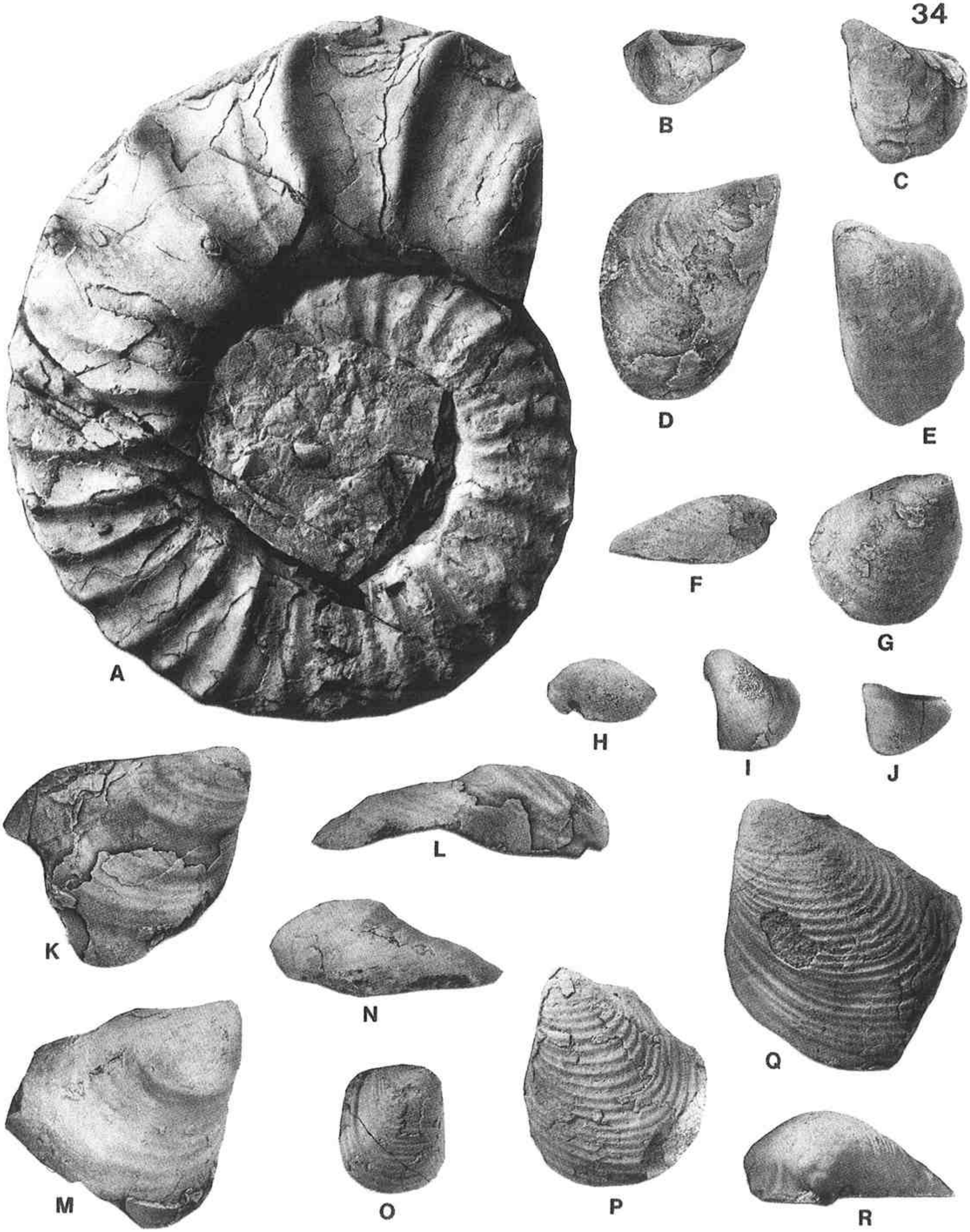

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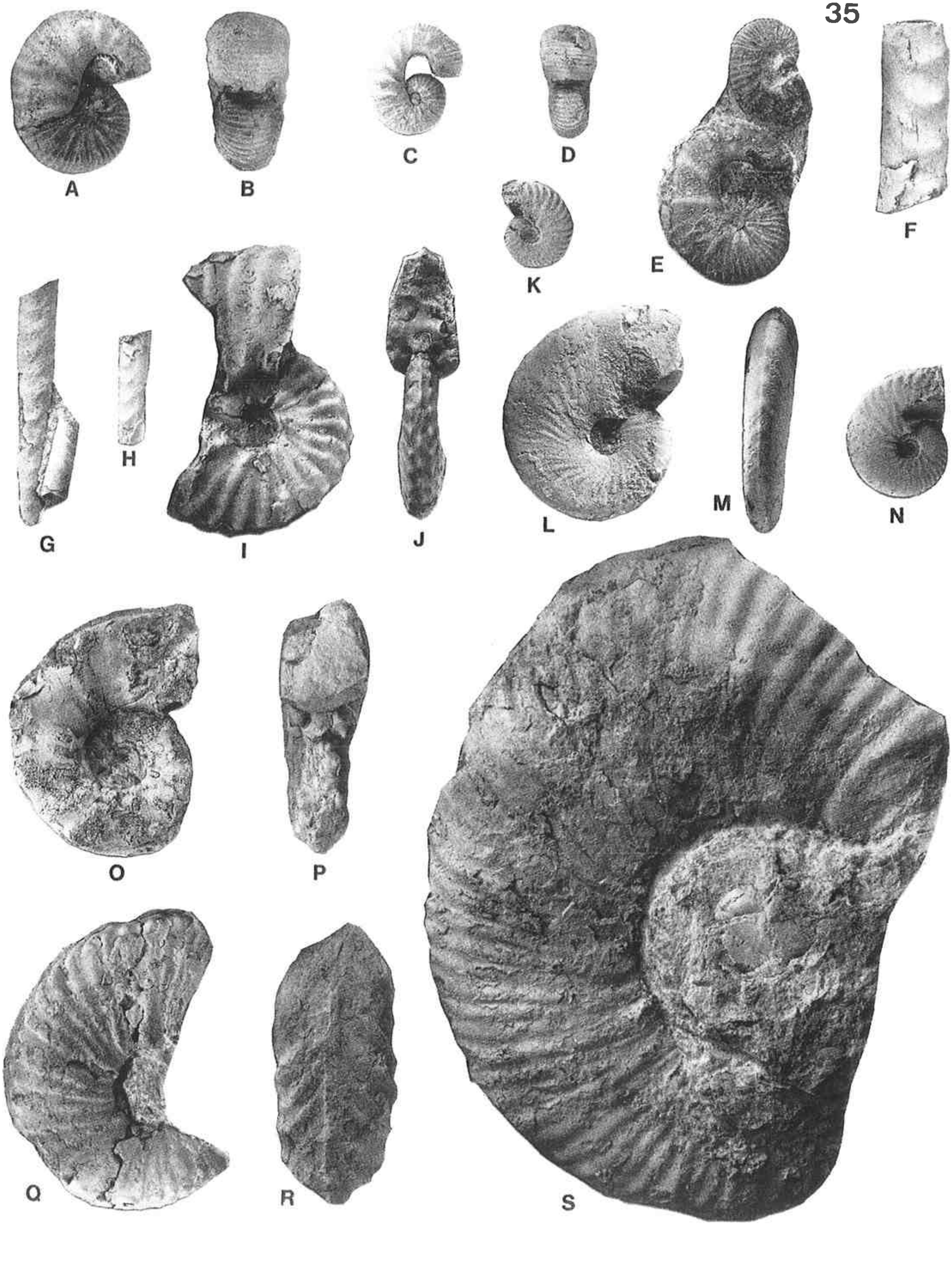

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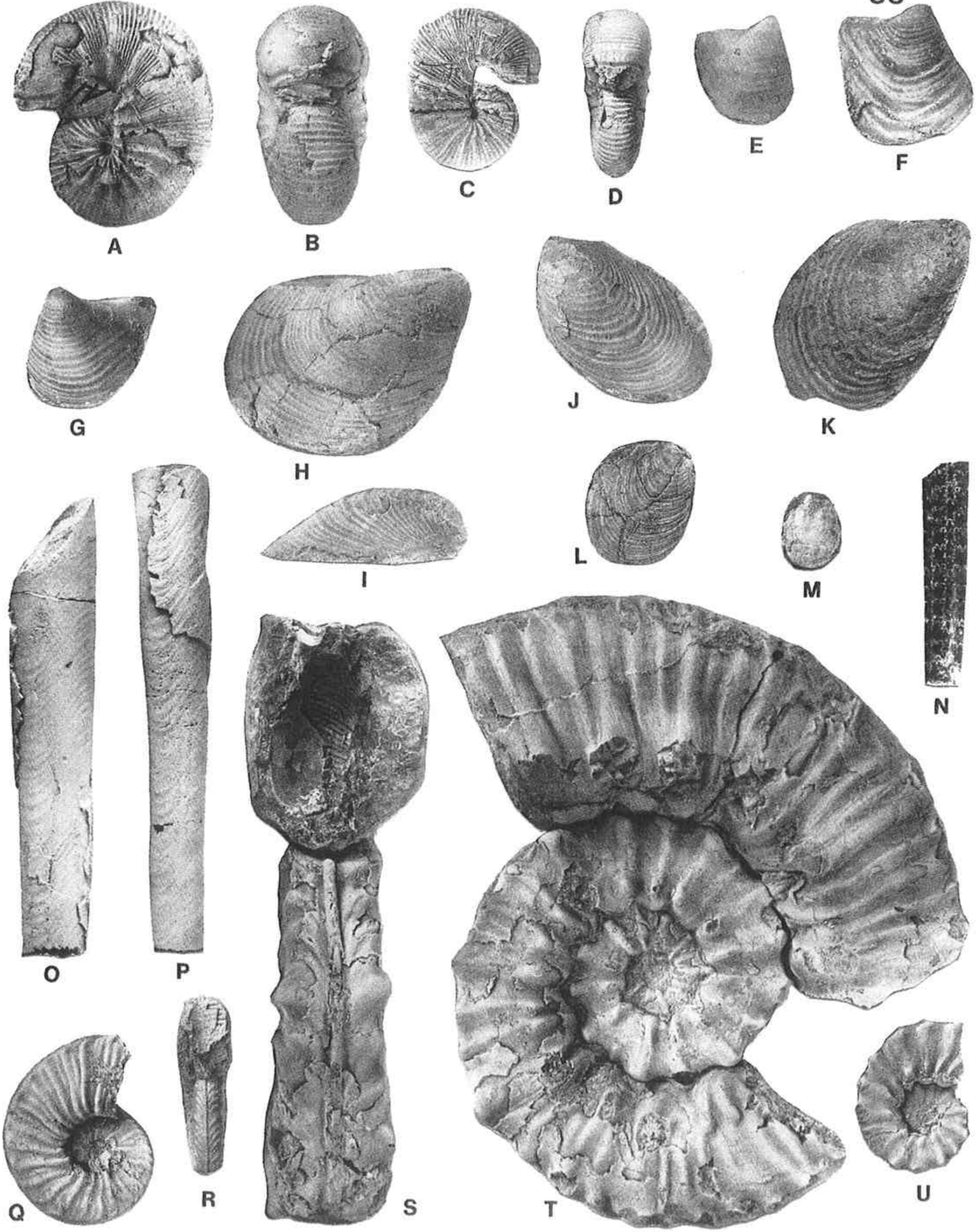

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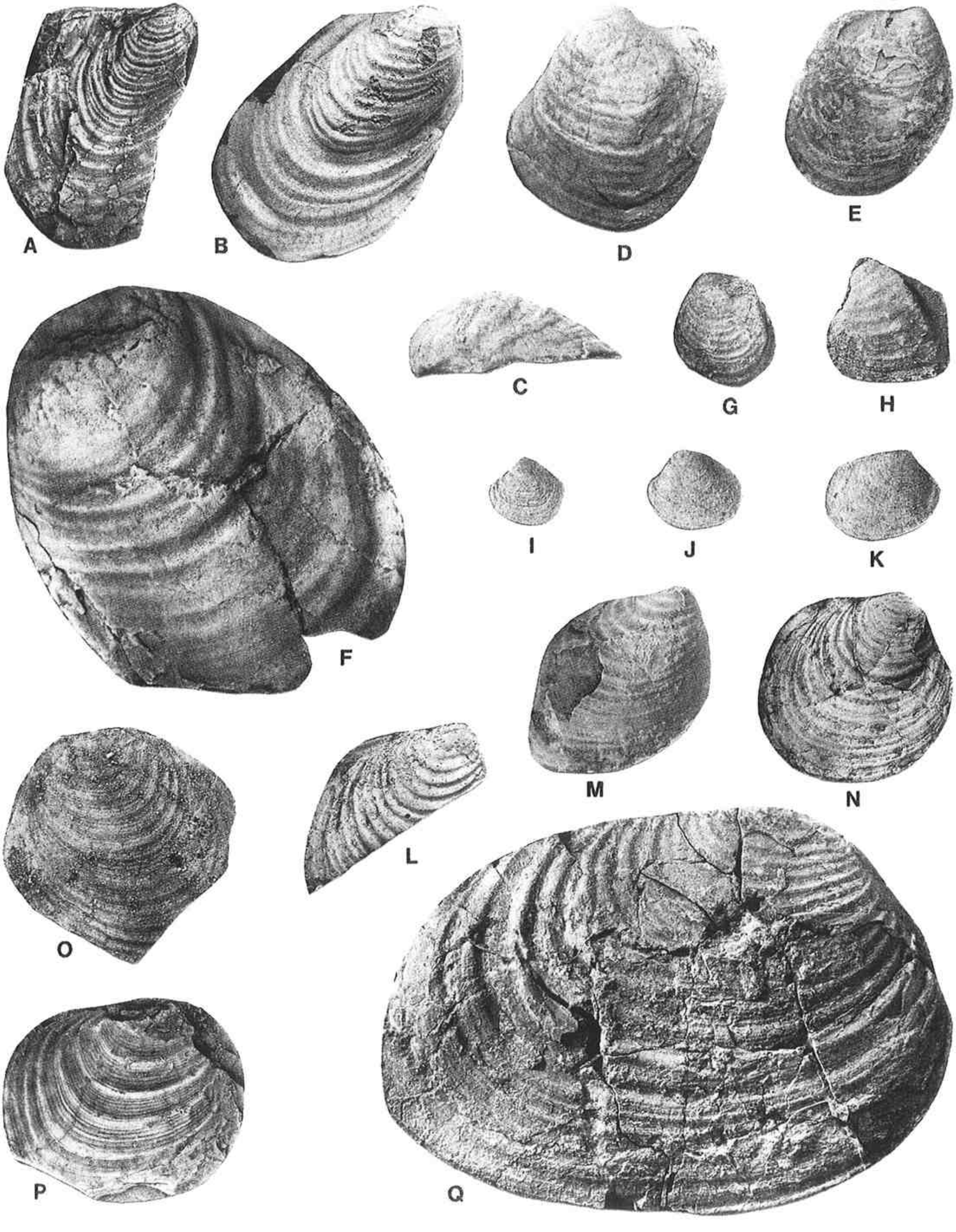

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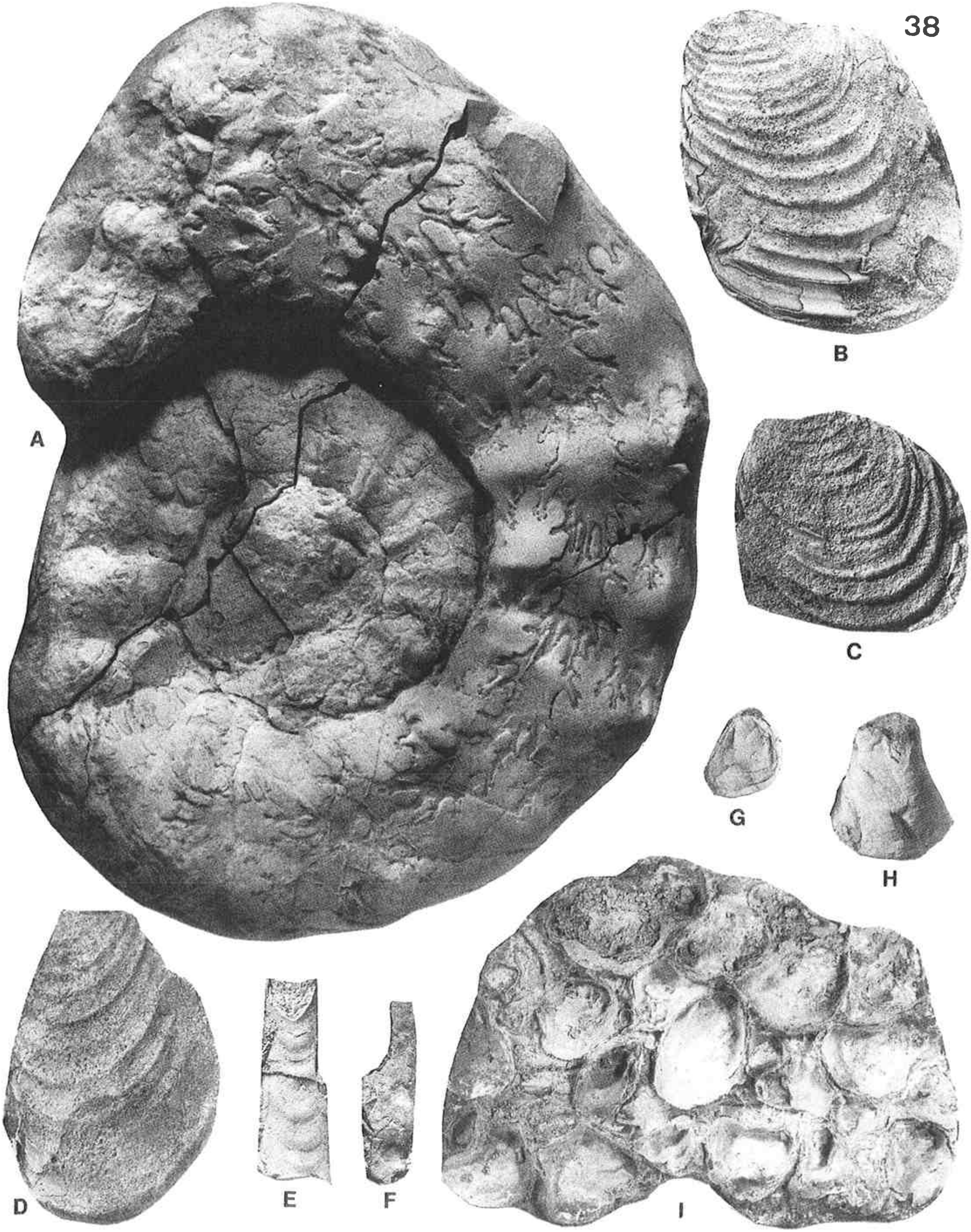

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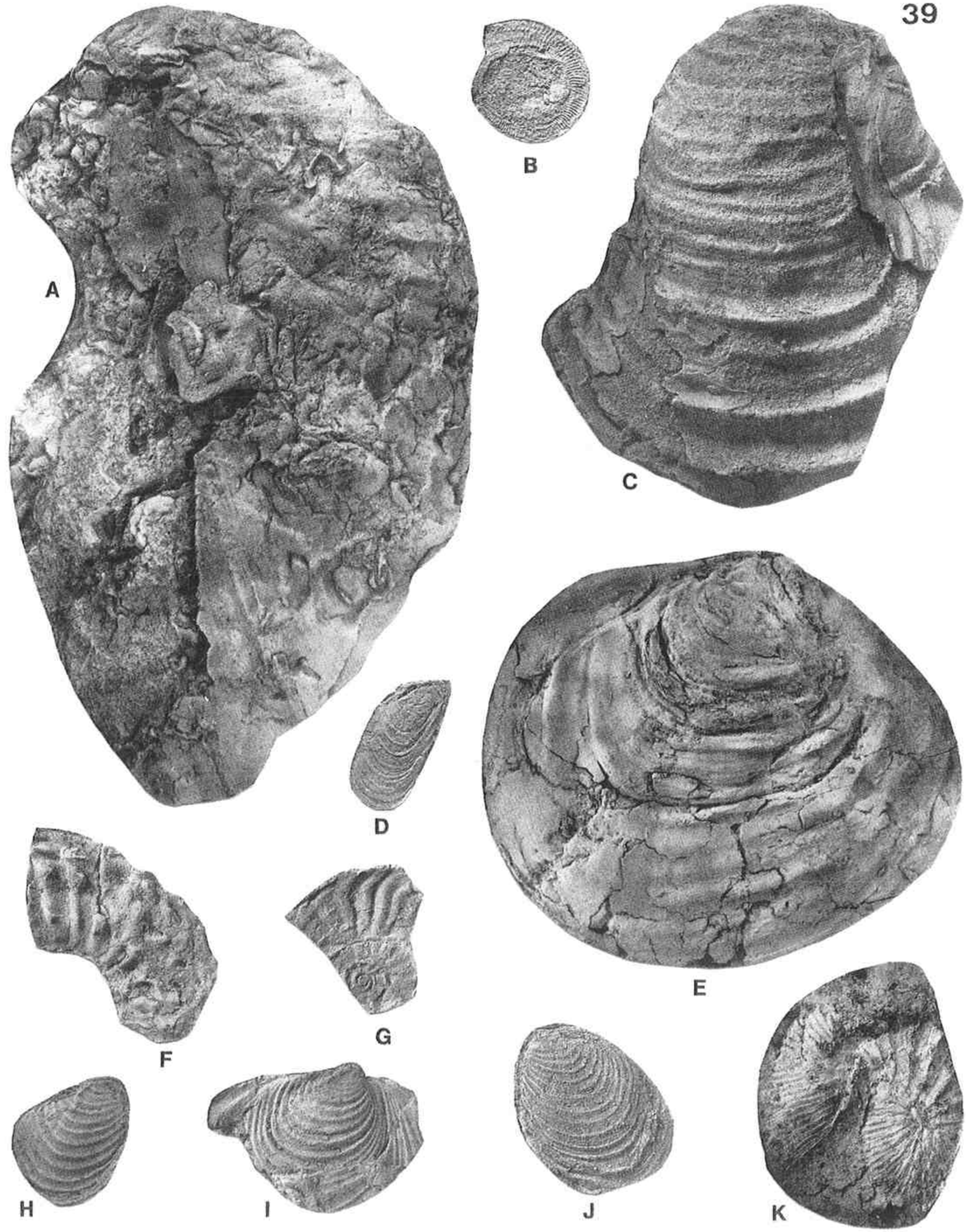

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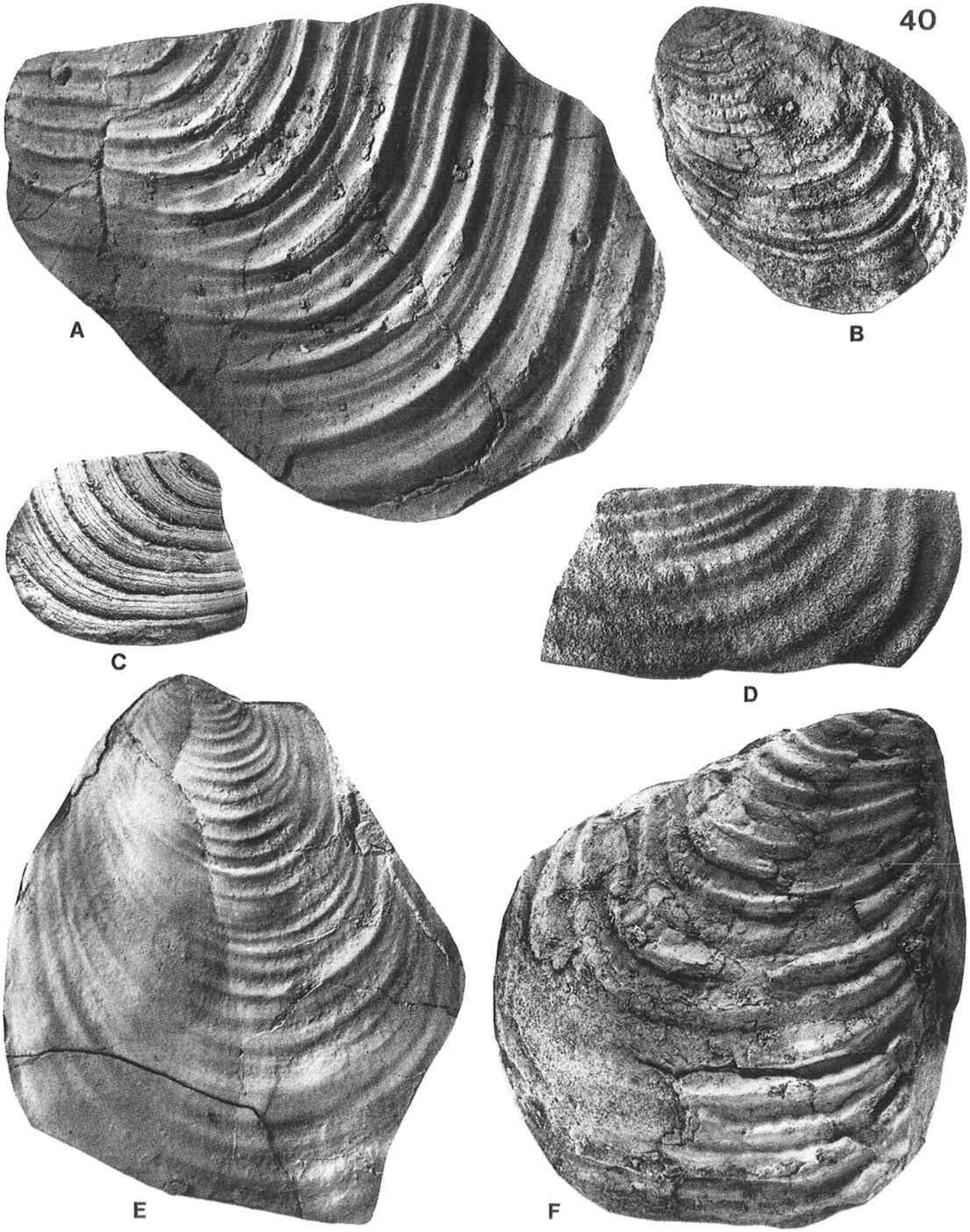

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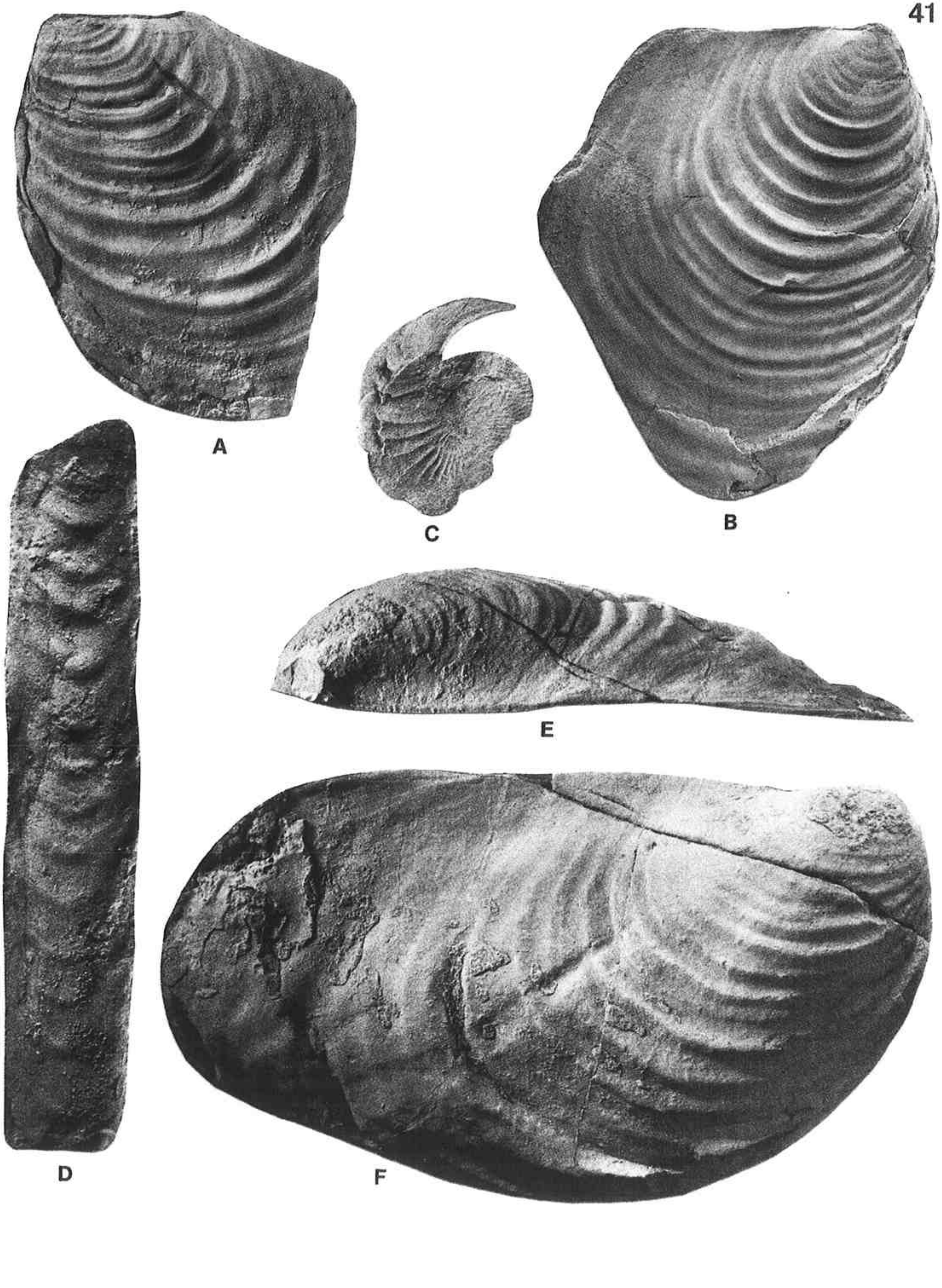

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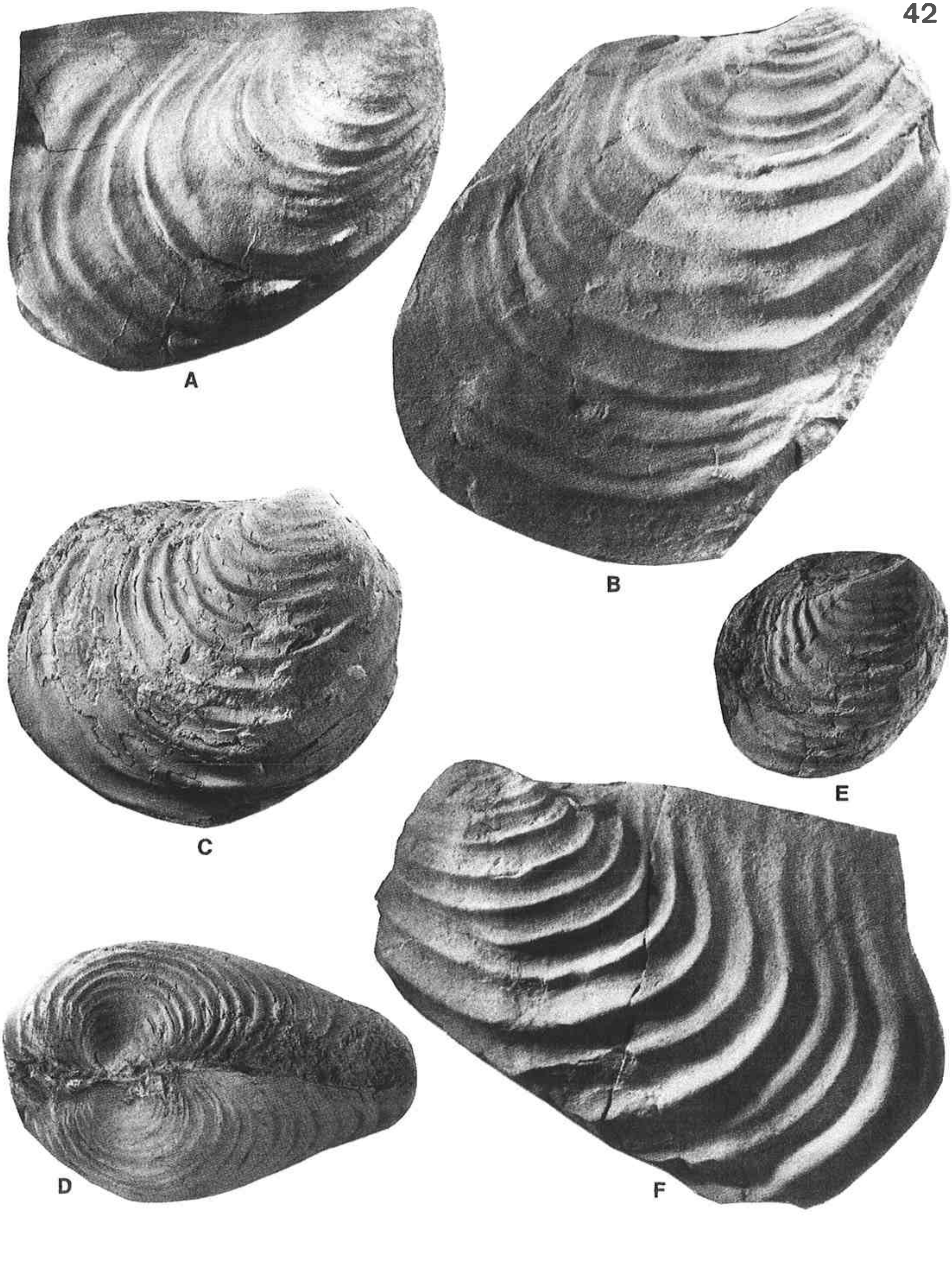

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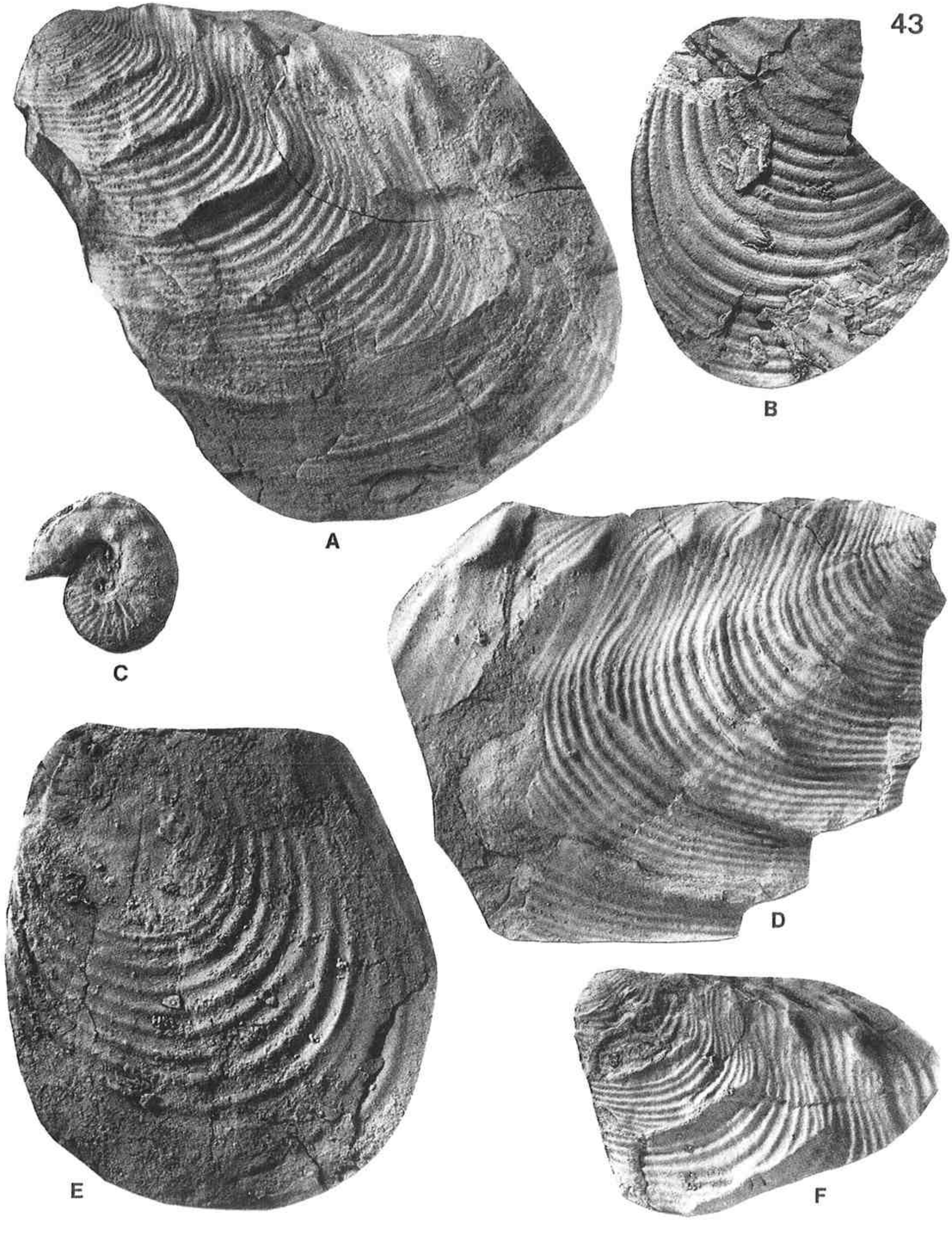

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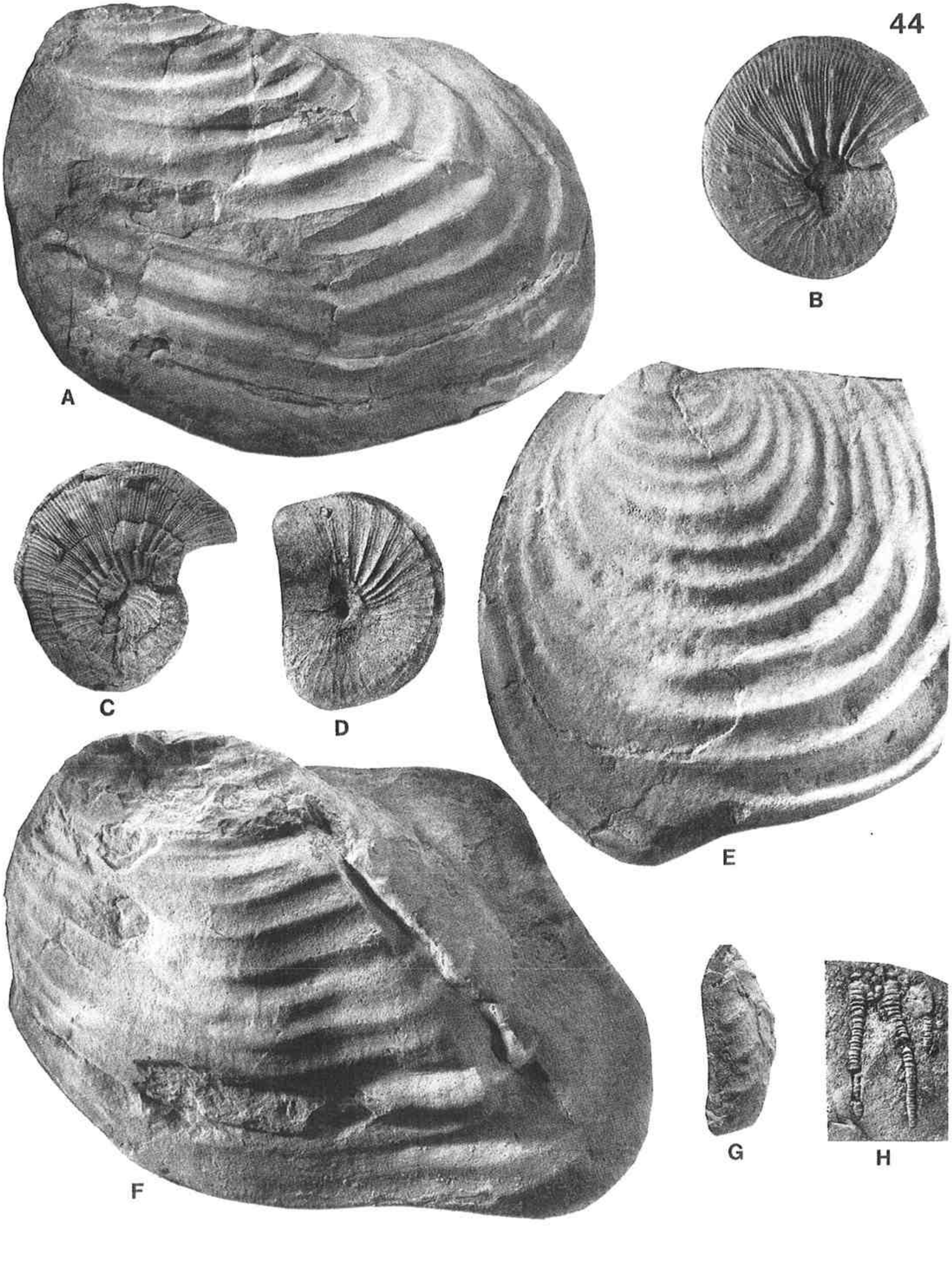

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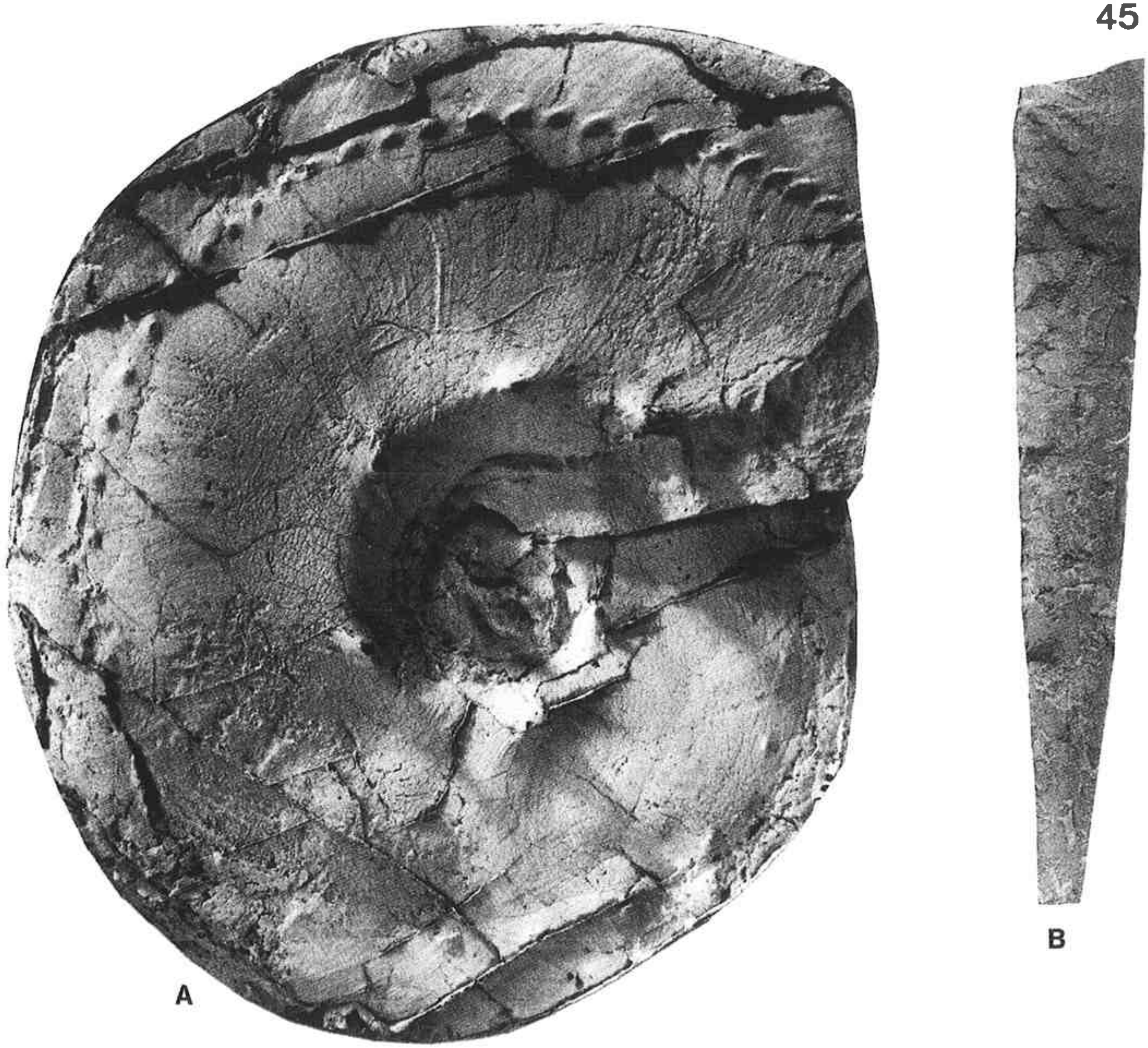
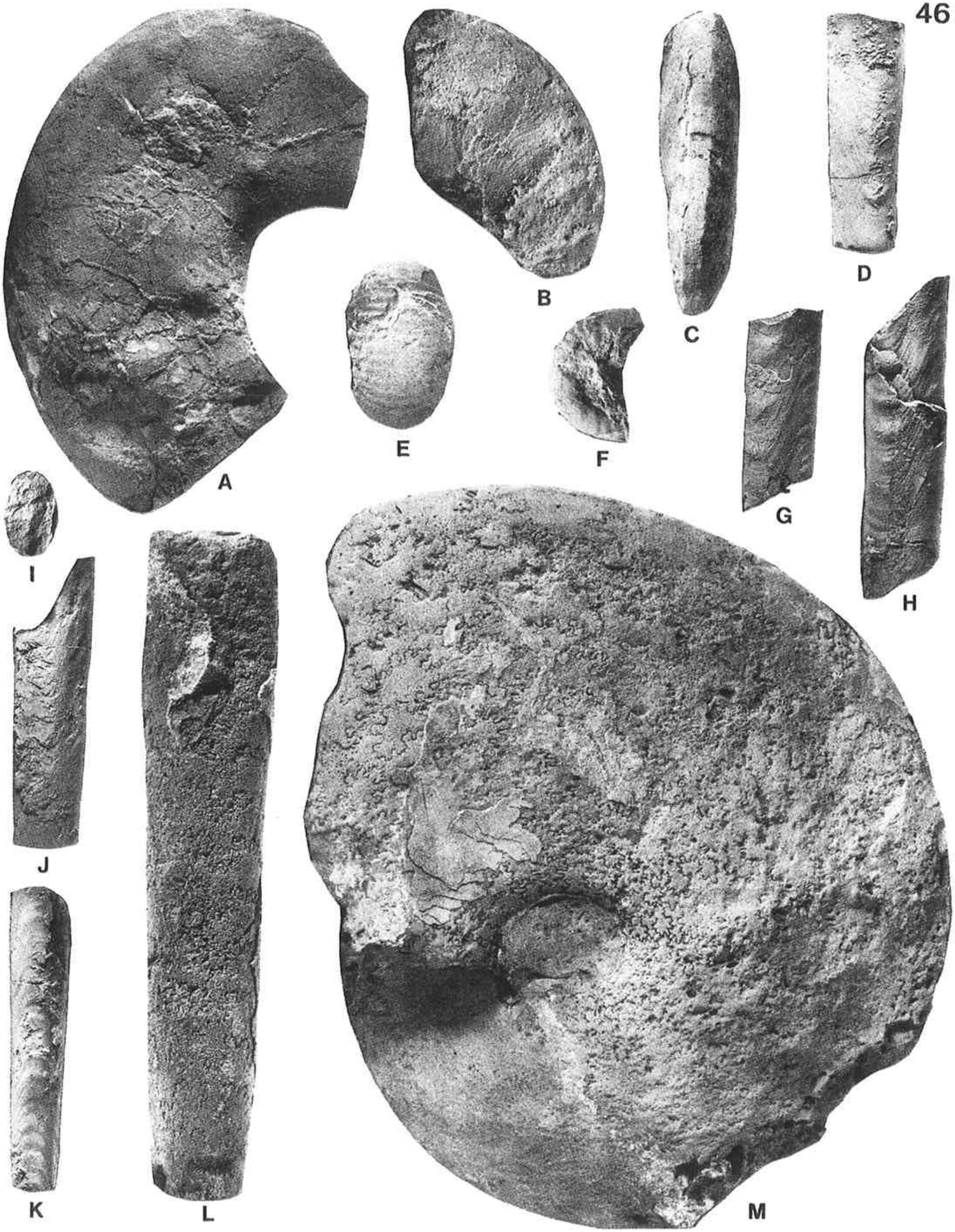


A

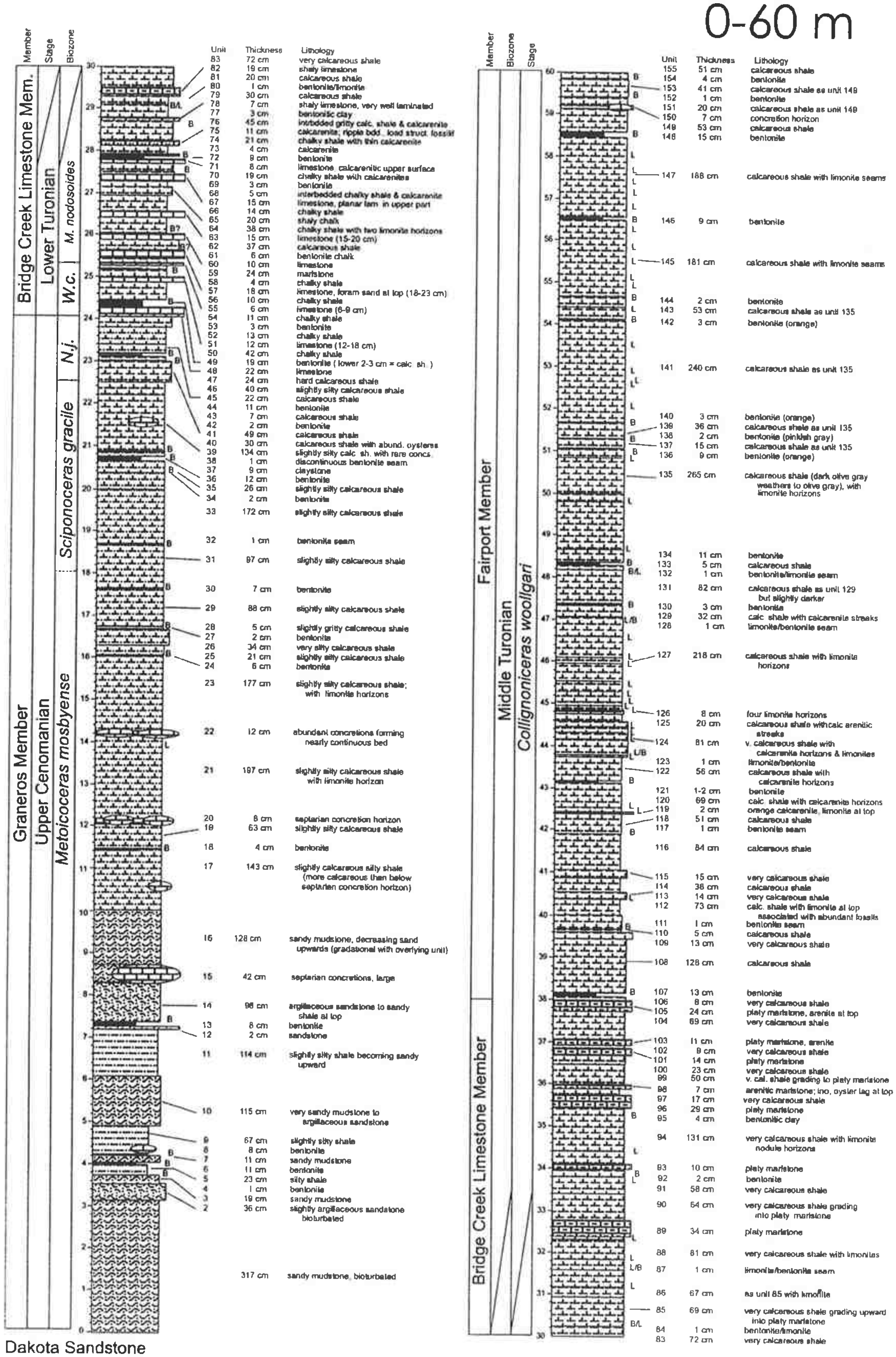
B

46

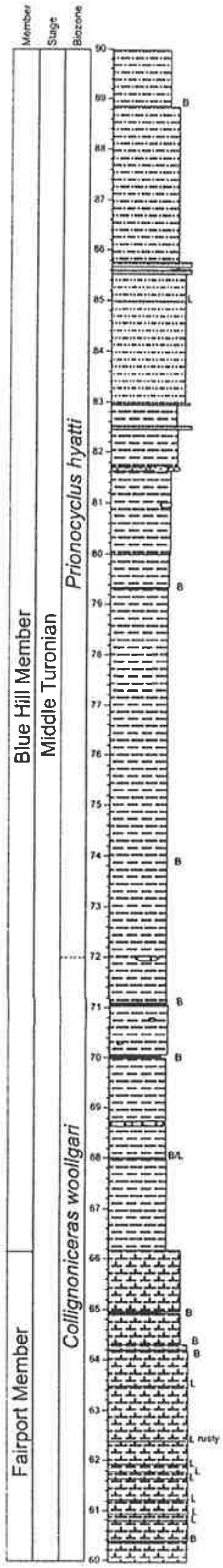


APPENDIX 1

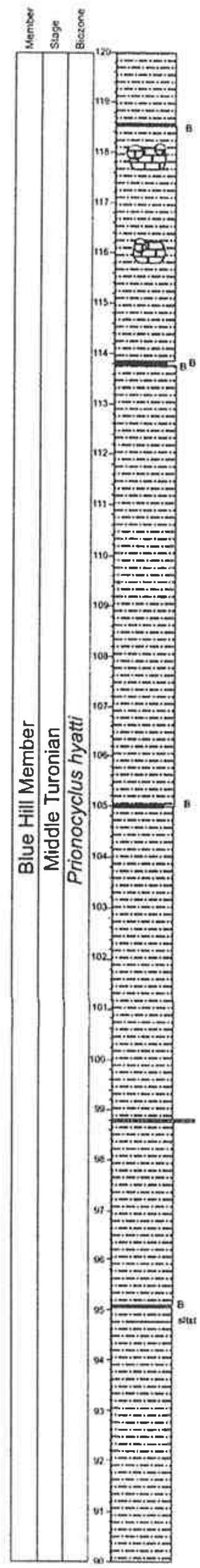
Graphic section of the Mancos Shale at Mesa Verde. Stratigraphic position refers to meters above the Dakota Sandstone. Note change in scale at 300 m. B = bentonite bed or bentonite seam, L = limonite seam.



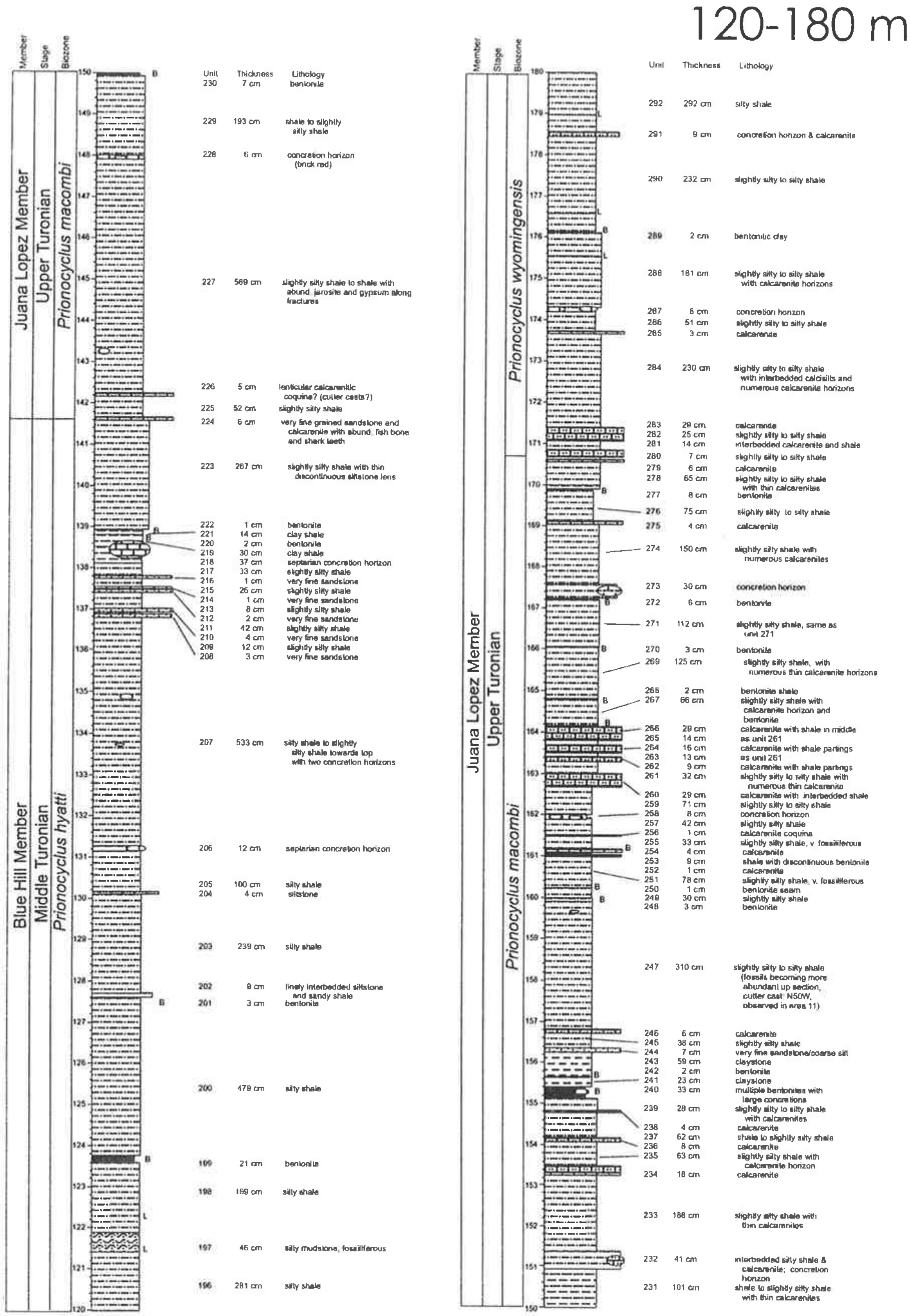
60-120 m



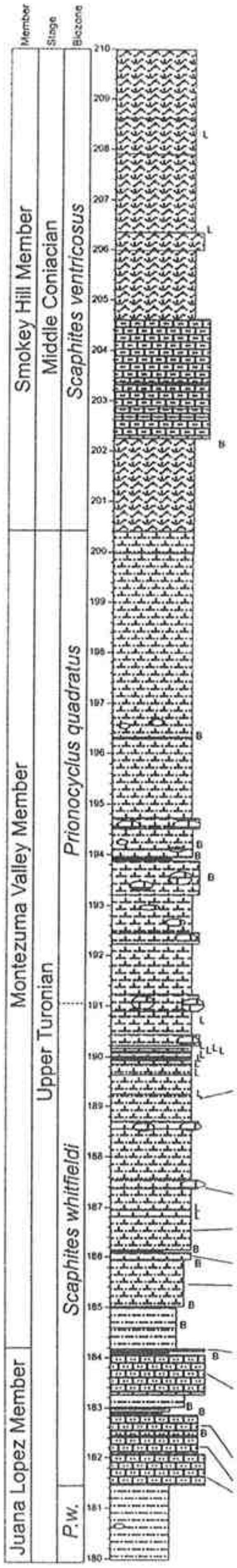
Unit	Thickness	Lithology
186	622 cm	slightly silty shale
185	1 cm	bentonite seam
184	310 cm	slightly silty shale
183	3 cm	siltstone as unit 181
182	10 cm	slightly silty shale
181	6 cm	concretionary siltstone (scoured base with sole marks))
180	260 cm	shale with 0.5 cm siltstone horizons & other thin siltstone lens
179	2 cm	siltstone
178	45 cm	shale as unit 176
177	2 cm	siltstone (thickens to 4 cm)
176	77 cm	shale with scattered siltstone lens
175	8 cm	sandy concretion horizon (cone-in-cone)
174	213 cm	shale with scattered thin siltstone (dark olive gray to olive black), widely scattered concretions (not observed in trench)
173	2 cm	bentonite (0-7 cm) with scoured base
172	820 cm	shale becoming darker toward top, nobbly in places; discontin. bentonite filling cutter casts (shale on shale scour), concretions at 72 m contain C. woollgari and marine reptile bones siderite-cemented siltstone lens near top of unit
171	7 cm	bentonite
170	84 cm	shale with small egg-shaped slightly calcareous nodules
169	12 cm	bentonite
168	122 cm	shale
167	7 cm	septarian concretion horizon
166	68 cm	shale
165	1 cm	bentonite/limonite (concretionary to 6-7 cm, septarized)
164	183 cm	non-calcareous shale (dark olive gray); with scattered limonite streaks, lag of broken juvenile ammonites & oysters at approx. 66.5 m
163	118 cm	slightly calcareous shale with scattered limonite streaks
162	5 cm	bentonite
161	61 cm	slightly calcareous shale as unit 157
160	2 cm	bentonite
159	10 cm	calcareous shale
158	1 cm	bentonite (thickens to 4 cm in troughs of ripples)
157	379 cm	calcareous shale with thin calcisilt streaks defining lamination ("rusty" limonite seam at base of discontin. 1-3 cm coarse siltstone layer)
156	3 cm	bentonite
155	51 cm	calcareous shale



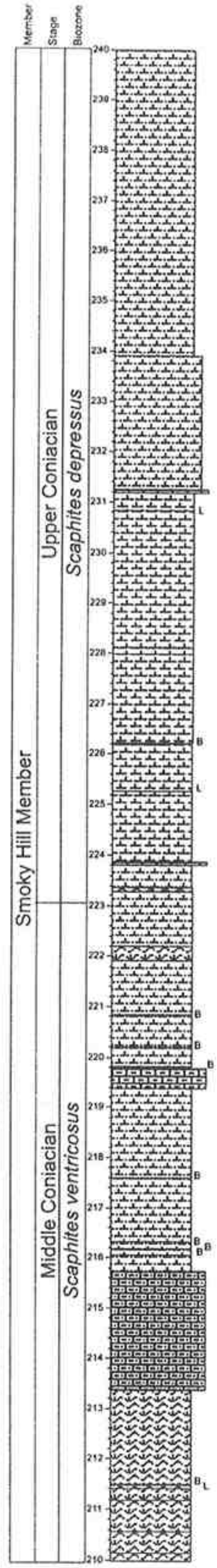
Unit	Thickness	Lithology
196	281 cm	silty shale
195	7 cm	bentonite
194	566 cm	silty shale; large bulbous septarian concretions at 116 & 118 m, gutter casts associated with upper concretionary zone
193	10 cm	bentonite, double
192	876 cm	silty shale
192	876 cm	slightly silty to silty shale with several thin siltstone horizons
191	4 cm	bentonite
190	619 cm	silty shale
190	619 cm	silty shale
189	1 cm	siltstone
188	370 cm	slightly silty shale (olive black) more silty towards top
187	5 cm	bentonite
186	622 cm	slightly silty shale; 1 cm siltstone near top


120-180 m
Member
Stage
Biozone
Juana Lopez Member
Upper Turonian
Prionocyclus macombi
Blue Hill Member
Middle Turonian
Prionocyclus hyatti
Prionocyclus wyomingensis
Unit Thickness Lithology
230 7 cm bentonite
229 193 cm shale to slightly silty shale
228 6 cm concretion horizon (brick red)
227 569 cm slightly silty shale to shale with abund. jarosite and gypsum along fractures
226 5 cm lenticular calcarenitic coquina? (cutter casts?)
225 52 cm slightly silty shale
224 6 cm very fine grained sandstone and calcarenite with abund. fish bone and shark teeth
223 267 cm slightly silty shale with thin discontinuous siltstone lens
222 1 cm bentonite
221 14 cm clay shale
220 2 cm bentonite
219 30 cm clay shale
218 37 cm septarian concretion horizon
217 33 cm slightly silty shale
216 1 cm very fine sandstone
215 26 cm slightly silty shale
214 1 cm very fine sandstone
213 8 cm slightly silty shale
212 2 cm very fine sandstone
211 42 cm slightly silty shale
210 4 cm very fine sandstone
209 12 cm slightly silty shale
208 3 cm very fine sandstone
207 533 cm silty shale to slightly silty shale towards top with two concretion horizons
206 12 cm septarian concretion horizon
205 100 cm silty shale
204 4 cm siltstone
203 239 cm silty shale
202 9 cm finely interbedded siltstone and sandy shale
201 3 cm bentonite
200 479 cm silty shale
199 21 cm bentonite
198 169 cm silty shale
197 46 cm silty mudstone, fossiliferous
196 281 cm silty shale
292 292 cm silty shale
291 9 cm concretion horizon & calcarenite
290 232 cm slightly silty to silty shale
289 2 cm bentonitic clay
288 181 cm slightly silty to silty shale with calcarenite horizons
287 6 cm concretion horizon
286 51 cm slightly silty to silty shale
285 3 cm calcarenite
284 230 cm slightly silty to silty shale with interbedded calcisilts and numerous calcarenite horizons
283 29 cm calcarenite
282 25 cm slightly silty to silty shale
281 14 cm interbedded calcarenite and shale
280 7 cm slightly silty to silty shale
279 6 cm calcarenite
278 65 cm slightly silty to silty shale with thin calcarenites
277 8 cm bentonite
276 75 cm slightly silty to silty shale
275 4 cm calcarenite
274 150 cm slightly silty shale with numerous calcarenites
273 30 cm concretion horizon
272 6 cm bentonite
271 112 cm slightly silty shale, same as unit 271
270 3 cm bentonite
269 125 cm slightly silty shale, with numerous thin calcarenite horizons
268 2 cm bentonite shale
267 66 cm slightly silty shale with calcarenite horizon and bentonite
266 28 cm calcarenite with shale in middle
265 14 cm as unit 261
264 16 cm calcarenite with shale partings
263 13 cm as unit 261
262 9 cm calcarenite with shale partings
261 32 cm slightly silty to silty shale with numerous thin calcarenite
260 29 cm calcarenite with interbedded shale
259 71 cm slightly silty to silty shale
258 8 cm concretion horizon
257 42 cm slightly silty shale
256 1 cm calcarenite coquina
255 33 cm slightly silty shale, v. fossiliferous
254 4 cm calcarenite
253 9 cm shale with discontinuous bentonite
252 1 cm calcarenite
251 78 cm slightly silty shale, v. fossiliferous
250 1 cm bentonite seam
249 30 cm slightly silty shale
248 3 cm bentonite
247 310 cm slightly silty to silty shale (fossils becoming more abundant up section, cutter cast: N50W, observed in area 11)
246 6 cm calcarenite
245 38 cm slightly silty shale
244 7 cm very fine sandstone/coarse silt
243 59 cm claystone
242 2 cm bentonite
241 23 cm claystone
240 33 cm multiple bentonites with large concretions
239 28 cm slightly silty to silty shale with calcarenites
238 4 cm calcarenite
237 62 cm shale to slightly silty shale
236 8 cm calcarenite
235 63 cm slightly silty shale with calcarenite horizon
234 18 cm calcarenite
233 188 cm slightly silty shale with thin calcarenites
232 41 cm interbedded silty shale & calcarenite; concretion horizon
231 101 cm shale to slightly silty shale with thin calcarenites

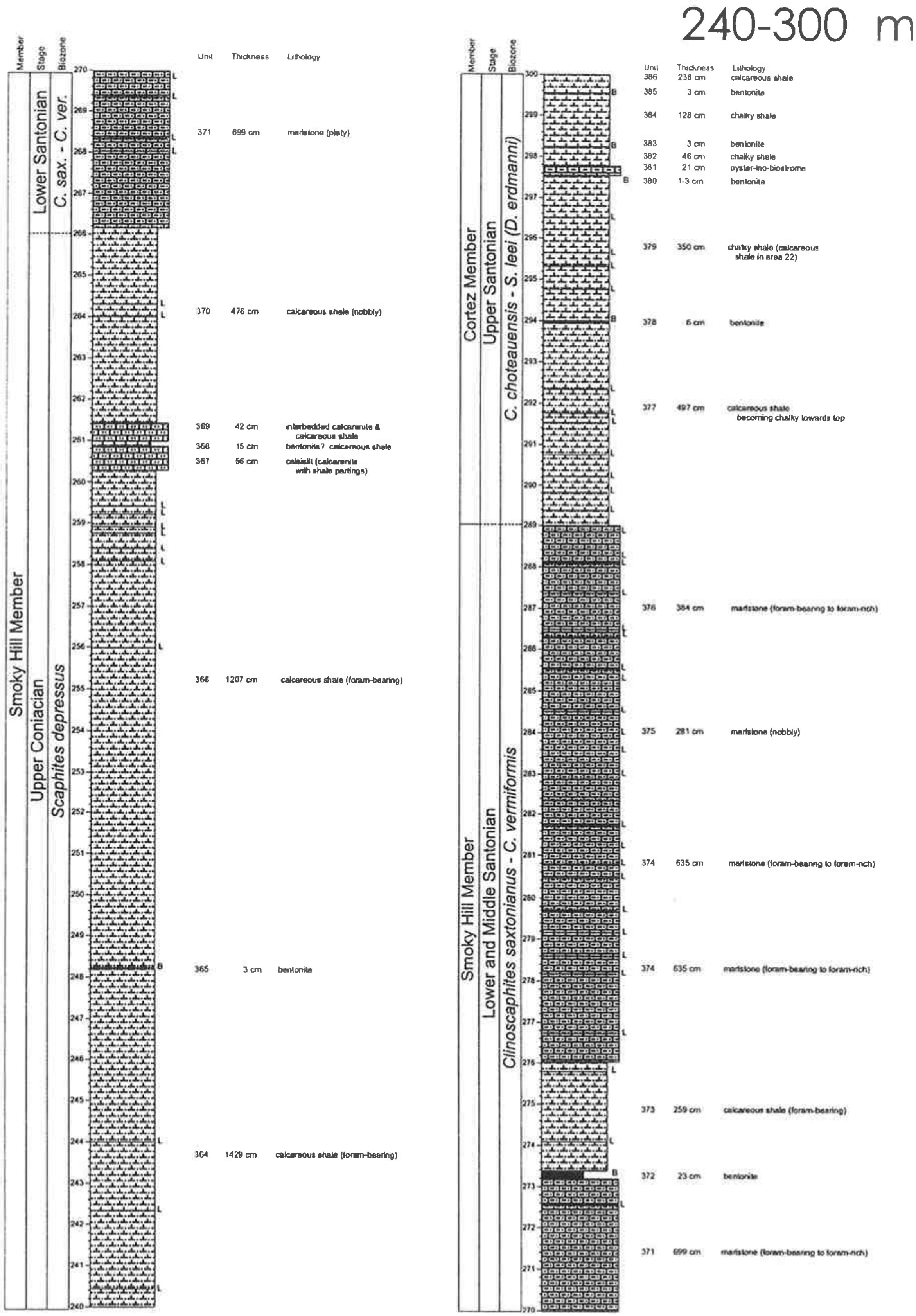
180-240 m



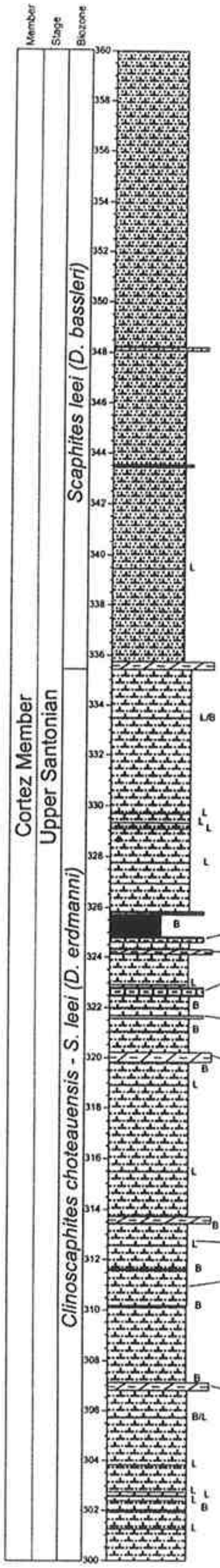
Unit	Thickness	Lithology
335	378 cm	calcareous mudstone with scattered limonite nodules
334	30 cm	very calcareous mudstone (foram-rich)
333	142 cm	calcareous mudstone (foram-bearing)
332	234 cm	marlstone with several thin calcarenites (foram-bearing)
331	2 cm	bentonite
330	184 cm	calcareous mudstone with disseminated glauconite and quartz sand at base (limonite nodules in upper 82 cm of unit)
		sharp shale-on-shale contact
329	409 cm	slightly silty calcareous shale
328	3 cm	bentonite
327	161 cm	slightly silty calcareous shale
326	18 cm	septarian concretion horizon
325	57 cm	slightly silty calcareous shale with concretion zone
324	10 cm	bentonite
323	16 cm	septarian concretion horizon
322	125 cm	slightly silty calcareous shale with concretion horizons
321	20 cm	septarian concretion horizon
320	104 cm	slightly silty calcareous shale with calcarenite horizons
319	29 cm	septarian concretion zone
318	50 cm	slightly silty calcareous shale with abundant lens of limonite
317	20 cm	septarian concretion horizon
316	58 cm	slightly silty calcareous shale with limonite swarm
315	95 cm	slightly silty calcareous shale
314	11 cm	septarian concretion horizon
313	105 cm	slightly silty calcareous shale
312	15 cm	septarian concretion horizon (calcarenite caps unit)
311	120 cm	slightly silty calcareous shale
310	8 cm	bentonite
309	10 cm	slightly silty calcareous shale
308	3 cm	bentonite
307	92 cm	slightly calcareous silty shale
306	3 cm	bentonite
305	84 cm	slightly calcareous silty shale
304	3 cm	calcarenite
303	3 cm	bentonitic shale
302	5 cm	bentonite
301	78 cm	calcarenites with shale partings
300	24 cm	slightly silty to silty shale with calcarenite
299	3 cm	bentonite
298	4 cm	claystone
297	13 cm	bentonite
296	38 cm	interbedded calcarenite & shale
295	3 cm	bentonite
294	35 cm	interbedded calcarenites & shale
293	59 cm	calcarenites with shale partings, concretionary, very fossiliferous
292	292 cm	silty shale, thin calcarenites towards top



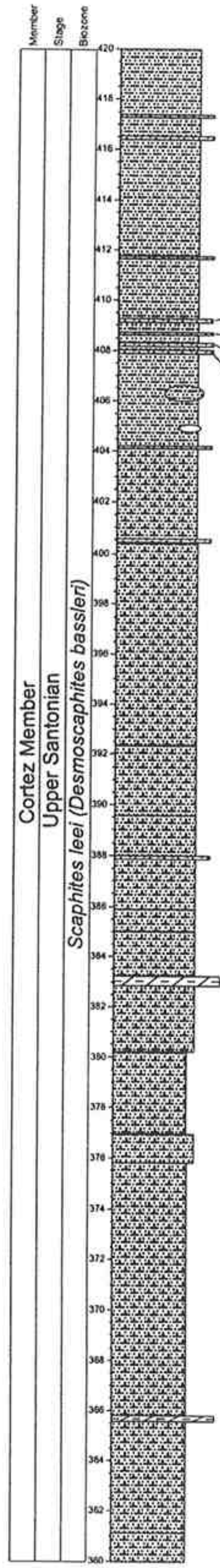
Unit	Thickness	Lithology
364	1429 cm	calcareous shale (foram-bearing)
363	266 cm	calcareous shale with numerous thin calcarenite streaks (foram-rich)
362	4 cm	calcarenite
361	308 cm	calcareous shale with limonite
361	308 cm	calcareous shale with limonite
360	13 cm	nobbly calcareous shale
359	178 cm	calcareous shale
358	1-2 cm	bentonite
357	234 cm	calcareous shale with discontinuous limonite
356	2 cm	calcisiltite
355	46 cm	slightly calcareous shale
354	8 cm	calcareous mudstone
353	108 cm	calcareous shale (foram-bearing)
352	28 cm	slightly calcareous mudstone
351	110 cm	slightly calcareous shale
350	2 cm	bentonite
349	99 cm	slightly calcareous shale
349	89 cm	slightly calcareous shale
348	5 cm	bentonite
347	36 cm	marlstone
346	180 cm	calcareous shale (marly in places)
345	2 cm	bentonite
344	148 cm	calcareous shale (marly in places)
343	4 cm	bentonite
342	45 cm	calcareous shale
341	234 cm	marlstone
340	186 cm	calcareous mudstone (large nobbly)
339	3 cm	bentonite
338	32 cm	calcareous mudstone (large nobbly)
337	61 cm	calcareous mudstone
336	44 cm	calcareous mudstone (large nobbly)


240-300 m
Member
Stage
Biozone
Unit
Thickness
Lithology
Lower Santonian
C. sax. - C. ver.
Smoky Hill Member
Upper Coniacian
Scaphites depressus
371 699 cm marlstone (platy)
370 476 cm calcareous shale (nobbly)
369 42 cm interbedded calcarenite & calcareous shale
368 15 cm bentonite? calcareous shale
367 56 cm calcisilt (calcarenite with shale partings)
366 1207 cm calcareous shale (foram-bearing)
365 3 cm bentonite
364 1429 cm calcareous shale (foram-bearing)
Cortez Member
Upper Santonian
C. choteauensis - S. leei (D. erdmanni)
Smoky Hill Member
Lower and Middle Santonian
Clinoscaphites saxtonianus - C. vermiformis
386 238 cm calcareous shale
385 3 cm bentonite
384 128 cm chalky shale
383 3 cm bentonite
382 46 cm chalky shale
381 21 cm oyster-ino-biostrome
380 1-3 cm bentonite
379 350 cm chalky shale (calcareous shale in area 22)
378 6 cm bentonite
377 497 cm calcareous shale becoming chalky towards top
376 384 cm marlstone (foram-bearing to foram-rich)
375 281 cm marlstone (nobbly)
374 635 cm marlstone (foram-bearing to foram-rich)
374 635 cm marlstone (foram-bearing to foram-rich)
373 259 cm calcareous shale (foram-bearing)
372 23 cm bentonite
371 699 cm marlstone (foram-bearing to foram-rich)

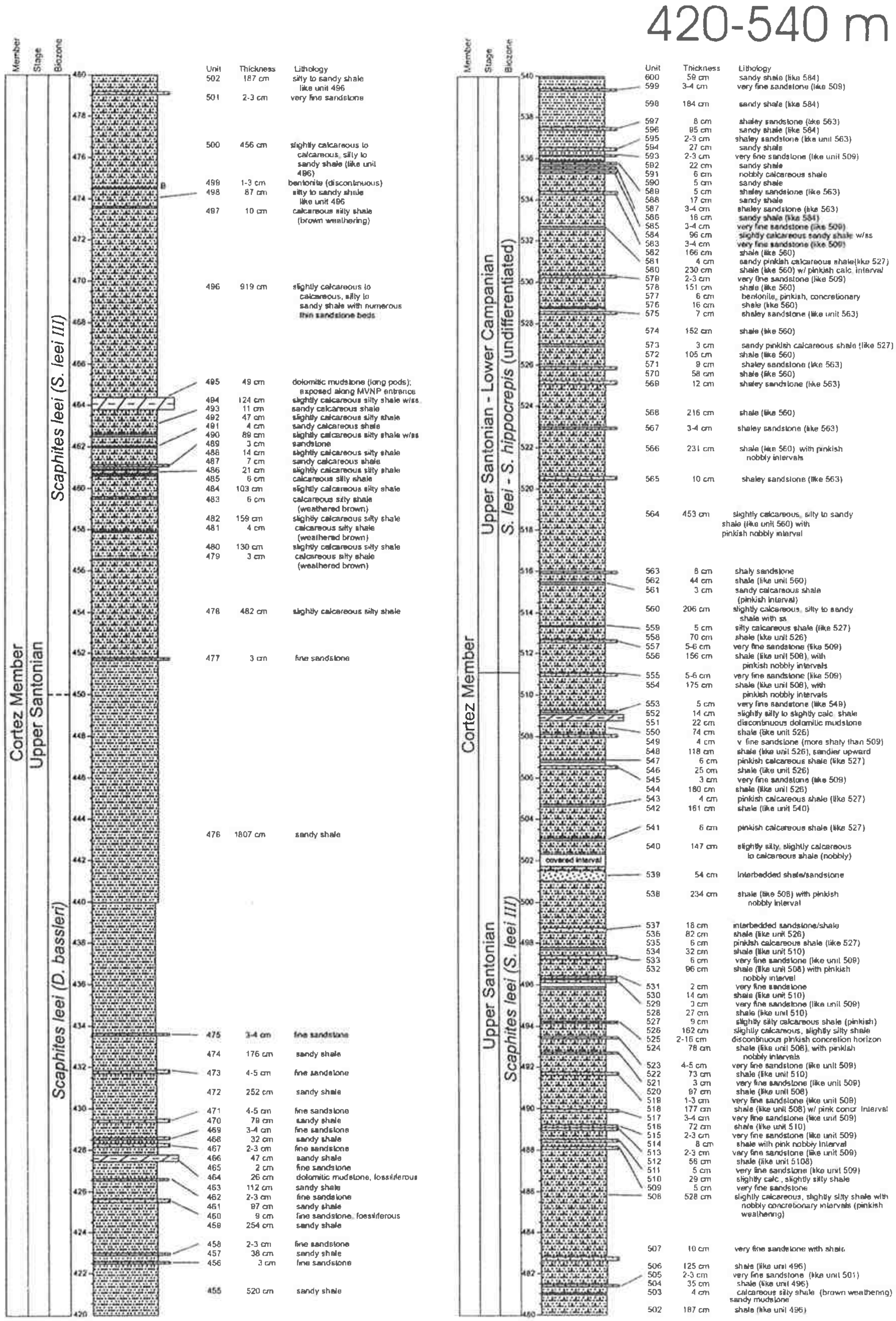
300-420 m



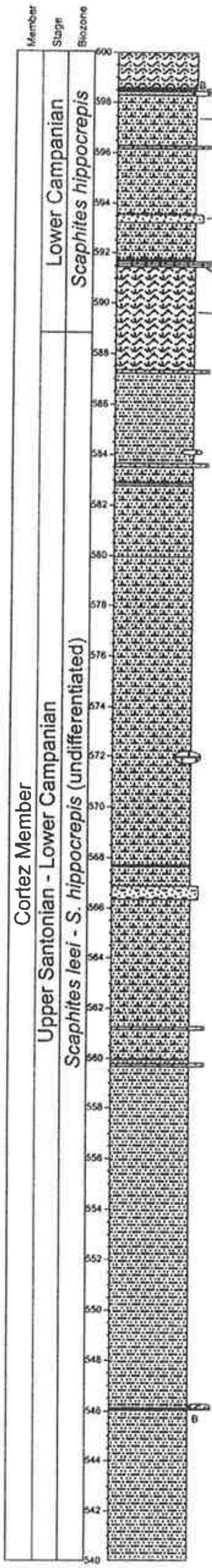
Unit	Thickness	Lithology
423	1299 cm	slightly calcareous silty shale
422	3-4 cm	very fine sandstone
421	457 cm	slightly calcareous silty shale with numerous v.f. to fine sandst. horizons/beds in upper 2 m
420	2-3 cm	coarse siltstone
419	781 cm	slightly calcareous silty shale with numerous thin v.f. ss. beds in upper 2.5 m
419	781 cm	slightly calcareous silty shale
418	22 cm	dolomitic mudstone, fossiliferous
417	850 cm	silty calcareous shale
416	115 cm	silty calcareous shale
415	7 cm	marlstone
414	95 cm	bentonite
413	16 cm	marlstone
412	34 cm	slightly silty calcareous shale
411	10 cm	dolomitic mudstone
410	153 cm	slightly silty calcareous shale
409	23 cm	marlstone
408	52 cm	slightly silty calcareous shale
407	3 cm	bentonite
406	34 cm	slightly silty calcareous shale
405	3 cm	storm sand (first)
404	57 cm	slightly silty calcareous shale
403	3 cm	bentonite
402	62 cm	slightly silty calcareous shale
401	30 cm	dolomitic mudstone, fossiliferous
400	8 cm	slightly gritty calcareous shale
399	3 cm	bentonite
398	604 cm	slightly sity calcareous shale
397	18 cm	dolomitic mudstone, fossiliferous
396	4 cm	bentonite
395	190 cm	slightly silty calcareous shale
394	1 cm	bentonite
393	137 cm	slightly silty calcareous shale
392	1 cm	bentonite
391	304 cm	slightly silty? calcareous shale
390	4 cm	bentonite
389	20 cm	dolomitic mudstone (fossiliferous)
388	490 cm	slightly silty? calcareous shale
387	1 cm	bentonite
386	238 cm	slightly silty? calcareous shale



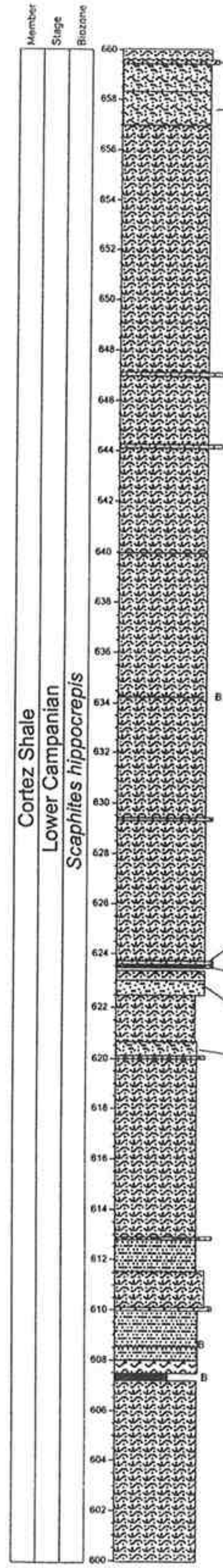
Unit	Thickness	Lithology
455	520 cm	sandy shale
454	5 cm	very fine sandstone
453	82 cm	sandy shale
452	4 cm	very fine sandstone
451	468 cm	sandy shale
450	6 cm	very fine sandstone
449	247 cm	sandy shale
448	5 cm	very fine sandstone
447	48 cm	sandy shale
446	4 cm	very fine sandstone
445	40 cm	sandy shale
444	2-3 cm	very fine sandstone
443	27 cm	sandy shale
442	4 cm	very fine sandstone
441	376 cm	sandy shale with large dolomitic concretions
440	6 cm	very fine sandstone with shale partings
439	364 cm	slightly calcareous silty shale (same as units 436/431)
438	7 cm	interbedded very fine sandstone & shale
437	804 cm	slightly calcareous silty shale same as units 436/431
436	278 cm	slightly calcareous silty shale with numerous very fine sandstone beds, laminae & lenses (starved ripples)
435	165 cm	same as unit 431
434	3-4 cm	very fine sandstone
433	204 cm	same as unit 431
432	88 cm	like 431, with more numerous crs. siltstone/ very fine sandstone
431	179 cm	slightly calcareous silty shale with numerous thin crs. siltstone/very fine sandstone
430	31 cm	dolomitic mudstone, fossiliferous
429	266 cm	slightly calcareous silty shale with numerous thin siltstone/ very fine sandstone
428	329 cm	slightly calcareous silty shale
427	110 cm	slightly calcareous silty shale with numerous thin siltstone and very fine sandstone beds
426	1009 cm	slightly calcareous silty shale
425	14 cm	dolomitic mudstone
424	448 cm	slightly calcareous silty shale with more frequent sandstone horizons
423	1299 cm	slightly calcareous silty shale


420-540 m
Member
Stage
Biozone
Cortez Member
Upper Santonian
Scaphites leei (S. leei III)
Scaphites leei (D. bassleri)
B
Unit Thickness Lithology
502 187 cm silty to sandy shale like unit 496
501 2-3 cm very fine sandstone
500 456 cm slightly calcareous to calcareous, silty to sandy shale (like unit 496)
499 1-3 cm bentonite (discontinuous)
498 87 cm silty to sandy shale like unit 496
497 10 cm calcareous silty shale (brown weathering)
496 919 cm slightly calcareous to calcareous, silty to sandy shale with numerous thin sandstone beds
495 49 cm dolomitic mudstone (long pods); exposed along MVNP entrance
494 124 cm slightly calcareous silty shale w/ss
493 11 cm sandy calcareous shale
492 47 cm slightly calcareous silty shale
491 4 cm sandy calcareous shale
490 89 cm slightly calcareous silty shale w/ss
489 3 cm sandstone
488 14 cm slightly calcareous silty shale
487 7 cm sandy calcareous shale
486 21 cm slightly calcareous silty shale
485 6 cm calcareous silty shale
484 103 cm slightly calcareous silty shale
483 6 cm calcareous silty shale (weathered brown)
482 159 cm slightly calcareous silty shale
481 4 cm calcareous silty shale (weathered brown)
480 130 cm slightly calcareous silty shale
479 3 cm calcareous silty shale (weathered brown)
478 482 cm slightly calcareous silty shale
477 3 cm fine sandstone
476 1807 cm sandy shale
475 3-4 cm fine sandstone
474 176 cm sandy shale
473 4-5 cm fine sandstone
472 252 cm sandy shale
471 4-5 cm fine sandstone
470 79 cm sandy shale
469 3-4 cm fine sandstone
468 32 cm sandy shale
467 2-3 cm fine sandstone
466 47 cm sandy shale
465 2 cm fine sandstone
464 26 cm dolomitic mudstone, fossiliferous
463 112 cm sandy shale
462 2-3 cm fine sandstone
461 97 cm sandy shale
460 9 cm fine sandstone, fossiliferous
459 254 cm sandy shale
458 2-3 cm fine sandstone
457 38 cm sandy shale
456 3 cm fine sandstone
455 520 cm sandy shale
Member
Stage
Biozone
Cortez Member
Upper Santonian - Lower Campanian
S. leei - S. hippocrepis (undifferentiated)
Upper Santonian
Scaphites leei (S. leei III)
covered interval
Unit Thickness Lithology
600 59 cm sandy shale (like 584)
599 3-4 cm very fine sandstone (like 509)
598 184 cm sandy shale (like 584)
597 8 cm shaley sandstone (like 563)
596 85 cm sandy shale (like 584)
595 2-3 cm shaley sandstone (like unit 563)
594 27 cm sandy shale
593 2-3 cm very fine sandstone (like unit 509)
592 22 cm sandy shale
591 6 cm nobbly calcareous shale
590 5 cm sandy shale
589 5 cm shaley sandstone (like 563)
588 17 cm sandy shale
587 3-4 cm shaley sandstone (like 563)
586 18 cm sandy shale (like 584)
585 3-4 cm very fine sandstone (like 509)
584 96 cm slightly calcareous sandy shale w/ss
583 3-4 cm very fine sandstone (like 509)
582 166 cm shale (like 560)
581 4 cm sandy pinkish calcareous shale(like 527)
580 230 cm shale (like 560) w/ pinkish calc. interval
579 2-3 cm very fine sandstone (like 509)
578 151 cm shale (like 560)
577 6 cm bentonite, pinkish, concretionary
576 16 cm shale (like 560)
575 7 cm shaley sandstone (like unit 563)
574 152 cm shale (like 560)
573 3 cm sandy pinkish calcareous shale (like 527)
572 105 cm shale (like 560)
571 9 cm shaley sandstone (like 563)
570 58 cm shale (like 560)
569 12 cm shaley sandstone (like 563)
568 216 cm shale (like 560)
567 3-4 cm shaley sandstone (like 563)
566 231 cm shale (like 560) with pinkish nobbly intervals
565 10 cm shaley sandstone (like 563)
564 453 cm slightly calcareous, silty to sandy shale (like unit 560) with pinkish nobbly interval
563 8 cm shaly sandstone
562 44 cm shale (like unit 560)
561 3 cm sandy calcareous shale (pinkish interval)
560 206 cm slightly calcareous, silty to sandy shale with ss
559 5 cm silty calcareous shale (like 527)
558 70 cm shale (like unit 526)
557 5-6 cm very fine sandstone (like 509)
556 156 cm shale (like unit 508), with pinkish nobbly intervals
555 5-6 cm very fine sandstone (like 509)
554 175 cm shale (like unit 508), with pinkish nobbly intervals
553 5 cm very fine sandstone (like 549)
552 14 cm slightly silty to slightly calc. shale
551 22 cm discontinuous dolomitic mudstone
550 74 cm shale (like unit 526)
549 4 cm v. fine sandstone (more shaly than 509)
548 118 cm shale (like unit 526), sandier upward
547 6 cm pinkish calcareous shale (like 527)
546 25 cm shale (like unit 526)
545 3 cm very fine sandstone (like 509)
544 180 cm shale (like unit 526)
543 4 cm pinkish calcareous shale (like 527)
542 161 cm shale (like unit 540)
541 6 cm pinkish calcareous shale (like 527)
540 147 cm slightly silty, slightly calcareous to calcareous shale (nobbly)
539 54 cm interbedded shale/sandstone
538 234 cm shale (like 508) with pinkish nobbly interval
537 18 cm interbedded sandstone/shale
536 82 cm shale (like unit 526)
535 6 cm pinkish calcareous shale (like 527)
534 32 cm shale (like unit 510)
533 6 cm very fine sandstone (like unit 509)
532 96 cm shale (like unit 508) with pinkish nobbly interval
531 2 cm very fine sandstone
530 14 cm shale (like unit 510)
529 3 cm very fine sandstone (like unit 509)
528 27 cm shale (like unit 510)
527 9 cm slightly silty calcareous shale (pinkish)
526 162 cm slightly calcareous, slightly silty shale
525 2-16 cm discontinuous pinkish concretion horizon
524 78 cm shale (like unit 508), with pinkish nobbly intervals
523 4-5 cm very fine sandstone (like unit 509)
522 73 cm shale (like unit 510)
521 3 cm very fine sandstone (like unit 509)
520 97 cm shale (like unit 508)
519 1-3 cm very fine sandstone (like unit 509)
518 177 cm shale (like unit 508) w/ pink concr. interval
517 3-4 cm very fine sandstone (like unit 509)
516 72 cm shale (like unit 510)
515 2-3 cm very fine sandstone (like unit 509)
514 8 cm shale with pink nobbly interval
513 2-3 cm very fine sandstone (like unit 509)
512 56 cm shale (like unit 5108)
511 5 cm very fine sandstone (like unit 509)
510 29 cm slightly calc., slightly silty shale
509 5 cm very fine sandstone
508 528 cm slightly calcareous, slightly silty shale with nobbly concretionary intervals (pinkish weathering)
507 10 cm very fine sandstone with shale
506 125 cm shale (like unit 496)
505 2-3 cm very fine sandstone (like unit 501)
504 35 cm shale (like unit 496)
503 4 cm calcareous silty shale (brown weathering) sandy mudstone
502 187 cm shale (like unit 496)

540-660 m

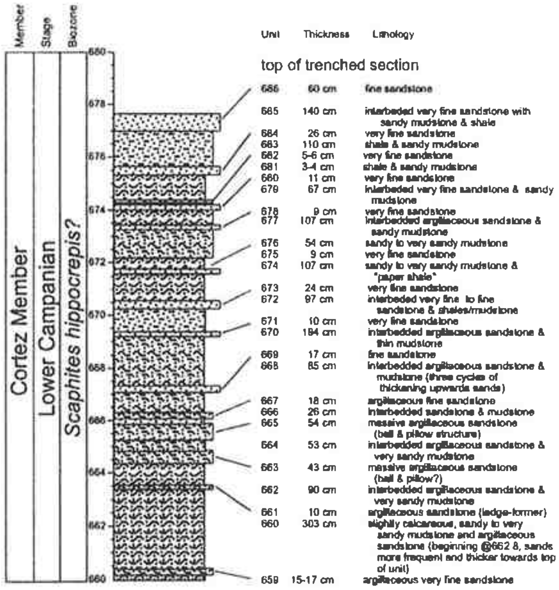


Unit	Thickness	Lithology
632	870 cm	slightly calcareous sandy shale to sandy mudstone (like unit 617)
631	4 cm	bentonite
630	2 cm	sandy shale
629	5 cm	concretion horizon
628	207 cm	slightly calcareous sandy shale w/ss
627	4-5 cm	shaley sandstone
626	173 cm	slightly calcareous sandy shale with pinkish concretions & ss
625	23 cm	interbedded sandy shale & very fine sandstones
624	158 cm	slightly calcareous sandy shale with pinkish concretions & ss
623	5 cm	pinkish sandy calcareous shale
622	2-3 cm	very fine sandstone (like 509)
621	10 cm	claystone
620	3-4 cm	shaley sandstone (like 563)
619	417 cm	slightly calcareous sandy shale to sandy mudstone (like unit 617)
618	10 cm	shaley sandstone
617	360 cm	slightly calcareous sandy mudstone to sandy shale with ss
616	4-5 cm	shaley sandstone (like unit 509)
615	71 cm	slightly calcareous sandy shale
614	4 cm	sandy calcareous shale (like unit 527)
613	1510 cm	slightly calcareous sandy shale with pinkish nobbly intervals & sep. concretion horizon
612	4 cm	pinkish sandy calcareous shale
611	79 cm	slightly calcareous sandy shale (like unit 584)
610	45 cm	interbedded sandy shale & shaley sandstone
609	513 cm	slightly calcareous sandy shale (like unit 605)
608	4-5 cm	shaley sandstone (like unit 563)
607	144 cm	slightly calcareous sandy shale (like 605)
606	2-3 cm	very fine sandstone (like unit unit 509)
605	1363 cm	slightly calc. sandy shale (like unit 584)
604	3-20 cm	laminated dolomitic mudstone, fossiliferous
603	3 cm	bentonite
602	607 cm	sandy shale (like unit 584)
601	4 cm	sandy calcareous shale (like unit 527) pinkish



Unit	Thickness	Lithology
658	68 cm	slightly calcareous sandy to very sandy mudstone
657	5-8 cm	shaley sandstone to argillaceous sandstone
656	115 cm	interbedded very sandy mudstone and argillaceous sandstone
655	138 cm	very sandy mudstone to argillaceous sandstone
654	991 cm	sandy to very sandy mudstone with numerous beds of argillaceous very fine sandstone (infrequent sandstone beds 651.5-655 5)
653	4-7 cm	very fine sandstone
652	280 cm	slightly calcareous sandy to very sandy mudstone (like unit 650)
651	8 cm	very fine sandstone
650	1501 cm	slightly calcareous, sandy to very sandy mudstone
649	5-8 cm	concretionary very fine sandstone
648	554 cm	slightly calcareous, sandy to very sandy mudstone (with several sandy concretion horizons)
647	4-5 cm	shaley sandstone
646	11 cm	slightly calcareous, sandy to very sandy mudstone/shale
645	3-4 cm	shaley sandstone
644	33 cm	interbedded argillaceous sandstone & sandy mudstone/shale
643	54 cm	interbedded shaley sandstone & sandy mudstone/shale
642	182 cm	slightly calcareous, sandy to very sandy mudstone/shale (like 637)
641	61 cm	argillaceous sandstone
640	711 cm	slightly calcareous sandy mudstone to sandy shale with very sandy to argillaceous sandstone intervals in lower 3 m
639	9-21 cm	micritic concretion interval
638	131 cm	slightly calcareous sandy mudstone to sandy shale (like 635)
637	142 cm	slightly calcareous sandy to very sandy mudstone/shale
636	9 cm	concretionary argillaceous sandstone
635	204 cm	slightly calcareous sandy mudstone to sandy shale
634	47 cm	sandy bentonitic mudstone
633	35 cm	bentonite
632	870 cm	slightly calcareous sandy shale to sandy mudstone (like unit 617) with numerous thin sandstone beds

660-680 m



Mancos Shale/Point Lookout Sandstone contact at 682 m (see Wright-Dunbar et al., this guidebook)