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CRETACEOUS STRATIGRAPHY AND BIOSTRATIGRAPHY, COOKE'S RANGE, LUNA COUNTY, NEW MEXICO

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Abstract—Cretaceous strata in the Cooke's Range pertain to the Sarten and Mancos formations. The Sarten Formation is at least 107 m of sandstone, siltstone and minor conglomerate and limestone that disconformably overlies the Lower Permian Abo Formation. The Mancos Formation (formerly Colorado Shale) is as much as 64 m of siltstone, shale, limestone and minor sandstone that disconformably overlies the Sarten Formation. Three intervals in the Sarten Formation produce marine mollusc fossils. The lowest interval, about 15 m above the base, is equivalent to the late Albian Duck Creek Formation of Texas. The middle interval is latest Albian, and the youngest Sarten assemblage, from the upper 2 m of the formation, includes taxa of early Cenomanian age, equivalent to the Del Rio-Buda sequence of Cerro de Cristo Rey and Texas. The overlying Mancos Formation contains late Cenomanian-early Turonian ammonites, bivalves and selachian teeth indicating close correlation with the Greenhorn Limestone of the Western Interior. The Sarten and Mancos also contain moderately diverse microfossil (foraminiferan and ostracode) faunas.

INTRODUCTION

Although the presence of Cretaceous strata in the Cooke's Range of Luna County, New Mexico (Fig. 1) was recognized as long ago as 1916, only in recent years have meaningful stratigraphic, sedimentologic and paleontologic observations been made of these strata. Recent publication of these observations (Cobban and Hook, 1981; Hook and Cobban, 1981; Hyde, 1984; Mack et al., 1986; Cobban, 1987; Mack, 1987a, b) has greatly improved our knowledge of the Cretaceous strata of the Cooke's Range. Here, we add new information based on a preliminary lithostratigraphic and biostratigraphic study of the Cretaceous strata in the Cooke's Range conducted in 1987 and 1988. All fossils referred to in this article are part of the collection of the Department of Geology, University of New Mexico, Albuquerque.

PREVIOUS STUDIES

Darton (in Darton and Burchard, 1911, p. 536) mentioned "about 200 feet [61 m]" of "Cretaceous sandstone" at Fluorite Ridge just south of the Cooke's Range. According to Darton, these strata contained "fossils of the Washita group of the Comanche Series in upper beds." Darton (1916, p. 43) subsequently coined the name Sarten Sandstone for these strata and equivalent rocks in the Cooke's Range. He took the name from Sarten Ridge ("Sarten" is Spanish for fryingpan or skillet) in the Cooke's Range, a prominent north-south-trending ridge now termed Rattlesnake Ridge on U.S. Geological Survey topographic maps. Darton (1916, p. 43) described the Sarten Sandstone in the Cooke's Range as about 91 m of "light-gray, massive sandstone, most of it quartzitic or very hard . . . at the base there is more or less conglomerate." Darton (1916, pp. 43–44) also reported the following fossil invertebrates from a locality "about a mile north of Fryingpan Spring, where limy beds [are present] not far below the middle of the formation": *Cardita belviderensis, Cardium kansasense, Protocardia texana, P. quadrans, Tapes belviderensis, Turritella* aff. *T. seriatimgranulata, Ostrea* sp., *Nucula* sp., *Trigonia* sp., *Lunatia* sp., *Cyprimeria* sp. and *Anchura* sp. T. W. Stanton identified these fossils, and Darton (1916, p. 44) reported Stanton's opinion "that they represent the forms of the Washita group of the Comanche series." Darton (1916, pp. 44–45) further described about 61 m of Colorado Shale above the Sarten Sandstone in the Cooke's Range. He listed some of the "numerous fossils [that] occur in the Colorado shale at all outcrops" (Darton, 1916, p. 45) and assigned them to the "Benton fauna." Darton (1917, p. 6) essentially repeated the observations of his earlier article except that, in a regional correlation chart, Darton (1917, fig. 3) indicated tentatively that the Sarten Sandstone is older than the Beartooth Sandstone of the Silver City area.

After the work of Darton, no new information on the Cretaceous strata in the Cooke's Range appeared in print for nearly 40 years. However, during that time, several authors commented on the age and correlation of Darton's Sarten Sandstone. Thus, for example, Adkins (1932, p. 281; also see Bates, 1942, p. 50–51) stated that the Sarten fauna "is a Fredericksburg fauna, and most resembles the Kiowa and Belvidere faunas of Kansas." And, Lasky (1938, p. 537; 1947, p. 24) noted that, although Darton believed that the Corbett Sandstone of the Little Hatchet Mountains was a correlative of the Sarten, the Corbett is of "Trinity" age, and thus older than the Sarten. Cobban and Reeside (1952, pl. 1) advocated the Kiamichi (late Albian) equivalence of the Sarten and also correlated it with the Beartooth Quartzite of the Silver City area (also see Dane and Bachman, 1957, p. 98).

Jicha (1954, pl. 1) mapped the distribution of the Sarten Sandstone and Colorado Shale in the Cooke's Peak area (Fig. 2). His comments on the Sarten Sandstone (p. 26) were little more than a recitation of the information provided earlier by Darton (1916). However, in describing the Colorado Shale near Cooke's Peak, Jicha (1954, p. 27) did note that "about 30 feet of slabby sandstone appears about 75 feet above the base of the formation." Jicha (1954) listed fossils collected from the Colorado Shale at two localities and noted that J. B. Reeside, Jr., who identified most of the fossils, considered them to indicate a horizon equivalent to the Greenhorn Limestone.

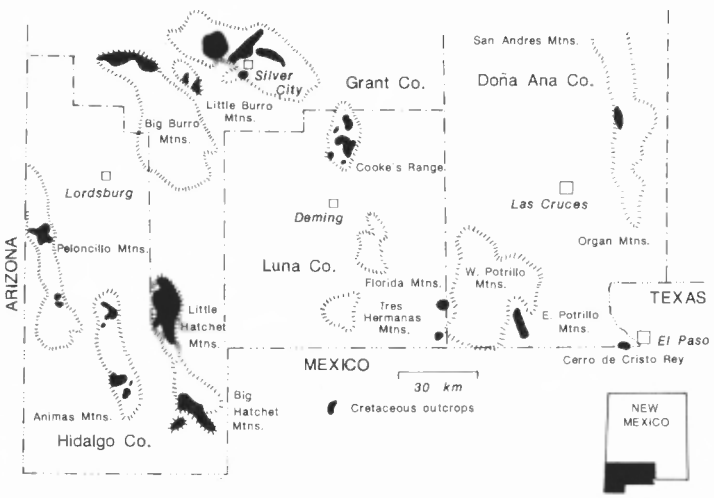


FIGURE 1. Map of southwestern New Mexico showing the distribution of Cretaceous strata and the Cretaceous outcrops in the Cooke's Range discussed in this article (after Hyde, 1984).

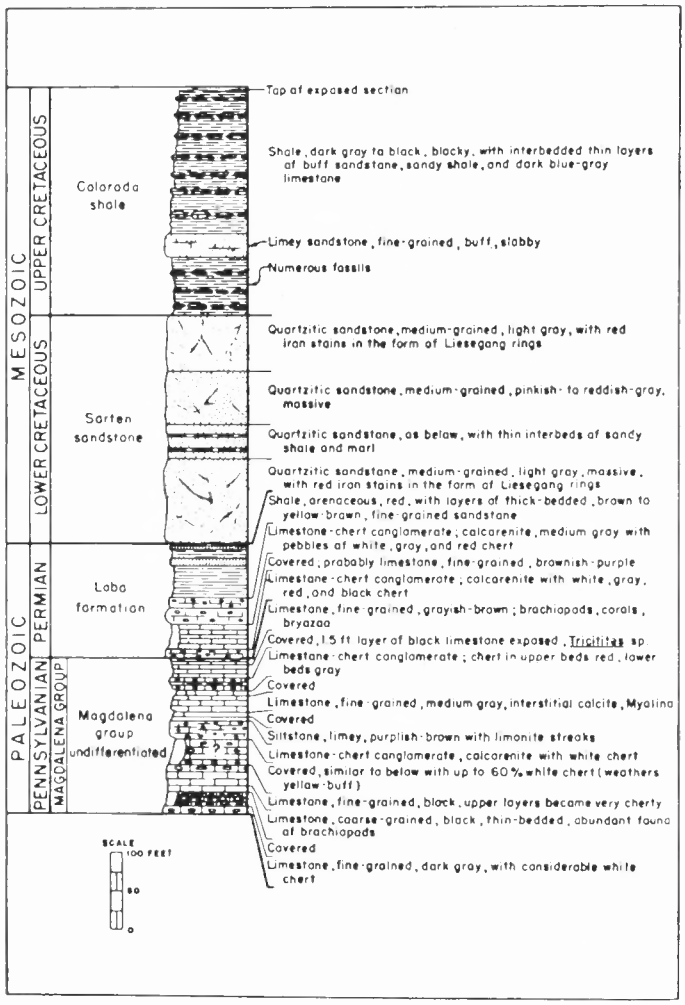


FIGURE 2. Summary stratigraphic section of Cretaceous rocks and some underlying strata in the Cooke's Range (from Jicha, 1954, fig. 3). Note Jicha's use of "Lobo Formation" for strata now assigned to the Abo Formation.

Elston (1957, p. 9) used the term Sarten-Beartooth Quartzite (or Formation) and reported its thickness as about 85 m north of the Cooke's Range in sec. 10, T18S, R11W, Grant County. In a road log from Deming to Cooke's Peak, Kottlowski and Trice (1958, p. 33–34) briefly described and illustrated the Sarten-Colorado contact near Cooke's Peak in sec. 30, T20S, R8W. Kottlowski (1963, p. 76) mentioned "about 600 feet" of Cretaceous strata near Cooke's Peak that he assigned to the Sarten Sandstone and Colorado Shale. Seager (1981, p. 33, sheet 1) applied the term "Sarten-Dakota" to strata containing Albian invertebrate fossils in the southern San Andres Mountains.

Hook and Cobban (1981) described Cenomanian-Turonian strata and fossils of what they termed the Bridge Creek Limestone Member of the Colorado Formation at Shale Spring near Cooke's Peak and near Rattlesnake Ridge. Cobban and Hook (1981) described the new ammonite *Neostlingoceras kottlowskii* from the Colorado Formation in the Cooke's Range and also listed other fossils from various horizons in the Colorado Formation. Clemons (1982) mapped the distribution of the Sarten and Colorado formations on the Massacre Peak quadrangle in the southern Cooke's Range.

Hyde (1984) undertook a sedimentologic and stratigraphic study of the Sarten Sandstone in the Cooke's Range and the southern San Andres Mountains. Mack et al. (1986; also see Mack, 1987a, b) summarized much recent work on the Sarten Sandstone in the Cooke's Range. They indicated an Albian-Cenomanian age for the Sarten, correlating it with the Beartooth Formation in the Silver City area and the Muleros through Buda formations at Cerro de Cristo Rey near El Paso. Mack et al. (1986, p. 315) also noted that the Sarten Formation (not Sandstone, as used by previous workers) "is composed of quartz sandstone and dark gray shale 97 to 227 m thick." Furthermore, they also (p. 326) stated that "sediment transport [of the Sarten] was probably southeast" and that three regressive beach cycles could be recognized in the Sarten Formation.

Cobban (1987) recently described and illustrated ammonites and listed other invertebrates from three stratigraphic levels in the Sarten Formation. Cobban (1987) assigned a middle late Albian age to the lowest of these horizons and correlated it with the Smeltertown Formation at Cerro de Cristo Rey and the Duck Creek Formation of northern Texas. An overlying fossiliferous level was correlated with late Albian post-Duck Creek units in Texas. The youngest fauna Cobban (1987) described from the Sarten Formation contains ammonites and other molluscs indicating correlation with the Buda Limestone (early Cenomanian) of Texas. Mack et al. (1988) present the most recent interpretation of Cretaceous sedimentation in the Cooke's Range.

STRATIGRAPHY

Previous workers have recognized two rock-stratigraphic units of Cretaceous age in the Cooke's Range: Sarten Formation (or Sandstone) and Colorado Formation (or Shale). Here we discuss the lithostratigraphy of these two units and comment briefly on the units immediately above and below them. Our discussion is based on a review of previous work and on seven stratigraphic sections we measured in the Cooke's Range (Figs. 3, 4).

Abo Formation

Red beds that underlie the Cretaceous strata in the Cooke's Range originally were assigned to the Lobo Formation by Darton (1916). In so doing, Darton (1916) equated these red beds with somewhat similar strata in the Lobo Draw-Capitol Dome area of the northern Florida Mountains, 40 km to the south. There, the type Lobo Formation overlies Ordovician strata (Montoya Formation) and is overlain by Eocene-Oligocene volcaniclastic rocks of the Rubio Peak Formation (e.g., Clemons, 1984). Other than some paleomagnetic data that may indicate a Paleocene or Eocene age (Lemley, 1982), no direct evidence of the age of the type Lobo Formation is known, and it has been assigned ages ranging from Permian to Eocene by various workers (see review in Clemons, 1984).

In the Cooke's Range, the strata Darton (1916) termed Lobo were correlated with the Abo Formation by Jicha (1954), Kottlowski (1958) and Lemley (1982) based on their lithologic similarity and similar stratigraphic position (they immediately overlie the Pennsylvanian Magdalena Group) to the Abo Formation in other parts of southern New Mexico. Kottlowski (1963) first applied the name Abo to these strata, dropping Darton's (1916) use of Lobo in the Cooke's Range, a decision upheld in recent mapping (Clemons, 1982) and sedimentological studies (Mack and James, 1986).

We measured as much as 27 m of Abo Formation in the Cooke's Range and found it to consist of four lithologies (in decreasing abundance): limestone-cobble conglomerate, grayish red/dark reddish brown siltstone and claystone with numerous limestone nodules (calcretes?), medium gray micritic limestone (Fig. 5B–C) and trough-crossbedded litharenite. These strata are very similar to strata assigned by Jones et al. (1967) to the Abo Formation in the Santa Rita area. They also closely resemble the lower part of the Abo Formation in the Sacramento Mountains of Otero County (e.g., Delgado, 1977a, b; Speer, 1983). The Early Permian (Wolfcampian) age of most of the Abo Formation is well established.

Sarten Formation

Most of the Cretaceous strata exposed in the Cooke's Range pertain to the Sarten Formation (Fig. 5A). We measured approximately 107 m of Sarten Formation in the Cooke's Range (Fig. 4, sections C and I), of which 41% is sandstone, 30% is sandy siltstone, 17% is silty sandstone, 9% is siltstone, 2% is conglomerate and 1% is limestone. Colors of these strata are dominantly gray, brown and yellowish orange. Sand-

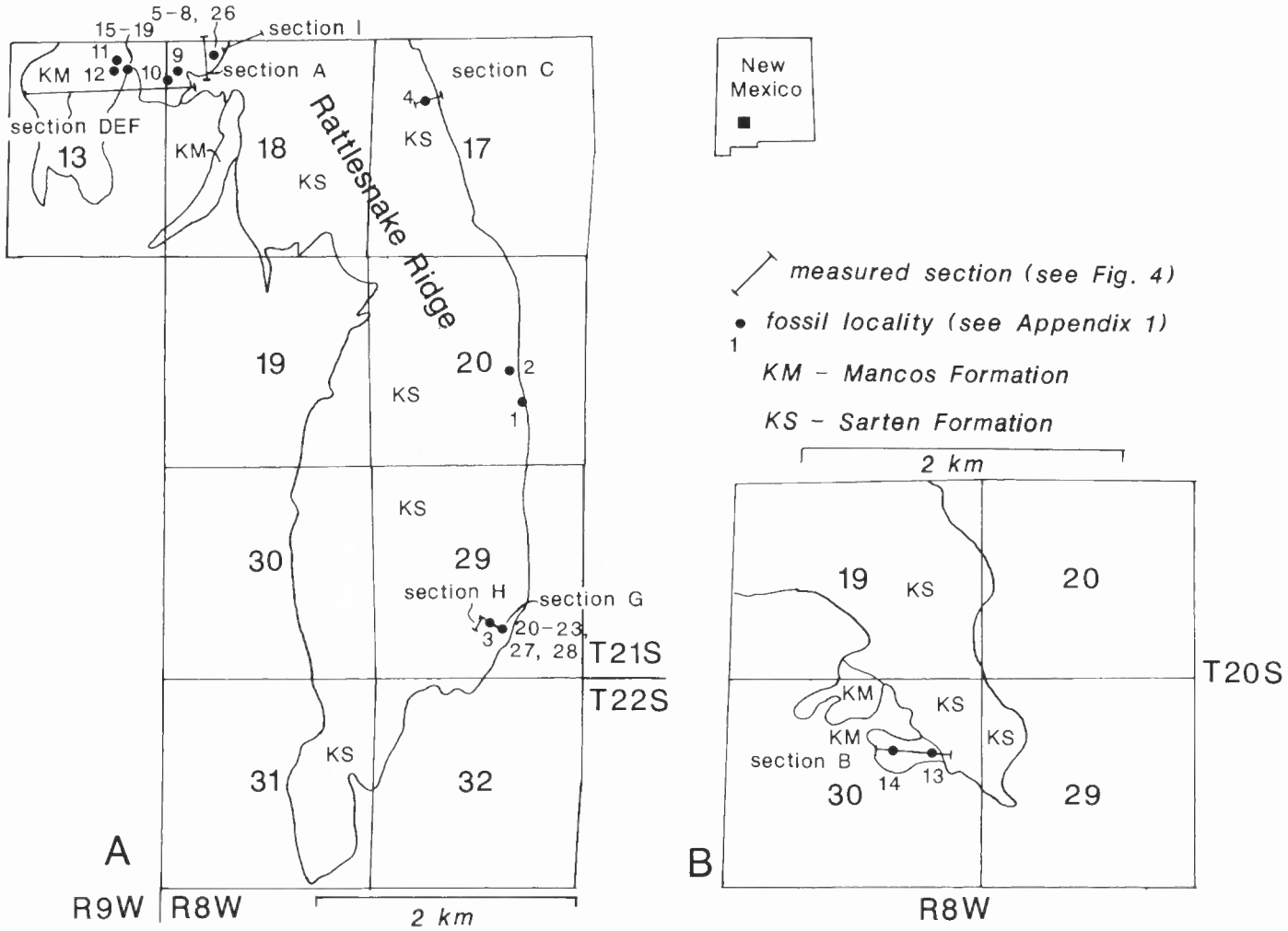


FIGURE 3. Locations of measured stratigraphic sections (Fig. 4, Appendix 2) and UNM fossil localities (Appendix 1) in Cretaceous strata in the Cooke's Range. A, Rattlesnake Ridge area (geology after Clemons, 1982). B, Shale Spring area (geology after Jicha, 1954).

stones of the Sarten Formation are mostly trough or planar-crossbedded, fine- to medium-grained quartzarenites. Siltstones are usually bioturbated to massive. The rare conglomerate is composed of chert, quartzite and lithic pebbles. The limestone is fossiliferous, micritic and nodular.

The base of the Sarten Formation in the Cooke's Range is a profound unconformity that represents about 150 million years. Putative Lower Permian (Wolfcampian) strata of the Abo Formation underlie strata of the Sarten that contain Early Cretaceous (late Albian) fossils about 15 m above the Abo-Sarten contact. Furthermore, some of the strata adjoining the Abo-Sarten contact differ lithologically from one section to the next, a feature often seen at major unconformities. Thus, in section G (Fig. 4), crossbedded, medium-grained quartzose sandstone of the Sarten Formation overlies a thick (~4 m) limestone-cobble conglomerate of the Abo Formation. However, in section C (Fig. 4), bioturbated-to-laminar, sandy siltstone of the Sarten rests on a thin (<2 m) limestone-cobble conglomerate of the Abo Formation. Furthermore, correlation of sections C and G (Fig. 4) based on lithology and the occurrence of late Albian fossils suggests there may be as much as 9 m of relief on the Sarten-Abo contact over a distance of about 4.25 km.

The lower 12 to 22 m of the Sarten Formation are dominated by crossbedded sandstone and generally massive siltstone devoid of fossils except for some fossil wood fragments. Above these strata is an interval approximately 11 m thick of fossiliferous marine sandstone, siltstone, shale and limestone (Fig. 4, section G, units 6–21; Fig. 5, D–E). Fossil localities north of Fryingpan Spring (UNM localities 1356, 1357) produce late Albian invertebrates from the same type of nodular limestone as unit 8 of section G (Figs. 4, 5 E–F). However, these localities are on colluviated fault blocks and cannot be located stratigraphically in section C (Fig. 4). Clearly, these limestones are not present in the lower 22 m (units 9–14) of the Sarten Formation at section C. We believe the covered interval above these strata (unit 15 of section C) conceals the fossiliferous marine strata, and thus correlates sections G and C as shown in Figure 4.

Above these marine fossiliferous strata are another 16 m or so of unfossiliferous crossbedded and bioturbated sandstone (Fig. 4, units 16–18 of section C). The overlying, bioturbated siltstone contains marine invertebrate fossils (UNM locality 1359); this is the same fossiliferous horizon near the middle of the Sarten that was collected by Darton (1916).

The granodiorite porphyry sill above this interval in section C marks a gap in our stratigraphic sections of the Sarten Formation. Sections C and I cannot be matched with confidence because of faulting along Rattlesnake Ridge (Clemons, 1982, cross section A-A'). It is possible that unit 6 of section I is equivalent to unit 19 of section C (Fig. 4). If this correlation is accepted, overlying strata of the Sarten consist of approximately 32 m of fluvial, crossbedded and laminar sandstone (Fig. 4, section I, units 7–15). However, if this correlation is accepted there is a significant discrepancy between the apparent thickness of the Sarten Formation reported here (± 100 m) and that reported by Hyde (1984; also see Mack et al., 1986) from a section measured in secs. 7 and 18, T21S, R8W, about 1.2 km north of our section. Hyde (1984, p. 44) assigned the Sarten Formation a thickness of 227.2 m in this area. A

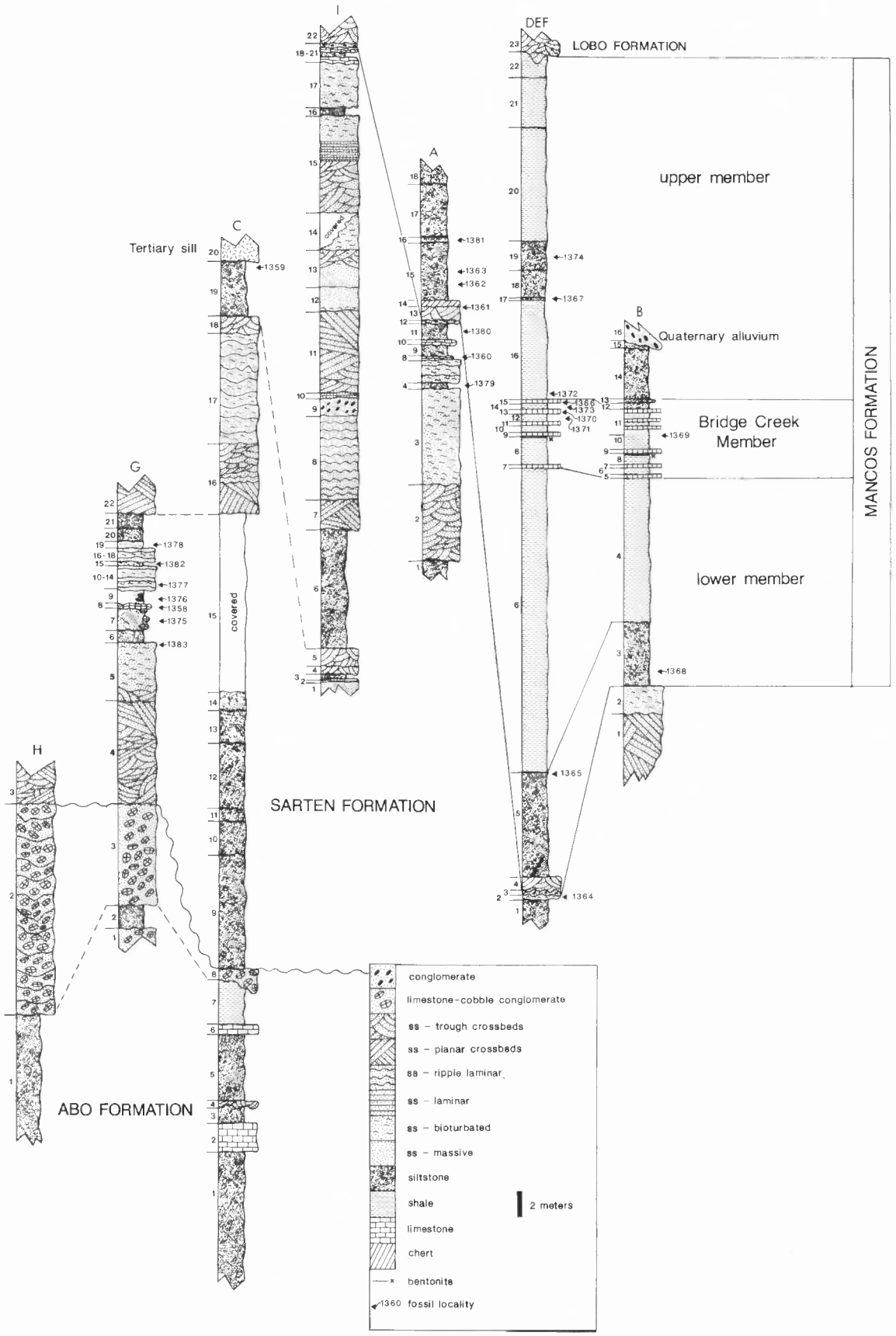


FIGURE 4. Measured stratigraphic sections of Cretaceous rocks in the Cooke's Range. See Figure 3 and Appendix 2 for locations and descriptions of lithologies in measured sections.

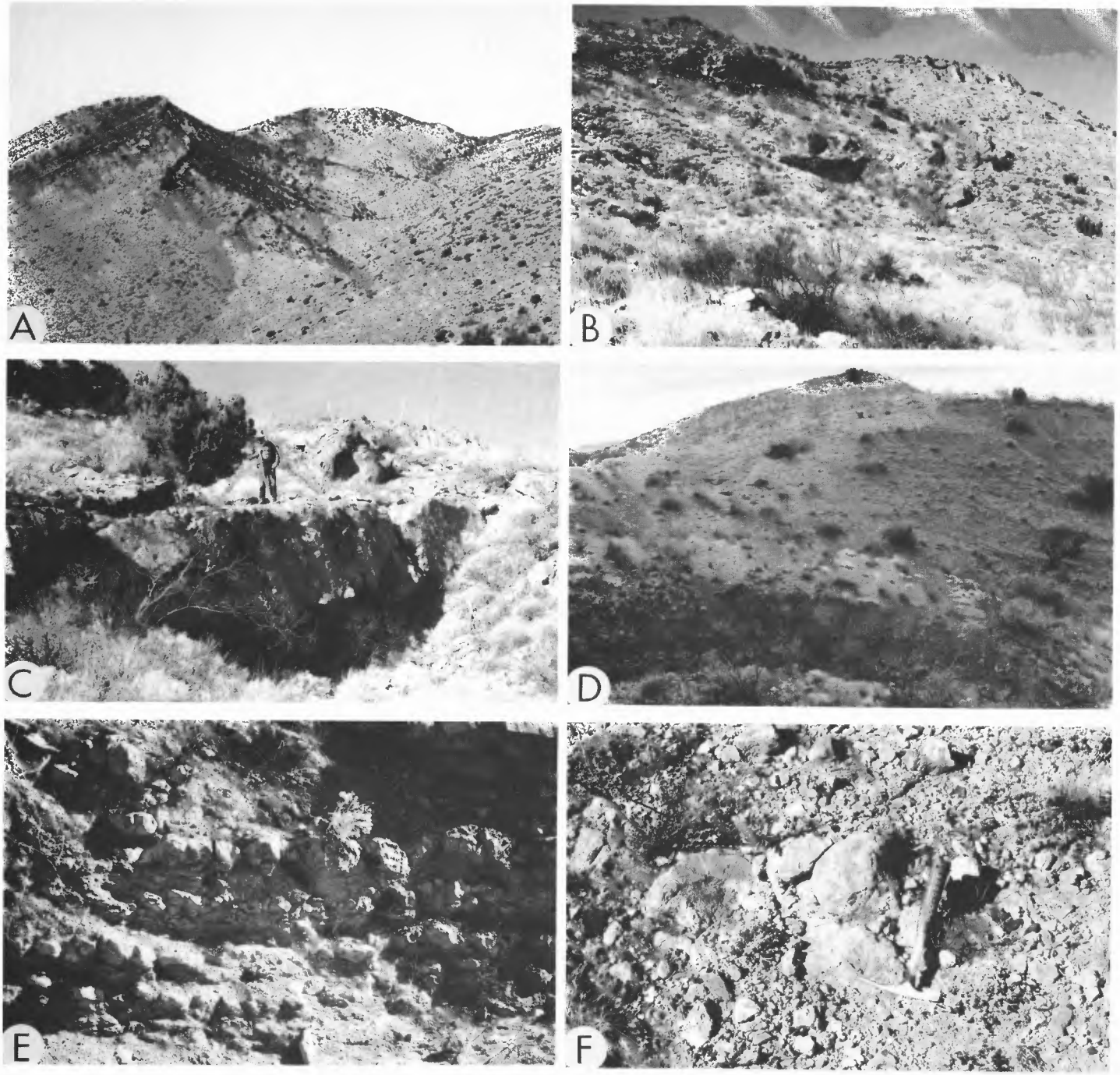


FIGURE 5. Photographs of Paleozoic and Lower Cretaceous (Albian) strata in the Cooke's Range. A, View of northern portion of Rattlesnake Ridge showing typical, resistant Sarten Formation (KS) above Abo Formation (PA) and older, Paleozoic limestones (Pl: Magdalena Group and Lake Valley Formation). B, View of section C on east side of Rattlesnake Ridge showing Abo limestone cliff (A), lower siltstone-dominated interval of the Sarten Formation (s) and overlying sandstone cliffs of the Sarten (c). C, Close-up of Abo limestone cliff shown in B. D, Overview of section G. Note interbedded nodular limestones and siltstones of lower part of Sarten Formation in arroyo cut in foreground. E, Close-up of interbedded nodular limestones and siltstones of G. F, Nodular limestones of lower part of Sarten Formation at UNM locality 1357 north of Fryingpan Spring.

comparison of her section with our sections C and I (Fig. 4; Appendix 2) indicates most of the discrepancy occurs above the stratigraphic level of the sill that tops our section C (Fig. 4). The shale intervals and much of the conglomeratic sandstone and sandstone in the upper two-thirds of Hyde's (1984) section are not present in our section I. Thus, our section I would only represent the uppermost Sarten and the tentative correlation of unit 6 of section I with unit 19 of section C would be incorrect. However, we believe that in measuring the Sarten down the dip slope on the west flank of Rattlesnake Ridge, Hyde (1984) exaggerated the thickness of some units in a much faulted and colluviated area. Indeed, G. H. Mack (written commun. 1988) has re-measured Hyde's section and found the Sarten to be 120 m thick (also see Mack et al., 1988).

The presence of horizontal *Ophiomorpha* and other ichnofossils of the *Cruziana* ichnofacies at the top of unit 15 in section I marks the base of a distinctive uppermost stratigraphic unit of the Sarten Formation. The 5-to-6-m-thick interval of bioturbated siltstone and sandstone and fossiliferous limestone nodules above this level completes

the Sarten section. The scour surface at the base of the overlying sandstone/conglomerate (Fig. 3, units 12–13 of section A and units 3–4 of section DEF) marks the base of the overlying Mancos Formation.

Mancos Formation

Hayden (1876) first used the term Colorado Group to include his Fort Benton, Niobrara and Fort Pierre (or numbers 2, 3 and 4) divisions of the Upper Cretaceous strata in the Western Interior. White (1878) restricted use of Colorado Group to the Fort Benton and Niobrara and their correlatives, and it is in this form that Colorado Group was used subsequently. However, during the past century the term has generally been abandoned in favor of more precise, localized terminology. Thus, in the San Juan and Raton basins of northern New Mexico, the terms Mancos, Graneros, Greenhorn, Carlile and Niobrara long ago supplanted use of Colorado Group (Rankin, 1944 was one of the last to use the latter term). Yet, despite this, in southwestern New Mexico the term Colorado Shale (or Formation), first used in this area by Paige (1916), continues to be used in the Cooke's Range (e.g., Hook and Cobban, 1981; Clemons, 1982), the Big Burro Mountains (e.g., Hewitt, 1959) and the Santa Rita-Silver City area (e.g., Jones et al., 1967; Chafetz, 1982). Indeed, only one recent worker, Molenaar (1983, p. 213), has advocated replacing the term Colorado Shale northwest of Lordsburg with the term Mancos Shale and related terminology of west-central New Mexico (Hook et al., 1983; McLellan et al., 1983). We, too, advocate replacing the term Colorado (Shale) Formation with Mancos Formation in southwestern New Mexico; thus, strata in the Cooke's Range formerly termed Colorado are here referred to as Mancos.

In the Cooke's Range we studied two outcrops of the Mancos Formation, one at Shale Spring and the other southwest of Rattlesnake Ridge (Fig. 3). Here, we measured a maximum of 68.5 m of Mancos (Fig. 4) that we divide into four lithostratigraphic units that comprise three members:

1. A basal sandstone and conglomerate that is about 1.3 thick (Fig. 4, units 12 and 13 of section A, units 3 and 4 of section D and units 21 and 22 of section I; Fig. 6A, C). The lower 0.2–0.3 m of this unit is a pebbly sandstone/conglomerate of chert, quartzite and limestone clasts. The ~1.1 m of yellowish brown/yellowish orange sandstone above this conglomerate is very fine- to medium-grained, trough-cross-bedded quartzarenite. Its top surface contains numerous casts and molds of ammonite shells (UNM locality 1361). Cobban and Hook (1981, p. 24) listed several ammonite taxa and the bivalve *Inoceramus prefragilis* from this basal sandstone unit (USGS locality D10105). This basal sandstone and conglomerate unit of the Mancos Formation is well exposed at the outcrops southwest of Rattlesnake Ridge (Fig. 4, sections I, A and DEF; Fig. 6A, C), but is absent at Shale Spring (Fig. 4, section B; Fig. 6B) where silty shale and siltstone of the Mancos rest directly on bioturbated quartzarenite of the upper Sarten Formation.

2. A relatively thick silty shale/siltstone unit overlies the basal sandstone/conglomerate unit (where present) of the Mancos Formation in the Cooke's Range. This unit (Fig. 4, section DEF, units 5 and 6, section B, units 3 and 4 and section A, units 14–18; Fig. 6F) is as much as 34.5 m of dominantly olive gray silty shale and siltstone. Some shale beds are bentonitic and some localized, nodular limestone beds (e.g., UNM locality 1363 and Cobban and Hook's, 1981 table 2, locality D10186) and thin gray laminated limestone ledges are present. We collected inoceramid bivalves as low as 0.9 m above the base of this unit, which is the majority of the Mancos Formation in the Cooke's Range. This shale and siltstone unit and the underlying conglomerate/sandstone are hereafter referred to as the "lower member" of the Mancos Formation (Fig. 4).

3. A 4.6–5.3-m-thick interval of interbedded gray micritic limestone, gray/olive gray silty shale and siltstone and gray/yellowish orange fossiliferous calcarenite overlies unit 2. Hook and Cobban (1981) termed this interval (Fig. 4, section D, units 7–13 and section B, units 5–13; Fig. 6F) the Bridge Creek Limestone Member of the Colorado Formation. Our stratigraphic observations of this unit confirm those of Hook and Cobban (1981), and we hereafter refer to this unit as the Bridge Creek Member of the Mancos Formation.

4. Above the limestone-dominated unit, we measured more than 27 m of gray and olive gray shale and siltstone that is fossiliferous at some stratigraphic levels. These strata (Fig. 4, section D, units 16–22 and section B, units 14–15) are the youngest Cretaceous marine rocks in the Cooke's Range, and we term them the "upper member" of the Mancos Formation (Fig. 4). They are disconformably overlain by fluvial red beds of the Lobo Formation.

Lobo Formation

Dusky red-purple and grayish red-purple arkosic sandstones and mudrocks are the oldest strata that overlie Cretaceous marine rocks in the Cooke's Range. Clemons (1982) termed these red beds the Starvation Draw Member of the Rubio Peak Formation. However, he subsequently (Clemons and Brown, 1983) recommended abandoning the name Starvation Draw and replacing it with Darton's (1916) term Lobo Formation, even though Darton had originally applied the term Lobo Formation to units beneath the Cretaceous section in the Cooke's Range. Darton's (1916) type section of the Lobo in the northern Florida Mountains is lithologically similar to the outcrops Clemons (1982) mapped as Starvation Draw Member in the southern Cooke's Range. No direct evidence of the age of the Lobo Formation in the Cooke's Range is known. However, regional tectonic reconstructions suggest it may be of Eocene age (e.g., Seager and Mack, 1986). Its contact with underlying strata of the Mancos Formation is an erosional disconformity (Fig. 4).

PALEONTOLOGY OF SARTEN FORMATION

Introduction

Until recently the paleontology and age of the Sarten Formation were known only from the list of Washita-age invertebrates near the middle of the formation reported by Darton (1916, 1917) and repeated by Darton (1928), Jicha (1954) and Zeller (1965). Cobban (1987) described the ammonoids from three fossiliferous levels within the Sarten and presented a faunal list for the uppermost level. He ascertained that the lower part of the Sarten contains late Albian Duck Creek-equivalent ammonoid zones, and the uppermost part is early Cenomanian, about the age of the Buda Limestone. Working independently of Cobban and associates, as part of our continuing regional studies of Albian faunas in New Mexico and adjacent areas, we collected marine fossils from approximately the same three intervals. Study of these fauna corroborates Cobban's age determination for the Sarten and adds new information about their contained taxa.

Collections were made from three intervals within the Sarten Formation (Fig. 4): (1) 14–18 m above the base (UNM localities 1356–1358), (2) 42 m above the base, just below the middle of the formation (UNM locality 1359), and (3) in the upper 2 m (UNM locality 1360), beneath the unconformity that marks the contact of the Sarten with the overlying Mancos Formation. A list of Sarten megafossil-invertebrate taxa identified by previous workers and during this study appears as Table 1. In general, Sarten fossils are fragmentary and poorly preserved, often as unidentifiable molds and steinkerns. Faunas preserved within the Sarten are probably more diverse than is indicated by the list of identified taxa, but do not appear to attain the diversity present within the Albian Washita units of Cerro de Cristo Rey or in the Tucumcari Formation of east-central New Mexico.

Lower Sarten

The lowest occurrence of marine invertebrates in the Sarten Formation is about 14 to 18 m above its base (Fig. 4). This is a bed of gray concretionary limestone, locally containing many quartz sand grains and shell debris (UNM localities 1356, 1357), overlain by fossiliferous sandstone (UNM locality 1358). Fragmentary, weathered steinkerns of large ammonites are the most conspicuous fossils in this limestone. The sandstone contains a few rounded chert and quartzite pebbles and molds of bivalves and gastropods. We collected fragments of *Mortoniceras equidistans*, *M.* aff. *M. leonense* and *Eopachydiscus marcianus* from the limestone. Because these ammonites were fully described and illustrated by Cobban (1987), they will not be discussed here.

One of the most common constituents of this assemblage is specimens

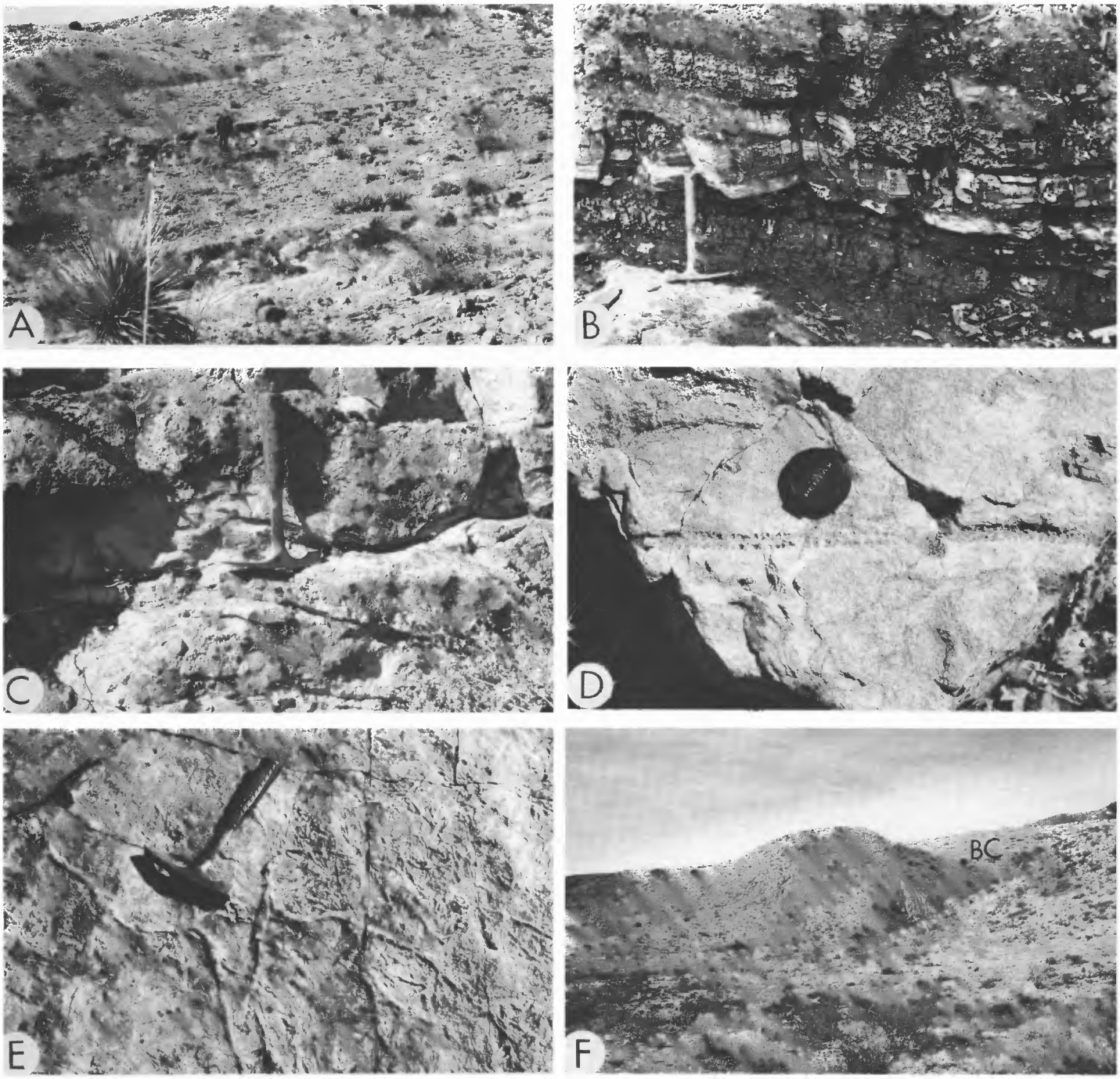


FIGURE 6. Photographs of Lower and Upper Cretaceous strata in the Cooke's Range. A, View of upper part of section A. The man is standing in front of the basal sandstone of the Mancos Formation (units 10–11). B, Siltstone of Mancos Formation (M) on uppermost sandstone of Sarten Formation (S) near section B. C, Units 10 and 11 of section A, basal conglomerate (c) and sandstone (s) of the Mancos Formation. D, *Ophiomorpha* in sandstone of Sarten Formation at top of unit 15, section I. E, *Cruziana*-facies ichnofauna in Sarten Formation near top of unit 2, section B. F, Overview of lower part of Mancos Formation, including Bridge Creek Member (BC) west of Rattlesnake Ridge.

of the large, uniserial foraminiferan *Cribratina texana* (Fig. 8C), some of which attain a length of 8 mm. The occurrence of this wide-ranging species in the Sarten was first noted by Zeller (1965), who used it to correlate the Sarten with the upper part of the Mojado Formation in the Big Hatchet Mountains to the south. *Cribratina texana* also occurs in the Tucumcari Shale (Kietzke, 1985; Kues et al., 1985) and in the interval from the Muleros to basal Anapra Formations at Cerro de Cristo Rey (Böse, 1910; Cornell and LeMone, 1987). We have observed it only in this lowest fossiliferous horizon of the Sarten.

Other constituents of this assemblage include unidentified small (diameter up to 25 mm) solitary corals, bivalves and gastropods (Table 1). Of special interest is a single, incomplete left valve of *Texigryphaea* (Fig. 7 D–F), which represents the westernmost well-documented occurrence of this genus. The specimen is about 42 mm high, has a relatively broad, oval commissure, a small beak and an umbonal angle of inclination slightly greater than 90°. It differs from any texigryphaeas we have seen from the late Albian units at Cerro de Cristo Rey and appears to be closest morphologically to *T. tucumcarii*, the common species of the Tucumcari and Glencairn formations of east-central and northeastern New Mexico.

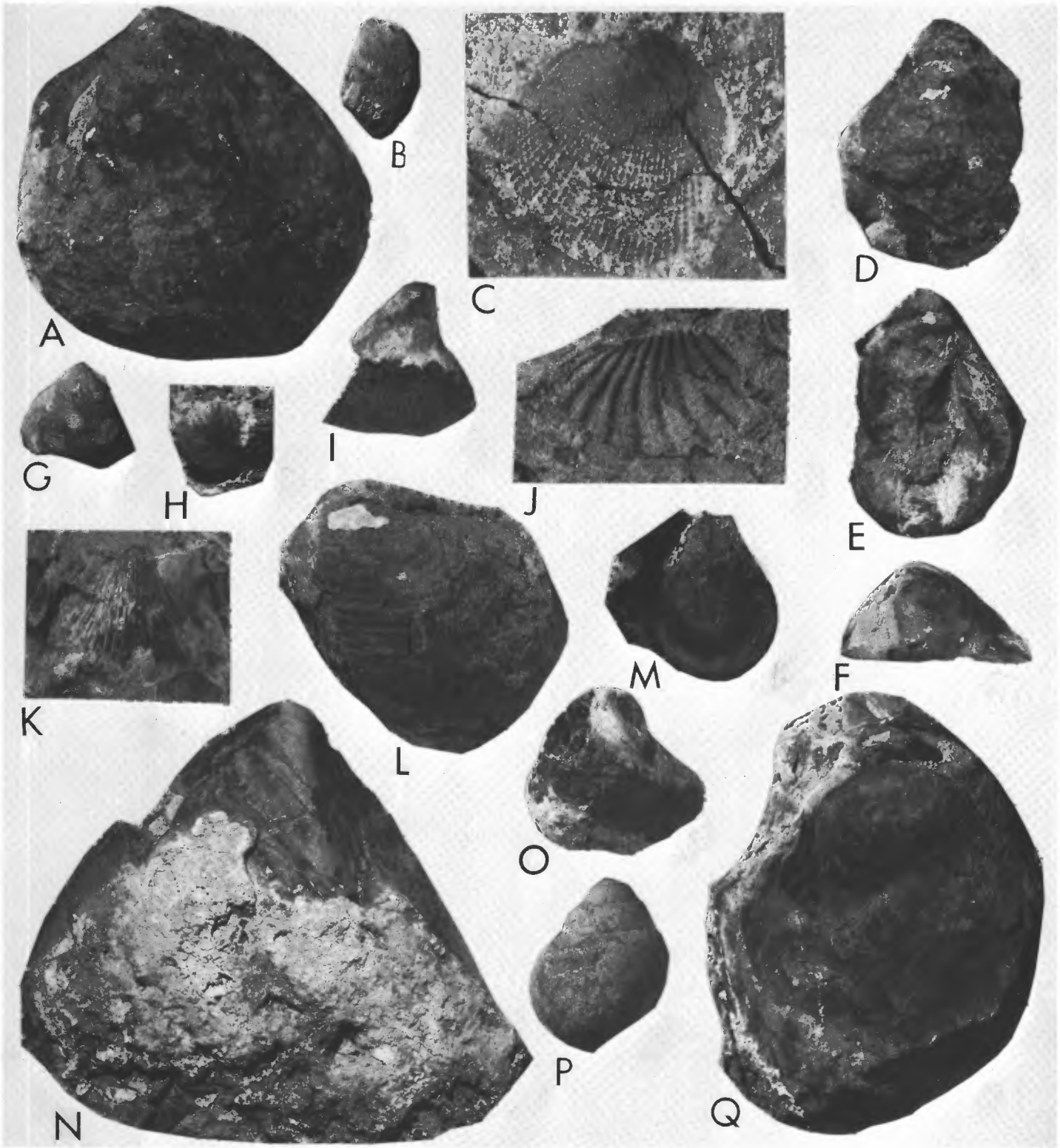


FIGURE 7. Molluscs from the Sarten Formation, Cooke's Range (× 1 unless otherwise indicated). A, *Protocardia* cf. *P. multistriata* (Shumard), weathered steinkern, UNM 10282, lower fauna, UNM locality 1356. B, *Ludbrookia* aff. *L. belviderensis* (Cragin), incomplete left valve, UNM 10287, upper fauna, UNM locality 1360. C, *Pleuriocardia kansasense* (Meek), external mold of right valve, UNM 10289, lower fauna, UNM locality 1356. D–F, *Texigryphaea* sp., external, commissural and umbonal views of left valve, UNM 10276, lower fauna, UNM locality 1358. G, *Protocardia multistriata* (Shumard), incomplete right valve of a small individual, UNM 10286, middle fauna, UNM locality 1359. H, *Anomia* sp., left valve, UNM 10285, middle fauna, UNM locality 1359, 2, I, *Protocardia* cf. *P. filosa* Conrad, incomplete steinkern of left valve, UNM 10284, middle fauna, UNM locality 1359. J, *Scabrotrigonia* cf. *S. emoryi* (Conrad), partial mold of left valve, UNM 10275, middle fauna, UNM locality 1359. K, *Neithea occidentalis* Conrad, partial right valve, UNM 10274, middle fauna, UNM locality 1359. L, *Homomya* cf. *H. budaensis* Shattuck, incomplete steinkern of left valve, UNM 10281, upper fauna, UNM locality 1360. M, *Syncyclonema* sp., right valve, UNM 10288, upper fauna, UNM locality 1360, × 3. N, Q, *Exogyra whitneyi* Böse, upper part of a large left valve (UNM 10280) and right valve view of a smaller, complete, articulated specimen (UNM 10279), both from upper fauna, UNM locality 1360. O, *Exogyra clarki* Shattuck, beak and umbo area of left valve, UNM 10278, upper fauna, UNM locality 1360. P, *Tylostoma harrisi* Whitney, adapertural view of steinkern, UNM 10277, upper fauna, UNM locality 1360.

Several other reports of *Texigryphaea* from southwestern New Mexico require verification. Weise (1982) reported *Texigryphaea* as an important element of the oyster limestone member of the U-Bar Formation (late Aptian) in the Big Hatchet Mountains. However, the earliest undoubted occurrence of the genus in North America is considerably later—the appearance of *T. mucronata* in the Walnut Formation (Fredericksburg Group, late middle Albian) of Texas. Zeller (1965), in his study of the Big Hatchet Mountains, did not find *Texigryphaea* in the U-Bar or in the overlying Mojado Formation. Both Lasky (1947) and Zeller (1970) did note *Gryphaea* from the Mojado of the Little Hatchet Mountains; these may be examples of *Texigryphaea*.

Texigryphaea is present in great abundance throughout the Albian part of the Washita section at Cerro de Cristo Rey, and in most other correlative units to the east. However, with the exception of the one Sarten specimen, and its possible presence in the Big and Little Hatchet Mountains, the genus is unknown west of Cerro de Cristo Rey. It is apparently absent from a thick Lower Cretaceous section (including Fredericksburg strata) in the East Potrillo Mountains, about 47 km west of Cerro de Cristo Rey (Bowers, 1960; Mack 1986). Although the paleontology of Lower Cretaceous formations across southwestern New Mexico has been little studied, what is known suggests that environmental conditions were generally unsuitable for the genus west of Cerro de Cristo Rey.

Other molluscs from the nodular limestone facies include fragments of a large, unidentified oyster, steinkerns of *Protocardia* and *Tylostoma* and fragments of *Neithea* valves. Molds of *Scabrotrigonia* cf. *S. emoryi* and *Turritella* sp. are common in the sandstone unit immediately above the lower fossiliferous limestone. The unusually large steinkern assigned to *Protocardia* cf. *P. multistriata* (Fig. 7A) closely resembles specimens of this species (see Scott, 1986) from the Albian Goodland Formation of Texas (Perkins, 1960, pl. 21, figs. 1, 2) and from the Albian of Mexico (Böse, 1910, pl. 28, figs. 1 and 3). A well-preserved external mold of a small cardiid bivalve (Fig. 7C) was also collected from the sandstone. The right valve is semicircular in shape, with height and length both about 15 mm. Ornamentation consists of many fine radial ribs (about 8–9 ribs/5 mm near the ventral margin) and concentric lirae that are somewhat more widely spaced and a little less sharp than the radial ribs. The radial ribs possess nodes where they cross the concentric ornamentation. Based on valve shape and ornamentation, this specimen appears to be *Pleuriocardia kansasense* (see Scott, 1978). Although best known from the Kiowa Formation of Kansas, this species was reported by Darton (1916, 1917) from the middle part of the Sarten, and tentatively by Zeller (1965) from the Mojado Formation of the Big Hatchet Mountains.

A small (height = 8 mm; length = 7 mm), ovoid, gently convex left valve having a low central beak and a nearly straight hingeline is referred to *Anomia* sp. (Fig. 7H). This specimen is virtually identical to *Anomia* sp. from the upper Greenhorn Limestone of Kansas (see Hattin, 1975, pl. 8, fig. E and pl. 10, fig. D). A larger and rounder form assigned to *Anomia* is present in the Kiowa Formation (Scott, 1970).

Siltstone and shale from units 7, 9, 11, 15 and 19 of section G (Fig. 4) contain a prolific and moderately diverse microfauna of foraminiferans and ostracodes (Table 2). The arenaceous, agglutinated foraminiferan *Cribratina texana* is particularly conspicuous in all units except 19 (UNM locality 1378). The calcareous species *Gavelinella plummerae* (Fig. 12E) is also common in units 7–11 of section G. Other characteristic forms include *Hedbergella delrioensis* (Fig. 12B), a simple planktonic foraminiferan, *Textulariopsis rioensis* (Fig. 12F) and *Triplasia acutocarinata* (Fig. 12G). Ostracodes are present and diverse in units 7 and 9, rare in units 11 and 15 and absent in unit 19. A characteristic ostracode is *Cythereis* aff. *C. nuda* (Fig. 12H).

The rarity and simple morphology of planktonic foraminiferans suggests an Albian age, although most taxa also range into early Cenomanian strata in Texas (Grayson Formation). However, overall similarity of the lower Sarten microfauna is closest to that of other late Albian units like the Tucumcari Shale (Kietzke, 1985) and Glencairn Formation (Kietzke, 1987). Particularly significant is the absence in the lower Sarten of characteristic early Cenomanian foraminiferan taxa like *Rotalipora*.

Middle Sarten

A little below the middle of the Sarten (UNM locality 1359: Fig. 4) marine invertebrates occur in a coarse-grained gray limestone bed that grades into a light brownish-gray quartz sandstone within a sequence of bioturbated siltstone. Dense accumulations of steinkerns, molds and some coarsely recrystallized shell fragments characterize the limestone, locally forming almost a coquina. Because they are poorly preserved, however, few of these fossils can be identified. This is almost certainly the level from which Darton (1916, 1917) collected his assemblage of Sarten fossils, described as coming from limy beds not far from the middle of the formation (see Table 1). This is also the probable level from which Cobban (1987, USGS locality D6833) reported *Mortoniceras* (*Drakeoceras*) sp. and *Engonoceras belviderense*. USGS locality D6833 was stated to be about 24 m above the lowest, nodular-limestone horizon that yielded most of the Sarten ammonites studied by Cobban. This position accords well with our unit 19 of section C, which is about 26 m above the lower nodular limestone (Fig. 4).

We observed only bivalves and gastropods in this middle fossiliferous unit. *Cribratina texana*, so common in the lower Sarten, is absent. A medium-sized (height = 50–60 mm) unidentified species of *Exogyra* is the largest bivalve in this unit; molds of *Scabrotrigonia* valves (Fig. 7J) are also present. Specimens of *Neithea* (Fig. 7K) are characterized by strong, high, rounded ribs on the convex right valve. Many of these are flanked by smaller ribs on one or both sides. This ornamentation is essentially that of *N. occidentalis*, the common pectinid in the Tucumcari and Kowa formations. *Neithea subalpina* and *N. texana*, the most common species in the uppermost Albian units of eastern Texas and Cerro de Cristo Rey, differ in having a simpler ornamentation consisting of single, generally undivided ribs of more or less equal size. *Neithea occidentalis* is present mainly in Fredericksburg to earliest Washita (Kiamichi) strata in Texas (Stanton, 1947), but apparently continued through later Washita units in some parts of New Mexico.

Two species of *Protocardia* occur in this unit. *Protocardia multistriata* is represented by large and small specimens. The illustrated specimen (Fig. 7G), a small individual, possesses more than 70 concentric lirae that are typically broad, relatively flat, and twice as wide as the interspaces between them. Two steinkerns having a high, triangular shape and elevated beaks are assigned tentatively to *P. filosa* (Fig. 7I), mainly on the basis of their shape, as the ornamentation is not preserved. Darton (1916, 1917) recorded *P. quadrans*, a synonym of *P. filosa* (Scott, 1986), in his middle Sarten fauna. Gastropods are represented by steinkerns of *Turritella* and *Tylostoma*.

Upper Sarten

The upper fossiliferous unit is in the top 2 m of the Sarten Formation. It consists of nodular gray limestone, locally containing numerous quartz sand grains and highly recrystallized shell fragments. This is the sandy nodular limestone bed at the top of the Sarten (USGS locality D10104) from which Cobban (1987) obtained an early Cenomanian molluscan fauna.

The most conspicuous fossils in this unit are pieces of medium-sized to large oysters, some with left and right valves articulated. The largest of these remains, indicating a shell more than 150 mm high, are *Exogyra whitneyi* (Fig. 7N, Q). A smaller species, *E. clarki* (Fig. 7O), is also present. It is ornamented with low radial ribs and prominent, closely-spaced growth lamellae, in contrast to small specimens of *E. whitneyi*, which have a relatively smooth shell and low, widely-spaced growth lines. Cobban (1987) noted both species in this interval of the Sarten, and both occur in the Del Rio Formation at Cerro de Cristo Rey.

Pectinid bivalves include *Neithea*, and small, smooth shells of *Syncyclonema* sp., also noted by Cobban (1987) in this interval. *Syncyclonema* sp. (Fig. 7M) has teardrop-shaped valves about 10 mm in height, and possesses small auricles. Ornamentation is limited to fine, obscure concentric lirae. The specimens in our collection differ from *S. inconspicua* from the Pawpaw and Kiowa formations (described and illustrated by Stanton, 1947) in being more narrow and elongate, and having smaller auricles.

A single, incomplete, weakly inflated left valve is about 20 mm high,

TABLE 1. Megafossil invertebrate taxa reported from the lower, middle and upper fossiliferous horizons of the Sarten Formation in the Cooke's Range.

MEGAINVERTEBRATE TAXA	LOWER FAUNA Cobban 1987	LOWER FAUNA This Study	MIDDLE FAUNA Darton, 1916	MIDDLE FAUNA Cobban, 1987	MIDDLE FAUNA This Study	UPPER FAUNA Cobban, 1987	UPPER FAUNA This Study
FORAMINIFERA							
Cribratina texana (Conrad)		x					
ANNELIDA							
Serpula sp.		x					
COELENTERATA							
Solitary corals, unidentified		x					
GASTROPODA							
Anchura sp.			x				
Aporrhaidae?							x
Lunatia sp.			x				
Turritella cf. *T. seriatimgranulata* Roemer			x			x	
Turritella sp.		x	x		x	x	x
Tylostoma harrisi Whitney						x	x
Tylostoma sp.		x			x		
BIVALVIA							
Anomia sp.		x					
Arctica? *compacta* (White)						x	
Cyprimeria sp.			x				
Exogyra clarki Shattuck						x	x
Exogyra whitneyi Böse						x	x
Exogyra? sp.					x		
Flaventia belviderensis (Cragin)			x				
Granocardium (*Criocardium*) *budaense* (Shattuck)						x	
Homomya cf. *H. budaensis* Whitney						x	x
Homomya sp.			x				
Leptosolen sp.			x				
Lima shumardi Shattuck						x	
Ludbrookia belviderensis (Cragin)			x				
Ludbrookia aff. *L. belviderensis* (Cragin)							x
Neithea occidentalis (Cragin)					x		
Neithea texana (Roemer)						x	
Neithea sp.		x					x
Nucula sp.			x				
Ostrea sp.			x				
Ostreidae, indet.		x					
Pleuriocardia kansasense (Meek)		x	x				
Plicatula? sp.		x					
Protocardia cf. *P. filosa* (Conrad)				x		x	
Protocardia multistriata (Shumard)					x		
Protocardia cf. *P. multistriata* (Shumard)		x					
Protocardia texana (Conrad)			x				
Protocardia? sp.						x	
Scabrotrigonia cf. *S. emoryi* (Conrad)		x			x		
Scabrotrigonia sp.						x	
Stearnsia sp.						x	
Syncyclonema sp.						x	x
Texigryphaea sp.		x					
NAUTILOIDEA							
Cymatoceras hilli (Shattuck)							x
Cymatoceras sp.						x	
AMMONOIDEA							
Engonoceras belviderense (Cragin)				x			
Engonoceras sp.	x						
Eopachydiscus marcianus (Shumard)	x	x					
Mantelliceras sp.						x	x
Mortoniceras equidistans (Cragin)	x	x					
Mortoniceras aff. *M. leonense* (Conrad)	x	x					
Mortoniceras (*Drakeoceras*) sp.				x			
Mortoniceras sp.	x						
Turrilites aff. *T. costatus* Lamarck						x	

TABLE 2. Foraminifera and Ostracoda from the Cretaceous strata of the Cooke's Range.

MICROFOSSIL TAXA	UNM LOCALITIES								
	SARTEN							LOWER MANCOS	
	1375	1376	1377	1382	1378	1379	1380	1362	1381
FORAMINIERA									
Acraliammina longa (Tappan)		x							
Ammobaculites goodlandensis Cushman & Alexander	x	x	x						
Bathysiphon sp.	x								
Cribratina texana (Conrad)	x	x	x	x					
Dentalina communis (d'Orbigny)		x	x						
Gavelinella plummerae (Tappan)	x	x	x						
Gumbelina globifera (Reuss)						x		x	
Gumbelina globulosa (Ehrenberg)						x			x
Haplophragmoides oneava (Chapman)	x	x							
Haplophragmoides sp. (large species)	x	x							
?Haplophragmoides sp.						x			
Hedbergella brittonensis Loeblich & Tappan						x	x	x	x
Hedbergella delrioensis (Carsey)			x						
Lagena striatifera Tappan		x							
Lenticulina gaultina (Berthelin)	x	x							
Neobulimina minima Tappan					x				
?Palmala sp.			x						
Pleurostomella nitida Morrow								x	x
Praebulimina spp.							x	x	x
Praeglobotruncana aff. P. stephani (Gandolfi)						?	x	x	x
Reophax deckeri Tappan	x	x							
Reophax minima Tappan					x				
Rotalipora cushmani (Morrow)								x	x
Textulariopsis rioensis (Carsey)	x	x							
Textulariopsis cf. T. washitensis (Carsey)		x							
Triplasia acutocarinata (Alexander & Smith)	x			x					
Trochammina depressa Lozo					x				
Trochammina aff. T. krumensis Tappan	x			x					
OSTRACODA									
Centrocythere ?concentrica (Reuss)		x							
Cythereis aff. C. nuda (Jones & Hinds)	x	x	x	x					
Cytherella obovata (Roemer)	x								
Cytheridea sp.		x							
Cytheropteron sp.		x	x						
Eocytheropteron sp.		x							
Isocythereis mahonae (Alexander)		x							
Shuleridea oliverensis (Alexander)	x	x	x	x					

and displays strong, somewhat nodose radial ribs separated by interspaces of about equal width, and a strongly prosogyrous beak. This specimen (Fig. 7B) is similar to *Ludbrookia belviderensis,* from the Kiowa and Tucumcari formations, but has somewhat finer and more closely-spaced radial ornamentation. Better specimens that show the shape of a complete valve and the nature of the hinge teeth are required for more precise identification of this distinctive bivalve. A large *Homomya* (cf. *H. budaensis:* Fig. 7L) also occurs in this assemblage. Other bivalves noted in the upper Sarten fauna are listed in Table 1. Gastropod steinkerns, mainly *Turritella* and *Tylostoma harrisi* Whitney (Fig. 7P), a species described from the Buda Limestone of Texas by Whitney (1911), are moderately common in this assemblage. One high-spired steinkern (Aporrhaidae?) possesses weathered remnants of the shell, which display strong, gently curved transverse costae extending from the upper to the lower sutures.

Ammonites are limited to fragments of the strongly-ribbed *Mantelliceras* sp. of Cobban (1987). One incomplete nautiloid (Fig. 8A–B) was collected. The fragment is 87 mm long and 45 mm high, suggesting a maximum whorl diameter of about 110 mm. The internal structures exposed on this specimen include gently curved septa and a siphuncle situated a little below the middle of each septum. The whorl is rather strongly arched across the venter, and the septa are relatively closely spaced and characterized by a broad, gently curved lateral lobe. The outer shell, which is well preserved and not significantly weathered on one side of the specimen, is smooth and displays no indication of ribbing. We refer this specimen to *Cymatoceras hilli* (Shattuck) based on whorl profile, gently curved sutures and apparent lack of external ornamentation. In Texas this species is limited to the Fort Worth-Buda interval (Miller and Harris, 1945). *Paracymatoceras texanum,* which has about the same range, is more laterally compressed, possesses strongly curved lateral lobes and is ornamented with flat ribs separated by narrow, incised interspaces. *Cymatoceras loeblichi* (Ft. Worth to Grayson interval in Texas) is more inflated, has low rounded ribs and possesses sutures that are less sinuous than those of *C. hilli.*

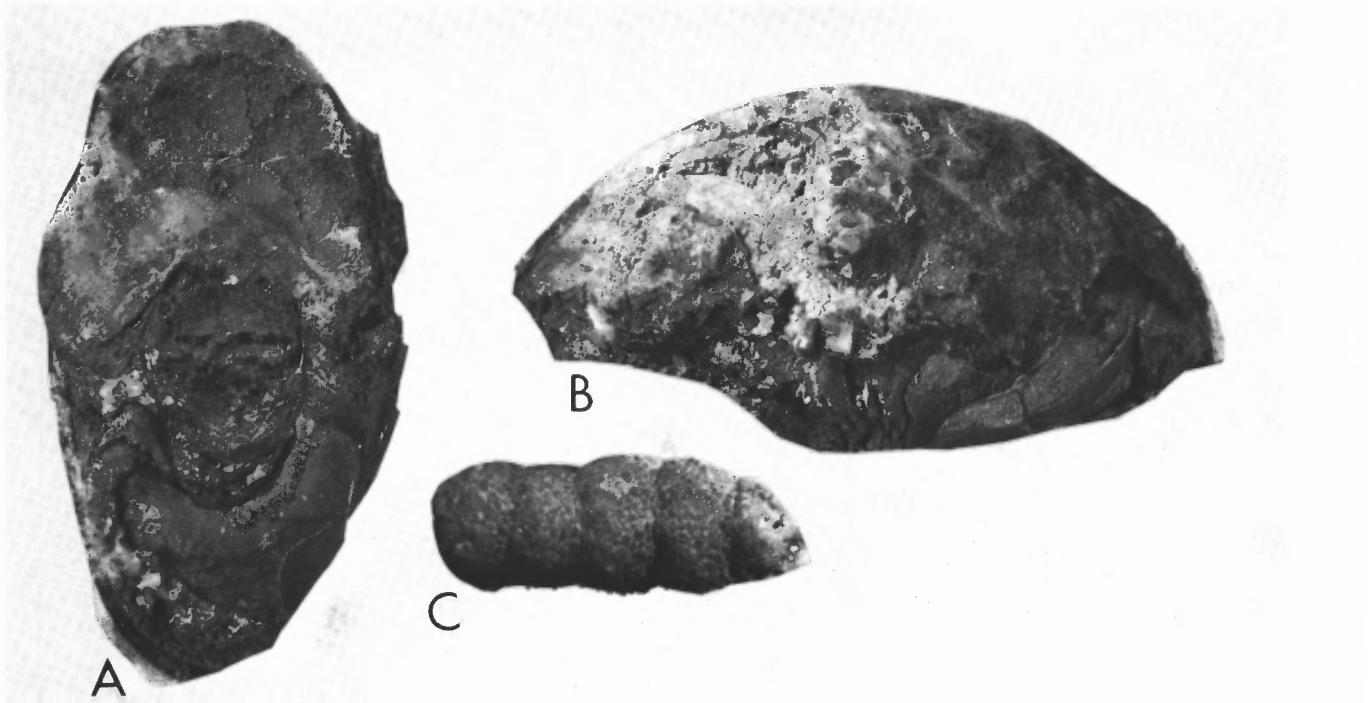


FIGURE 8. Sarten Formation fossils. A, B, *Cymatoceras hilli* Shattuck, cross section showing septum and siphuncle (A), and external view showing sutures (B), UNM 10283, upper fauna, UNM locality 1360, ×1. C, *Cribratina texana* (Conrad), partial test, UNM 10290, lower fauna, UNM locality 1357, ×6.

Foraminifera from units 4 and 11 of section A (Fig. 4) are planktonic taxa except for the benthonic species ?*Haplophragmoides* sp. (Table 2). No ostracodes are present. These foraminiferans are consistent with an early Cenomanian age assignment.

PALEONTOLOGY OF MANCOS FORMATION

Invertebrate fossils

Most information regarding the paleontology of the Mancos Formation in the Cooke's Range resulted from the recent studies of Cobban and Hook. The fauna of the lower member of the Mancos was listed by Cobban and Hook (1981) in connection with their description of *Neostlingoceras kottlowskii*, the turrilitid ammonite that is abundant in this member. Hook and Cobban (1981) studied the fauna and illustrated a few of the ammonites and bivalves that occur in the Bridge Creek Member. Little information is presently available concerning the Mancos fauna above the Bridge Creek. Earlier, Darton (1916, 1917) and Jicha (1954) mentioned some fossils from the Colorado Formation in the Cooke's Range, noting *Pycnodonte newberryi* and a limestone interval near the middle of the formation (our Bridge Creek Member) that produced many scattered cephalopods. We sampled all three intervals of the Mancos but did not intensively study the faunas. Here we summarize the paleontology of the Mancos and report information that augments earlier studies.

The lower member of the Mancos Formation includes the basal sandstone unit that rests unconformably on the Sarten, overlain by about 30 m of a predominantly shale and siltstone sequence. Cobban and Hook (1981) reported several ammonites and the bivalve *Inoceramus prefragilis* from several localities in the lower 11 m of this sequence. The occurrence of this bivalve and *Calycoceras*? cf. *C*? *canitaurinum* about 3.3 m above the base suggests that the lower member is roughly a correlative of the Lincoln and Hartland members of the Greenhorn Limestone in Colorado and Kansas. Our collections from the lower member were obtained mainly from a thin but persistent bed of dark gray, brown-weathering limestone within the lower 10 m of the member (Fig. 4, section D, unit 5). Fossils are preserved primarily as molds, and nearly all are incomplete. The most abundant taxa in this unit (UNM locality 1365) are molds of *Neostlingoceras kottlowskii* and *Inoceramus prefragilis*. A thin, hard, dark-gray siltstone unit (Fig. 4, section B, unit 3; UNM locality 1368) about 1 m above the basal sandstone contains mainly *I. prefragilis*.

Inoceramus prefragilis (Fig. 11A) is characterized by rather large size (some specimens are more than 100 mm high) and relatively coarse, evenly-spaced, rounded growth lines. It has a range zone that extends from the upper part of the upper member of the Graneros Shale through the Hartland Member of the Greenhorn in the Midcontinent area (Hattin, 1975; Kauffman et al., 1978). Some inoceramids from UNM locality 1365 possess irregularly-spaced growth rugae that appear relatively early in the growth of the valve (Figs. 11G–I). These specimens belong to the *I. pictus* species group, which is especially diverse in the Hartland Member of the Greenhorn in the Western Interior. However, our material is not sufficiently well preserved to assign these specimens to species with confidence. A single, large, incomplete inoceramid mold (*Inoceramus* sp. 1: Fig. 11C) suggests a valve having low, broad growth lamellae punctuated by deep but narrow concentric furrows at fairly regular, wide intervals.

Our collections of ammonites from the lower member add little to the information presented by Cobban and Hook (1981). One small specimen (diameter = 50 mm) with part of the shell preserved from locality 1362 displays narrow, widely-spaced, rectiradiate ribs adorned with sharp nodes (Fig. 9H). Every second or third rib extends from the umbilicus to the venter and includes a prominent umbilical node and a slightly smaller, lower, ventrolateral node about one-fourth to one-third of the distance from venter to umbilicus. The intercalated ribs carry the ventrolateral but not the umbilical node. Upper ventrolateral nodes appear to be present on most or all of the ribs. This specimen resembles an ammonite identified as *Watinoceras* sp. (possibly a coarse variant of *W. reesidei*) by Hattin (1975, pl. 6, fig. J) from the Hartland Member of the Greenhorn Limestone in Kansas. However, the stratigraphic position of the Cooke's Range specimen is lower than the interval (Bridge Creek Member) in which undoubted examples of the genus occur, and it may better be placed in another genus such as *Cunningtoniceras* (W. A. Cobban, written commun. 1988).

A partial steinkern and external mold of a small heteromorph ammonite (Fig. 9I) was also obtained from locality 1362. Height of the preserved arcuate whorl ranges from 3 to 8 mm, and it is ornamented

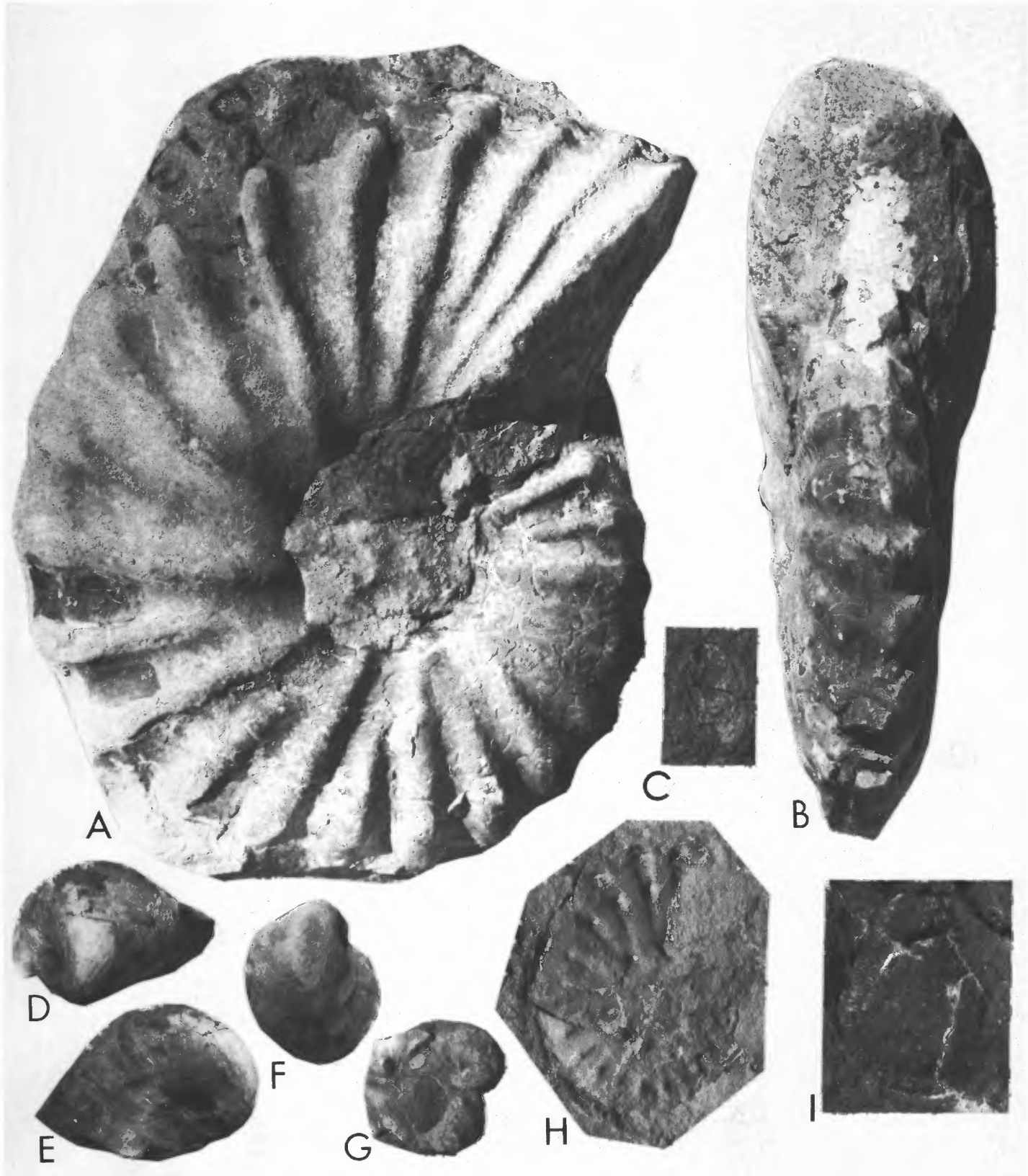


FIGURE 9. Fossils from the Mancos Formation, Cooke's Range (× 1 unless otherwise indicated). A, B, *Metoicoceras geslinianum* (d'Orbigny), side and front views of a large complete specimen, UNM 10255, Bridge Creek Member, UNM locality 1370, ×0.7. C, *Lingula* sp., incomplete, partially exfoliated specimen, UNM 10264, upper unit, UNM locality 1367, ×2. D–G, *Exogyra levis* Stephenson; D, E, umbonal and side views of a large left valve, UNM 10269, F, external view of partially exfoliated left valve, UNM 10270, G, cluster of small left valves, UNM 10271, all from Bridge Creek Member, UNM locality 1369. H, *Watinoceras*? sp., side view, UNM 10261, lower member, UNM locality 1362. I, *Hamites cimarronensis* Kauffman and Powell, partial steinkern and external mold, UNM 10263, lower member, UNM locality 1362.

with numerous, closely-spaced, straight, slightly oblique ribs, about 8 per a length equal to the whorl height near the middle of the whorl. At least some of the ribs appear to become broader or nodose at the venter. This specimen is similar to *Stomohamites* cf. *S. simplex* from the upper Graneros and Bridge Creek Member of the Greenhorn in Colorado (Cobban and Scott, 1972); *S.* cf. *S. simplex* was also reported from the lower member of the Mancos in the Cooke's Range (Cobban and Hook, 1981). However, the specimen is larger than any mentioned by Cobban and Scott and has more closely-spaced ribs (rib index = 8, compared with 4–6 on the Colorado specimens). In this feature it closely resembles *Hamites cimarronensis,* described by Kauffman et al. (1977) as *S. simplex cimarronensis* from the Hartland Member of the Greenhorn Limestone in western Oklahoma. Following Cobban (written commun. 1988), we assign this specimen to *H. cimarronensis*.

Planktonic foraminiferans collected from units 15 and 16 of section A (Fig. 4) include *Rotalipora cushmani* (Fig. 12A) and *Gumbelina globulosa* (Fig. 12C–D) (Table 2). These foraminiferans suggest a late Cenomanian (*Rotalipora cushmani* zone) age (cf. Marks, 1984).

In the Cooke's Range, the Bridge Creek Member includes a sequence of several nodular limestone and calcarenite beds separated by calcareous shales near the middle of the Mancos Formation. A particularly fossiliferous nodular limestone (UNM locality 1366; bed 111 of Hook and Cobban, 1981) occurs near the top of the Bridge Creek, and it contains large numbers of fragmentary ammonite steinkerns. Hook and Cobban (1981) reported several ammonite taxa from their bed 111, including a large, horned form (*Pseudaspidoceras* n. sp.) and a small, highly ribbed species identied as *Neocardioceras juddii*. Later, Cobban and Hook (1983) referred the ammonites they called *P.* n. sp. to *P. pseudonodosoides* and described and illustrated the species. Cobban (1984a) also reported *P. flexuosum,* a weakly-ribbed species, from units just above the *N. juddii* concretionary limestone level, and noted possible specimens of *Vascoceras birchbyi* several meters above the *P. flexuosum* zone in southwestern New Mexico. The Bridge Creek Member, as defined by Hook and Cobban (1981) in the Cooke's Range, includes only the lower and middle parts of this member as it is expressed in the Colorado-Kansas area.

We sampled the Bridge Creek fauna during the course of collecting from two hardground units (UNM localities 1371 and 1372) that contain abundant shark-tooth assemblages (see below). A distinctive *Exogyra* (Fig. 9D–G) from near the base of the member (UNM locality 1369) has a convex left valve with a small but strongly coiled beak, and attains a height of more than 40 mm. Ornamentation consists of numerous, fine, rounded, undulating radial costae that extend from the beak part of the distance across the left valve towards the ventral margin. On most specimens this ornamentation is restricted to the beak and umbo, but on a few the costae extend one-half or more of the distance from the beak to the ventral margin. These specimens accord well in size and shape with specimens of *Exogyra levis* from the upper Woodbine Formation of Texas (Stephenson, 1952) and from several units of the intertonguing Dakota-Mancos sequence in the San Juan Basin (Cobban, 1977). The specimens reported by those authors are typically smooth, however, with beak costae present on only an occasional valve, whereas nearly all of the Bridge Creek specimens we collected display radial costae. *E. columbella,* a related Woodbine/Dakota-Manocs/Greenhorn species, is generally highly costate, but varies considerably in this regard with some specimens being nearly smooth (Stephenson, 1952). Detailed study of variation in the two species probably will reveal them to intergrade.

The small oyster *Pycnodonte newberryi* (Fig. 11D, E) is present throughout much of the Bridge Creek Member and overlying beds, from unit 10 in section B and units 8–17 in section DEF, about 7 m above the ammonite steinkern bed (unit 15 in section DEF: Fig. 4). It is very abundant in the UNM lcoality 1371 and 1372 hardground units. These oysters have deep, convex left valves and lived freely on the substrate during most of their lives. Attachment scars are usually small, but on a few specimens represent more than one-third of the periphery of the left valve. Left valves vary considerably in shape. Some lack a posterior sulcus and are similar to forms that have been called *P.* cf. *P. kellumi* by recent workers (e.g., Hook and Cobban, 1977). Another species, *P. kansasense,* remained attached throughout growth; many of its flat left valves were observed cemented completely to ammonite steinkerns (see also Hook and Cobban, 1981).

The ammonite steinkerns that compose much of the nodular limestone bed (UNM locality 1366) are mostly referable to *Pseudaspidoceras pseudonodosoides*. There is moderate variation in the prominence and spacing of the lateral ribs and in the size and shape of the umbilical and ventrolateral tubercles.

Several typical specimens of the ammonite long known as *Metoiceras whitei* but now included in *M. geslinianum* by Wright and Kennedy (1981), were obtained from units 12–15 of section D (Fig. 4). Generally, as with Hyatt's (1903, pl. 14, fig. 7) holotype of *M. whitei* and Cobban and Scott's (1972, pl. 14, figs. 3–4, 9–11; pl. 16) specimens from the basal Bridge Creek of the Pueblo, Colorado area, the species possesses coarse, straight, moderately prominent ribs numbering 13 or 14 per half-whorl. Such specimens are not uncommon in the Bridge Creek Member of the Cooke's Range (e.g., Fig. 10).

An unusually large, complete specimen of *M. geslinianum* (Fig. 9A, B) has a diameter of 215 mm, a maximum whorl height of 84 mm and is 72 mm wide. It is very similar to, but larger than, the largest of the specimens of *M. whitei* described by Hyatt (1903, pl. 13, figs. 3–4) from Utah. The ribs are higher and more prominent than on typical specimens at the same stage of growth (whorl height = 60 mm), and on the last half-whorl become very high and sharply rounded, especially toward the venter. The three ribs nearest the aperture of this gerontic specimen, in contrast, are reduced and more closely spaced than preceding ribs. Total rib count for the last half-whorl is 12, slightly less than on typical specimens. Another difference between this large specimen and typical North American examples of *M. geslinianum* is the lesser development of ventrolateral swellings on the ribs of the former. In this respect the ribs of the large specimen approach those of *M. mosbyense*.

We made small collections from four thin beds within an interval extending from the top of the ammonite-rich nodular limestone (UNM locality 1366) to 11 m above it (UNM locality 1374). Identifiable specimens of *Pycnodonte newberryi* occur up to unit 15 in section B (Fig. 4); oyster remains in units 17 and 19 of section DEF are too fragmentary to identify but may be *P. newberryi*. Inoceramid shell fragments and a few unidentifiable molds of small ammonites are the other main constituents of this 11-meter-thick interval. Most of the inoceramids in unit 15 of section B and unit 17 of section DEF are relatively small forms with evenly-spaced, prominent, concentric growth rugae separated by furrows that are as wide or wider than the rugae. Doubling of growth lines on the concentric rugae is moderately developed on some specimens (Fig. 11B), generally only on the youngest half of a valve. The shape and ornamentation of these specimens seem closest to the *Mytiloides opalensis-M.* aff. *M. duplicostatus* group within the early Turonian North American *M. labiatus* lineage (see Kauffman et al., 1977). Better specimens are required to assess more precisely the taxonomic status of these inoceramids. A single, poorly-preserved specimen of the inarticulate brachiopod *Lingula* (Fig. 9C) was also collected from unit 17 of section DEF.

The only reasonably well-preserved bivalve we obtained from unit 19 of section DEF (UNM locality 1374) is *Inoceramus* sp. 2, a medium-sized (height = 57+ mm) individual with a low, only slightly inflated left valve and a long, straight hingeline (Fig. 11F). Early ornamentation to a distance of about 25 mm from the tip of the beak consists of relatively fine, narrow, evenly-spaced, concentric ridges, separated by interspaces at least twice as wide as the ridges. One or more much smaller growth lines are present between each pair of concentric ridges. This ornamentation gives way rather abruptly to a succession of fairly regularly-spaced, subdued growth lamellae that comprise the external surface of most of the valve. Concentric rugae and raised growth lines on this part of the valve are poorly developed to absent. A less complete specimen probably representing the same species was obtained from unit 15 in section B (Fig. 4). The round, cap-shaped inarticulate brachiopod *Discinisca* sp. is also present in unit 19 of section DEF.



FIGURE 10. *Metoicoceras geslinianum* (d'Orbigny), side view of a partial specimen, UNM 10253, Bridge Creek Member, UNM locality 1371, ×1.

Selachian fauna of the Bridge Creek Member

Although Hook and Cobban (1981) discussed at length the hardgrounds present in the Bridge Creek Member of the Mancos Formation southwest of Rattlesnake Ridge, they did not mention the prolific fauna of fossil fishes, especially selachians, in these hardgrounds. We collected fossil fishes from two hardground layers, one of latest Cenomanian age (Fig. 4, section DEF, unit 12: UNM locality 1371) and another of earliest Turonian age (Fig. 4, section DEF, unit 16: UNM locality 1372). Approximately 50 kg of calcarenite from each hardground were disaggregated in acetic acid (diluted to 10%), sieved and picked to produce approximately 1,000 teeth. We present here a brief description of the more common selachians in the Bridge Creek hardgrounds (Fig. 13), pending further study of the entire collection.

Ptychodus anonymus

The distinctive teeth of *Ptychodus* are present at both UNM localities 1371 and 1372 and can be referred to *P. anonymus* Williston, 1900. These teeth have low, broad, gently conical and antero-posteriorly elongate crowns. Ridges on the crown cross its apex but do not extend to its base. The relatively elongate and low, conical crowns on the teeth from the Cooke's Range distinguish them from *P. whipplei* (Williston, 1900; Wolberg, 1985). Specimens of *P. anonymus* from UNM locality 1371 include UNM MV-3005, 3045, 3104–3109 and 3112–3115 (Fig. 13A, D). *P. anonymus* is somewhat less common in the locality 1372 sample; representative specimens include UNM MV-3095, 3129 (Fig. 13C) 3130 and 3138 (Fig. 13B).

Squalicorax falcatus

Teeth we assign to *Squalicorax falcatus* (sensu Bilelo, 1969) dominate the collections from both localities. Catalogued specimens from locality 1371 are: UNM MV-3007, 3010–3020 (Fig. 13E), 3023–3030, 3032–3035 (Fig. 13G), 3030–3041, 3044, 3046, 3049 and 3054–3065 (Fig. 13F). From UNM locality 1372 fewer catalogued specimens are present: UNM MV-3066, 3067, 3070, 3072–3073, 3075, 3077, 3081–3085, 3089, 3093, 3136 (Fig. 13H) and 3137. These trenchant teeth have a triangular-shaped, compressed blade with serrated edges. A notch separates the blade from a posterior lobe which is preserved on only a few specimens from the Cooke's Range. Measurements of the apex angle (cf. Bilelo, 1969, fig. 3) of the Cooke's Range *Squalicorax* approximate 50°, and thus further support assignment of the specimens to *S. falcatus*. In the Texas Cretaceous, *S. falcatus* is not known from pre-Turonian strata (Bilelo, 1969). However, it has a wider stratigraphic range in Europe (Cappetta, 1987).

Scapanorhynchus raphiodon

Teeth of *S. raphiodon* are reasonably abundant at both localities 1371 and 1372. These teeth have long, slender, recurved and pointed blades on strongly arcuate and bilobed roots. Specimens from UNM locality

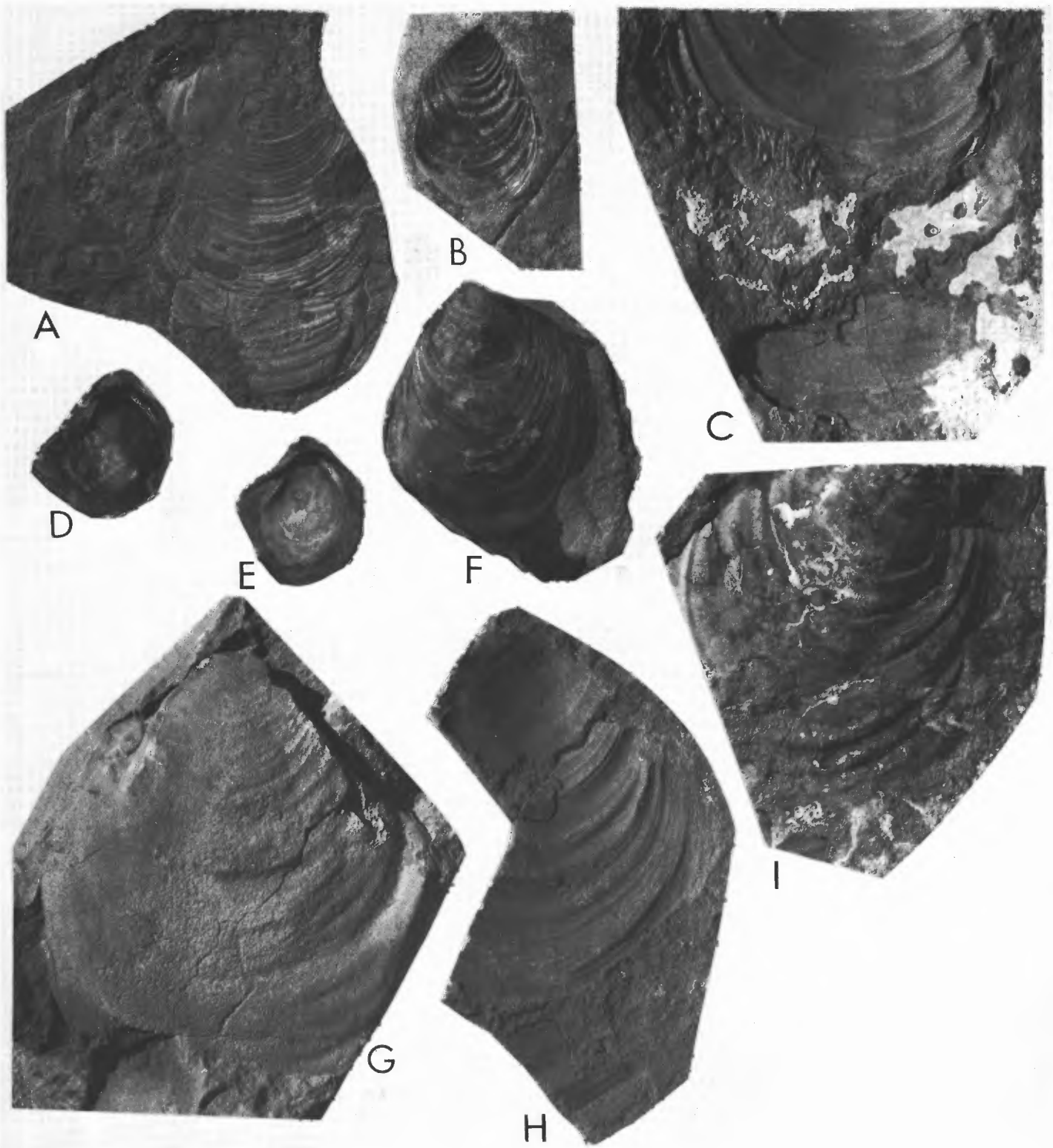


FIGURE 11. Bivalves from the Mancos Formation, Cooke's Range (all ×1). A, *Inoceramus prefragilis* Stephenson, two incomplete specimens, UNM 10262, lower member, UNM locality 1368. B, *Mytiloides* aff. *M. duplicostatus* (Anderson), interior surface of left valve, UNM 10266, upper member, UNM locality 1367. C, *Inoceramus* sp. 1, incomplete mold of right valve showing widely spaced, narrow, concentric furrows, UNM 10260, lower member, UNM locality 1365. D, E, *Pycnodonte newberryi* Stanton, interior views of left valves, UNM 10273 and 10272, Bridge Creek Member, localities 1366 and 1373, respectively. F, *Inoceramus* sp. 2, incomplete left valve, UNM 10265, upper member, UNM locality 1374. G–I, *Inoceramus pictus* Sowerby group; G, steinkern of right valve, UNM 10268, H, external mold, UNM 10259, I, steinkern bearing external mold of right valve, UNM 10267, all from lower member, UNM locality 1365.

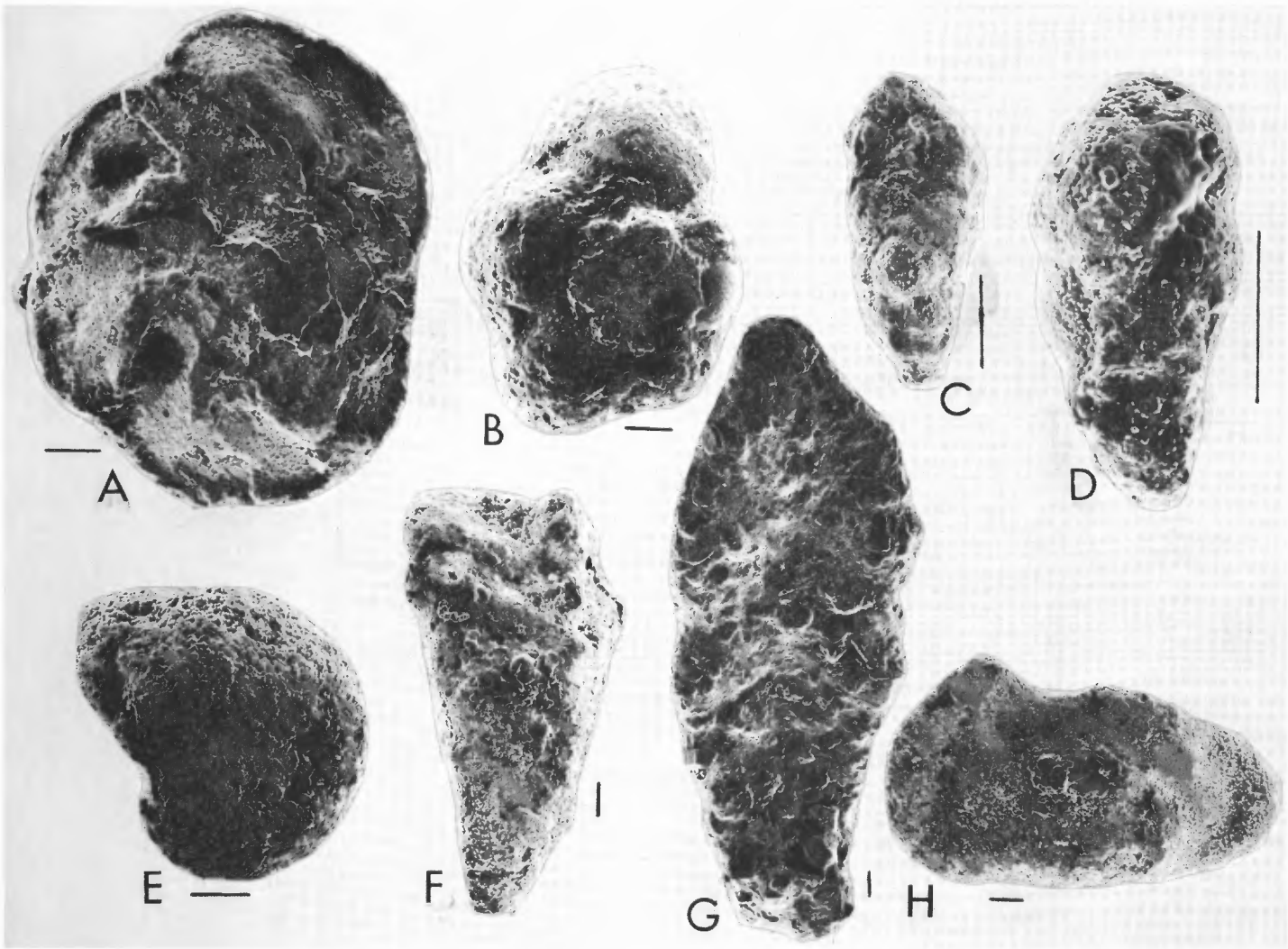


FIGURE 12. Selected microfossils (Foraminifera and Ostracoda) from Cretaceous strata in the Cooke's Range (all bar scale = 50 μ). A, *Rotalipora cushmani* (Morrow), lower member, Mancos Formation, UNM locality 1362. B, *Hedbergella delrioensis* (Carsey), Sarten Formation, UNM locality 1377. C–D, *Gumbelina globulosa* (Ehrenberg), lower member, Mancos Formation, UNM locality 1381. E. *Gavelinella plummerae* (Tappan), Sarten Formation, UNM locality 1375. F, *Textulariopsis rioensis* (Carsey), Sarten Formation, UNM locality 1375. G, *Triplasia acutocarinata* (Alexander & Smith), Sarten Formation, UNM locality 1375. H, *Cythereis* aff. *C. nuda* (Jones & Hinds), Sarten Formation, UNM locality 1375.

1371 are UNM MV-3003, 3006, 3009 (Fig. 13L–M), 3031, 3042, 3043 (Fig. 13N–O), 3047, 3051 and 3053. From UNM locality 1372 about the same number of specimens are known: UNM MV-3071, 3074, 3076, 3079, 3088, 3092, 3094, 3128, 3133 (Fig. 13J) and 3135 (Fig. 13K).

Odontaspis macrota

Teeth we tentatively assign to *O. macrota* are similar to those of *S. raphiodon* except for their relatively small roots and greatly curved blade. Nevertheless, the fine distinctions usually made between *S. raphiodon* and *O. macrota* (cf. Thurmond and Jones, 1981, p. 49) probably are not enough to distinguish the two taxa. Specimens from UNM locality 1371 we refer to *O. macrota* are: UNM MV-3050, 3096–3101, 3121 (Fig. 13I) and 3132 (Fig. 13P). *O. macrota* from locality 1372 are UNM MV-3086 (Fig. 13R), 3096 (Fig. 13Q) and 3124–3127.

***Ptychotrygon triangularis* and others**

The small, flat, diamond-shaped teeth of the ray *P. triangularis* are abundant in the collection (e.g., Fig. 13S–T). Also common are teeth of batoids and of ptychodontid teleosts. The only postcranial material recovered is an incomplete centrum (Fig. 13U) of a lamnoid selachian (cf. Lucas et al., 1985).

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Cobban (1987) correlated the lower part of the Sarten with the Duck Creek Formation (late Albian) of Texas, based on the occurrence of the ammonites *Mortoniceras equidistans* and *Eopachydiscus marcianus*, which define successive zones in the Duck Creek. The middle part, containing *Mortoniceras* (*Drakeoceras*) and *Engonoceras belviderense*, was tentatively placed within the *Drakeoceras lasswitzi* zone (upper Duck Creek through Denton formations of the north and east Texas section) by Cobban. He considered the uppermost Sarten to be approximately equivalent to the Buda Limestone (early Cenomanian) and noted the presence of several bivalves also found in the Buda in central Texas and at Cerro de Cristo Rey. The information presented by Cobban (1987) and study of our Sarten collections leads us to approximately the same conclusions regarding the age of the formation. Some additional information and interpretations are presented below.

Eopachydiscus marcianus and *Mortoniceras equidistans* co-occur in the lower part of the Duck Creek Formation in eastern Texas, but *M. equidistans* ranges higher within the Duck Creek than *E. marcianus* (Slocki, 1967; Cobban, 1987). Both species occur in Trans-Pecos Texas, and both are present in the Smeltertown Formation at Cerro de Cristo Rey and in the Tucumcari Formation of east-central New Mexico. At

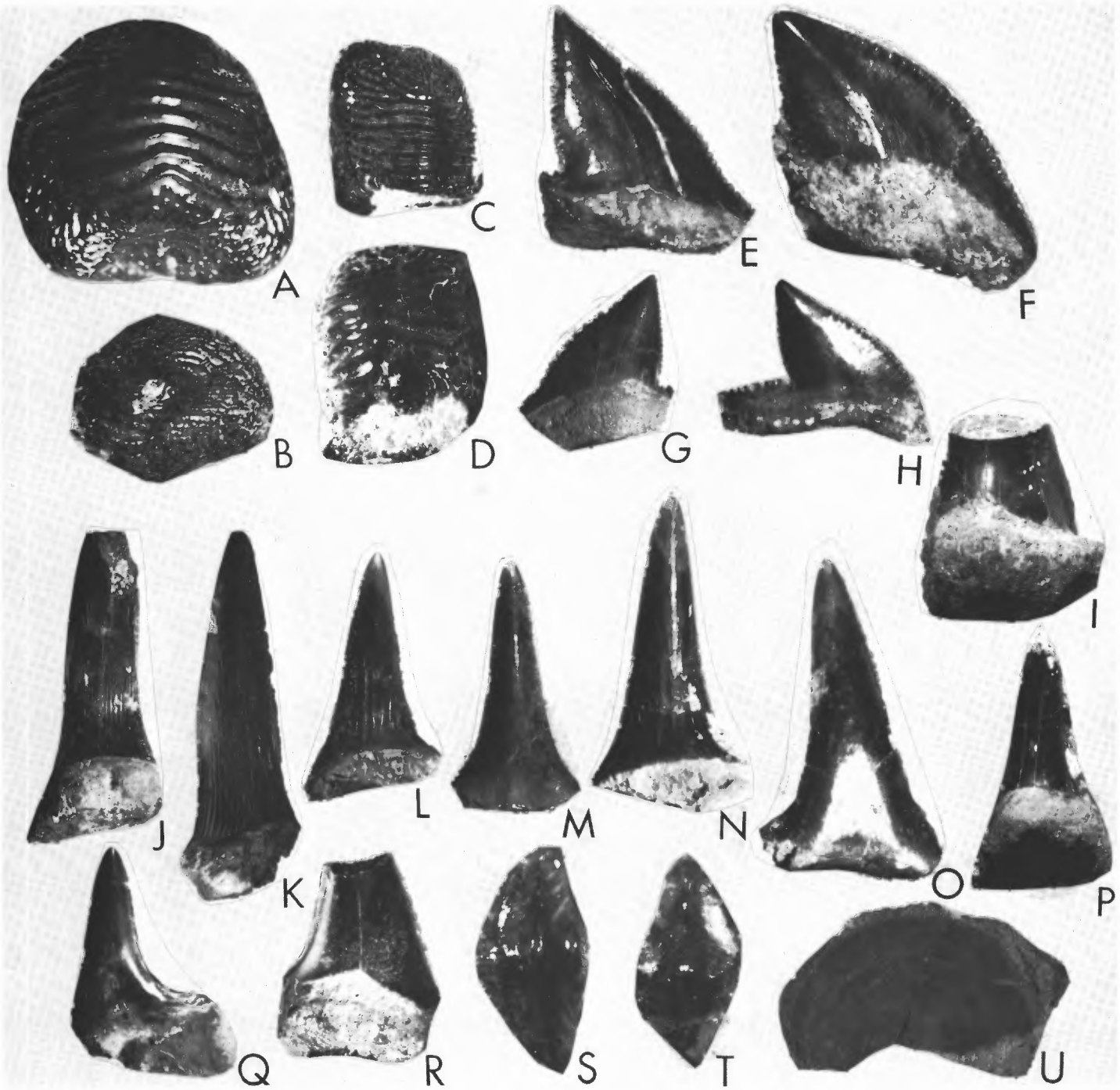


FIGURE 13. Some fossil selachians from the Bridge Creek Member of the Mancos Formation, Cooke's Range. A, *Ptychodus anonymus*, UNM MV-3112, UNM locality 1371, ×6. B, *P. anonymus*, UNM MV-3138, UNM locality 1372, ×4. C, *P. anonymus*, UNM MV-3129, UNM locality 1372, ×5. D, *P. anonymus*, UNM MV-3113, UNM locality 1371, ×6. E, *Squalicorax falcatus*, UNM MV-3020, UNM locality 1371, ×6. F, *S. falcatus*, UNM MV-3055, UNM locality 1371, ×10. G, *S. falcatus*, UNM MV-3035, UNM locality 1371, ×6. H, *S. falcatus*, UNM MV-3136, UNM locality 1372, ×7. I, *Odontaspis macrota*, UNM MV-3121, UNM locality 1371, ×4. J, *Scapanorhynchus raphiodon*, UNM MV-3133, UNM locality 1372, ×4. K, *S. raphiodon*, UNM MV-3135, UNM locality 1372, ×4. L–M, *S. raphiodon*, UNM MV-3009, UNM locality 1371, ×13. N–O, *S. raphiodon*, UNM MV-3043, UNM locality 1371, ×13. P, *Odontaspis macrota*, UNM MV-3132, UNM locality 1371, ×2.5. Q, *Odontaspis macrota*, UNM MV-3096, UNM locality 1372, ×2.5. R, *Odontaspis macrota*, UNM MV-3086, UNM locality 1372, ×4. S, *Ptychotrygon* sp., UNM MV-3203a, UNM locality 1371, ×38. T, *Ptychotrygon* sp., UNM MV-3203b, UNM locality 1371, ×38. U, Selachian centrum, UNM MV-3195, UNM locality 1372, ×1.

Cerro de Cristo Rey, Böse (1910) reported *Schloenbachia whitei*, a synonym of *M. equidistans* (Cobban, 1985, 1987), from his unit 4 (= Smeltertown Formation). He also described *S. trinodosa*, another synonym of *M. equidistans* (Cobban, 1985, 1987), from his units 5 and 6, the present Muleros and Mesilla Valley formations. *Schloenbachia trinodosa* was the youngest ammonite reported by Böse from the Washita Group at Cerro de Cristo Rey. The Muleros and Mesilla Valley formations are considered post-Duck Creek, Fort Worth to Pawpaw (latest Albian) equivalents (Strain, 1976), and contain small texigryphaeas that have been called *T. washitaensis*, the dominant gryphaeid species of the latest Albian of eastern Texas.

Mortoniceras equidistans in the New Mexico area occurs with other species that commonly characterize units younger than its zone in eastern Texas. According to information presented in Zeller (1965), the foraminiferan *Cribratina texana* is probably limited to the upper part of the Washita Group in Texas; it is an important marker for the upper part of Weno Formation (Adkins, 1918; Slocki, 1967) in eastern Texas and occurs at higher intervals (Del Rio Formation) in western Texas. At Cerro de Cristo Rey it occurs in the Muleros, Mesilla Valley and basal Anapra formations (Böse, 1910; Cornell and LeMone, 1987). In the Tucumcari Formation and in the Muleros Formation of Cerro de Cristo Rey, both *M. equidistans* and *C. texana* occur with the bivalve *Lopha quadriplicata*. Although this bivalve may occur in Duck Creek-equivalent strata (e.g., Scott, 1970), its earliest occurrence in eastern Texas is in the Fort Worth (Adkins, 1928) or Denton formations (e.g., Perkins, 1960; Slocki, 1967). Taken together, these relationships suggest that *M. equidistans* may have survived past the time of eastern Texas Duck Creek deposition in the western part of its geographic range, and that its zone may encompass younger strata in the west than in the east.

The fauna of the upper 2 m of the Sarten includes several taxa indicative of an early Cenomanian age. Cobban (1987) correlated this interval with the Buda Limestone, mainly on the basis of ammonites, but also noted several bivalves that were originally described for the Buda (Shattuck, 1903) in Texas. *Exogyra whitneyi* and *E. clarki* have short stratigraphic ranges essentially restricted to the Del Rio and Buda formations. At Cerro de Cristo Rey both species are conspicuous in the Del Rio Formation, but we have not positively identified either species in the Buda. The nautiloid *Cymatoceras hilli* was originally described from the Buda (Shattuck, 1903) and ranges no higher than that formation (Young and Powell, 1978). Cobban (1987) suggested that the Buda equivalent at the top of the Sarten rests disconformably on sandstones equivalent to the Anapra at Cerro de Cristo Rey. An alternative possibility is that the sandy nodular limestone at the top of the Sarten is equivalent to the entire Del Rio-Buda section at Cerro de Cristo Rey and represents a thin western tongue of that marine sequence. A 5-m-thick sandstone bed immediately below the nodular limestone contains burrows, including *Ophiomorpha*, that suggest it was deposited as a shoreline sand marking the initial transgression of the Buda-Del Rio sea into the Cooke's Range area. Both in the Cooke's Range and at Cerro de Cristo Rey the top of the Sarten (Buda) is truncated by an unconformity, above which lie marine sediments of middle or late Cenomanian age.

The faunal evidence indicates that the unconformity between the Sarten and basal units of the Mancos is a significant one (Fig. 14) representing at least three ammonite zones, approximately the time during which the upper part of the lower member, Thatcher Member, and upper member of the Graneros were being deposited in Colorado and Kansas. In addition, the unconformity encompasses the time during which the part of the Boquillas Formation overlying the Buda at Cerro de Cristo Rey was deposited.

Correlation of the lower and Bridge Creek Members is relatively straightforward and is shown on Figure 14 (also see Hook and Cobban, 1981). Our collections from units above 15 in section DEF do not permit firm conclusions regarding the stratigraphy and correlation of this interval. *Pycnodonte newberryi*, which is restricted to the lower

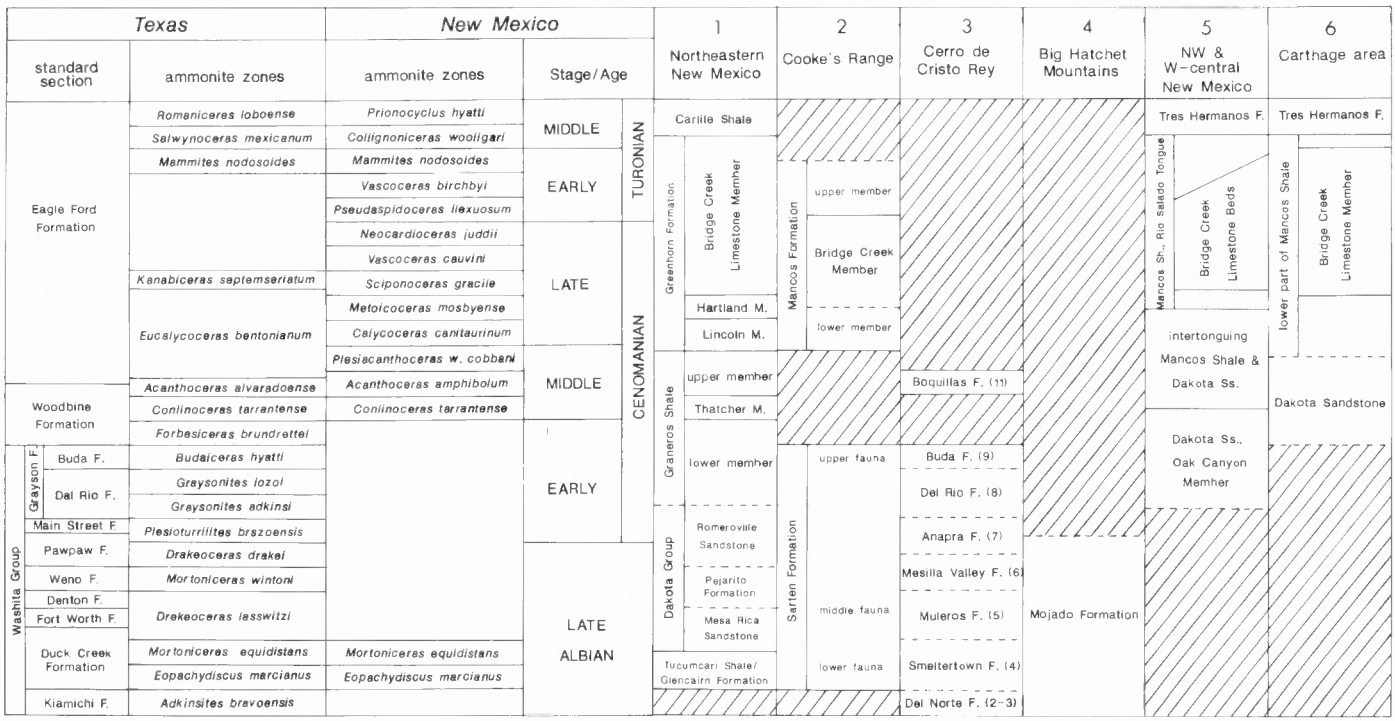


FIGURE 14. Correlation of Cretaceous sequence in the Cooke's Range (column 2) with Texas formations and ammonite zones (Young and Powell, 1978; Young, 1982, 1986), New Mexico ammonite zones (Cobban, 1986), and equivalent strata in the southwestern New Mexico area. Column 1—Northeastern New Mexico and adjacent areas (Hattin, 1975; Kauffman et al., 1977, 1978; Kues and Lucas, 1987); Column 2—Cooke's Range (Hook and Cobban, 1981; Cobban, 1984, 1987; this paper); Column 3—Cerro de Cristo Rey (Böse, 1910; Strain, 1976; the numbers applied to the units are those of Böse, 1910); note that the Boquillas Formation may include units younger than the *A. amphibolum* zone (W. A. Cobban, written commun. 1988); Column 4—Big Hatchet Mountains (Zeller, 1965); Column 5—West-central and northwestern New Mexico (Cobban, 1977; Hook et al., 1983; Cobban, 1984a); Column 6—Carthage area, Socorro County (Cobban and Hook, 1979; Hook, 1983; Hook et al., 1983).

half of the Bridge Creek in the Western Interior (Kauffman et al., 1978), is present 5 m or more above unit 15 in section DEF. The inoceramids of unit 17 in section DEF are also suggestive of a Bridge Creek correlation. The highest ammonite zone recognized in southwestern New Mexico is possibly that of *Vascoceras birchbyi* (Cobban, 1984a), which characterizes the upper but not uppermost Bridge Creek. Although Hook and Cobban (1981) did not report the inoceramid *Mytiloides mytiloides* from their Bridge Creek sections, and we did not observe it either, Cobban (1984b) reported this species from the Cooke's Range. It presumably was collected some distance above the top of the Bridge Creek Member as defined by Hook and Cobban (1981). This species characterizes the upper Bridge Creek Member throughout the Western Interior.

In summary, it is probable that most, or all of the Mancos section above the top of the Bridge Creek Member (of Hook and Cobban, 1981) is correlative with the upper Bridge Creek to the north. There is as yet no evidence that Carlile-age marine sediments were deposited in southwestern New Mexico. Reconstructions of shoreline position during Cenomanian-Turonian time (e.g., Hook, 1983; Cobban, 1984b) indicate that marine conditions prevailed in this area only to (approximately) the time of *Mammites nodosoides* and *Mytiloides mytiloides*. By the time of *Collignoniceras woollgari*, at the transition between Bridge Creek and Carlile deposition in Kansas (Hattin, 1975) and Colorado (Cobban and Scott, 1972), the shoreline in southwestern New Mexico had regressed northeastward, and the Cooke's Range area was above sea level (Cobban and Hook, 1979). Based on its fauna, the entire Mancos section in the Cooke's Range is almost exactly coeval with the Greenhorn Limestone in Kansas and Colorado, and is closely correlative with the Rio Salado Tongue of the Mancos in west-central New Mexico.

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APPENDIX 1—FOSSIL LOCALITIES

1. UNM locality 1356—NE¼ SE¼ NW¼ SE¼, sec. 20, T21S, R8W; stratigraphically equivalent to section C, unit 15 (Fig. 4), Sarten Formation.
2. UNM locality 1357—NW¼ NE¼ NW¼ SE¼, sec. 20, T21S, R8W; stratigraphically equivalent to section C, unit 15 (Fig. 4), Sarten Formation.
3. UNM locality 1358—NE¼ NW¼ SW¼ SE¼, sec. 29, T21S, R8W; section G, unit 8 (Fig. 4), Sarten Formation.
4. UNM locality 1359—SW¼ SW¼ NE¼ NW¼, sec. 17, T21S, R8W; section C, unit 19 (Fig. 4), Sarten Formation.
5. UNM locality 1360—center NE¼ NW¼ NW¼, sec. 18, T21S, R8W; section A, unit 8 (Fig. 4), Sarten Formation.
6. UNM locality 1361—center NE¼ NW¼ NW¼, sec. 18, T21S, R8W; section A, unit 13 (Fig. 4), Mancos Formation (top surface of basal sandstone).
7. UNM locality 1362—center NE¼ NW¼ NW¼, sec. 18, T21S, R8W; section A, unit 15 (Fig. 4), Mancos Formation.
8. UNM locality 1363—NW¼ SW¼ NW¼ NW¼, sec. 18, T21S, R8W; section A, unit 15 (Fig. 4), Mancos Formation (lenticular horizon of limestone nodules).
9. UNM locality 1364—center SW¼ NW¼ NW¼, sec. 18, T21S, R8W; section DEF, unit 2 (Fig. 4), Sarten Formation.
10. UNM locality 1365—E½ NE¼ NE¼, sec. 13, T21S, R9W; section DEF, unit 5 (Fig. 4), Mancos Formation.
11. UNM locality 1366—SW¼ NW¼ NE¼ NE¼, sec. 13, T21S, R9W; section DEF, unit 15 (Fig. 4), Mancos Formation, Bridge Creek Member.
12. UNM locality 1367—NW¼ SW¼ NE¼ NE¼, sec. 13, T21S, R9W; section DEF, unit 17 (Fig. 4), Mancos Formation.
13. UNM locality 1368—SE¼ NW¼ SE¼ NE¼, sec. 30, T20S, R8W; section B, unit 3 (Fig. 4), Mancos Formation.
14. UNM locality 1369—NW¼ NE¼ SW¼ NE¼, sec. 30, T20S, R8W; section B, unit 10 (Fig. 4), Mancos Formation.
15. UNM locality 1370—SW¼ NW¼ NE¼ NE¼, sec. 13, T21S, R9W; section DEF, unit 13 (Fig. 4); Mancos Formation, Bridge Creek Member.
16. UNM locality 1371—SW¼ NW¼ NE¼ NE¼, sec. 13, T21S, R9W; section DEF, unit 12 (Fig. 4); Mancos Formation, Bridge Creek Member.
17. UNM locality 1372—SW¼ NW¼ NE¼ NE¼, sec. 13, T21S, R9W; section DEF, unit 16 (Fig. 4); Mancos Formation, Bridge Creek Member.
18. UNM locality 1373—SW¼ NW¼ NE¼ NE¼, sec. 13, T21S, R9W; section DEF, unit 14 (Fig. 4); Mancos Formation, Bridge Creek Member.
19. UNM locality 1374—NW¼ SW¼ NE¼ NE¼, sec. 13, T21S, R9W; section DEF, unit 19; Mancos Formation, upper member.
20. UNM locality 1375—NE¼ NW¼ SW¼ SE¼, sec. 29, T21S, R8W; section G, unit 7 (Fig. 4), Sarten Formation.
21. UNM locality 1376—NE¼ NW¼ SW¼ SE¼, sec. 29, T21S, R8W; section G, unit 9 (Fig. 4), Sarten Formation.
22. UNM locality 1377—NE¼ NW¼ SW¼ SE¼, sec. 29, T21S, R8W; section G, unit 11 (Fig. 4), Sarten Formation.
23. UNM locality 1378—NE¼ NW¼ SW¼ SE¼, sec. 29, T21S, R8W; section G, unit 19 (Fig. 4), Sarten Formation.
24. UNM locality 1379—center NE¼ NW¼ NW¼, sec. 18, T21S, R8W; section A, unit 4 (Fig. 4), Sarten Formation.
25. UNM locality 1380—center NE¼ NW¼ NW¼, sec. 18, T21S, R8W; section A, unit 11 (Fig. 4), Sarten Formation.
26. UNM locality 1381—NW¼ NE¼ NW¼ NW¼, sec. 18, T21S, R8W; section A, unit 16 (Fig. 4); Mancos Formation, lower member.
27. UNM locality 1382—NE¼ NW¼ SW¼ SE¼, sec. 29, T21S, R8W; section G, unit 15 (Fig. 4), Sarten Formation.
28. UNM locality 1383—NE¼ NW¼ SW¼ SE¼, sec. 29, T21S, R8W; section G, unit 5 (Fig. 4), Sarten Formation.

APPENDIX 2—MEASURED SECTIONS

Section A

Measured in the NE¼ NW¼ NW¼, sec. 18, T21S, R8W, Luna County. Strata dip 6–10° to S30°E. Colors in this and subsequent sections are those of Goddard et al. (1984).

unit	lithology	thickness (m)
	Mancos Formation (lower member):	
18	Siltstone; same colors and lithology as unit 15	not measured
17	Siltstone; dark gray (N 3); weathers to grayish orange (10 YR 7/4); calcareous; laminar.	4.3
16	Clayey siltstone; light olive gray (5 Y 5/2); calcareous, microfossils (UNM locality 1381).	0.4
15	Siltstone; dark gray (N 3); calcareous; laminar; 1.2 m above base is fossiliferous layer (UNM locality 1362); limestone nodular horizon 2 m above base is lenticular and fossiliferous (UNM locality 1363).	4.6
14	Chert; moderate yellowish brown (10 YR 5/4) to moderate brown (5 YR 4/4).	0.6
13	Sandstone; grayish orange (10 YR 7/4); weathers moderate yellowish brown (10 YR 5/4); quartzose; very fine to medium grained; angular to subrounded; poorly sorted; calcareous; trough crossbedded; base is scour surface; top surface has ammonoids (UNM locality 1361).	1.1
12	Silty sandstone; medium dark gray (N 4) and grayish orange (10 YR 7/4); quartzose; silt to medium grained; subrounded; poorly sorted; calcareous; some scattered quartzite pebbles as much as 0.5 cm in diameter.	0.1
	Disconformity	
	Sarten Formation:	
11	Clayey siltstone; dark gray (N 3) and dark yellowish orange (10 YR 6/6); slightly calcareous; upper 0.4 m contain limestone septaria like unit 10; microfossils (UNM locality 1380).	1.3
10	Limestone septaria; light olive gray (5 Y 6/1); weathers yellowish orange (10 YR 6/6).	0.4
9	Sandy siltstone; same colors as unit 7; bioturbated; some limestone septaria.	0.9
8	Limestone septaria; light olive gray (5 Y 6/1); fossiliferous (UNM locality 1360).	0.3
7	Silty sandstone; greenish gray (5 G 6/1); weathers moderate yellowish brown (10 YR 5/4); fine to coarse grained, angular to subangular; poorly sorted; bioturbated; some glauconite.	0.5
6	Silty sandstone; same lithology as unit 5; liesegang bands are dark yellowish orange (10 YR 6/6), pale reddish purple (5 RP 6/2) and very light gray (N 8).	0.8
5	Silty sandstone; grayish orange (10 YR 7/4) and dark yellowish orange (10 YR 6/6); silty to medium grained; subangular; poorly sorted; some muscovite, apatite and zircon; bioturbated.	0.5
4	Siltstone and silty sandstone; medium dark gray (N 7); weathers grayish orange (10 YR 7/4); siltstone is laminar; sandstone is quartzose, silty to medium grained; angular to subrounded, poorly sorted, calcareous and bioturbated in places; microfossils (UNM locality 1379).	0.5
3	Sandstone; grayish orange (10 YR 7/4); weathers dark yellowish orange (10 YR 6/6); quartzose; fine to medium grained, subangular to well rounded; poorly sorted; non-calcareous; bioturbated.	7.6
2	Sandstone; medium light gray (N 6); weathers moderate brown (5 YR 4/4) and dusky yellowish brown (10 YR 2/2); quartzose; medium grained; subangular to well rounded; well sorted; calcareous; trough crossbedded; some dispersed chert pebbles.	6.1
1	Sandy siltstone; light brownish gray (5 YR 6/1) with dusky red (5 R 3/4) mottles; calcareous; bioturbated.	1.0+

Section B

Measured in the N1/2 NE1/4, sec. 30, T20S, R8W. Strata dip 13° to S30°W.

unit	lithology	thickness (m)
	Mancos Formation (upper member):	
15	Siltstone; medium gray (N 5); weathers grayish orange (10 Y 7/4); oyster hardground; calcareous.	0.1
14	Siltstone; dusky yellow (5 Y 6/4) with some dark gray (N 4) laminae; laminar; slightly calcareous.	4.0
	Mancos Formation (Bridge Creek Member):	
13	Siltstone; medium light gray (N 6) and grayish orange (10 YR 7/4); oyster hardground; calcareous; some fine grains of quartz sand; bed is lenticular and pinches out laterally into unfossiliferous siltstone.	0.2
12	Siltstone; dark gray (N 3); calcareous.	0.4
11	Limestone and siltstone interbedded; limestone is medium gray (N 5) and weathers to grayish orange (10 YR 7/4); siltstone is dark gray (N 3) and calcareous; sequence, from bottom to top is: siltstone (0.6 m), limestone (0.2 m), siltstone (0.4 m), limestone (0.2 m), siltstone (0.4 m), limestone (0.2 m).	2.0
10	Silty shale and siltstone; same colors and lithology as unit 4; fossiliferous (UNM locality 1369).	1.0
9	Limestone; same colors and lithology as unit 7.	0.1
8	Silty shale and siltstone; same colors and lithology as unit 4; top of unit is thin bentonite.	0.8
7	Limestone; dark gray (N 3); weathers grayish orange (10 YR 7/4); micrite.	0.1
6	Silty shale and siltstone; same colors and lithology as unit 4.	0.6
5	Nodular limestone; dark gray (N 3); weathers yellowish gray (5 Y 8/1).	0.1
	Mancos Formation (lower member):	
4	Silty shale and siltstone; light gray (N 7); weathers olive gray (5 Y 6/1) and light olive gray (5 Y 5/2); calcareous; some thin bentonites; horizontal trace fossils, especially 1.5 m above the base.	11.6
3	Siltstone; grayish black (N 2); weathers to olive gray (5 Y 4/1) and light olive brown (5 Y 5/6); top layer is moderate yellowish brown (10 Y 5/4); calcareous; mostly laminar with some blocky beds; 0.9 m above base are fossils (UNM locality 1368).	5.0
	Disconformity	
	Sarten Formation:	
2	Sandstone; olive gray (5 Y 4/1); weathers moderate yellowish brown (10 YR 5/4) and dark yellowish orange (10 YR 6/6); quartzose; medium grained; subangular to rounded; well sorted; slightly calcareous; some trough crossbeds arranged in 0.3-m-thick sets but mostly bioturbated.	2.3
1	Sandstone; pinkish gray (5 YR 8/1) to very light gray (N 8); weathers yellowish gray (5 Y 8/1), dark reddish brown (10 R 3/4) and grayish orange (10 YR 7/4); quartzose; fine grained; subangular to rounded; well sorted; non-calcareous; silty in places; planar crossbedded.	12.0+

Section C

Measured in the SW1/4 NE1/4 NW1/4, sec. 17, T21S, R8W, Luna County. Strata dip 19° to S27°W.

unit	lithology	thickness (m)
	Tertiary sill:	
20	Granodiorite porphyry; medium dark gray (N 4) groundmass olive gray (5 Y 4/1) and white (N 9) phenocrysts; phenocrysts are feldspar and hornblende.	not measured
	Nonconformity	
	Sarten Formation:	
19	Sandy siltstone; fossiliferous upper 0.3 m; olive gray (5 Y 4/1); fossils are medium dark gray (N 4); calcareous; bioturbated (UNM locality 1359).	4.3
18	Sandstone; same lithology as unit 16 except has some 0.5-cm-diameter pebbles of quartzite; weathers medium light gray (N 6) and dark yellowish orange (10 YR 6/6).	1.5
17	Sandstone; same lithology as unit 16 except bioturbated and has scour surfaces every 0.9 m; weathers pale red (5 R 6/2) and dusky yellowish brown (10 YR 2/2).	8.8
16	Sandstone; grayish orange pink (10 R 8/2); weathers moderate orange pink (5 YR 8/4); quartzose; fine grained; subangular to rounded; well sorted; non-calcareous; lower half displays planar crossbeds, then ripple laminae with upper half dominated by trough crossbeds.	5.3
15	Covered by colluvium of overlying Sarten Formation sandstone and granodiorite porphyry.	14.0
14	Sandy siltstone; same lithology and colors as unit 10.	1.5
13	Siltstone; yellowish gray (5 Y 7/2) and dark yellowish orange (10 YR 6/6); some very fine sand; calcareous; bioturbated; many joints with iron oxide.	2.7
12	Sandy siltstone; same lithology and colors as unit 10.	5.2
11	Siltstone; same lithology and colors as unit 9.	0.9
10	Sandy siltstone; very light gray (N 8); weathers light brown (5 YR 5/6) and grayish orange (10 YR 7/4); non-calcareous; trough crossbedded; has oxidized impressions of plant stems.	2.6
9	Sandy siltstone; light gray (N 7) and grayish orange (10 YR 7/4); calcareous; bioturbated to weakly laminar.	8.7
	Abo Formation:	
8	Limestone-pebble conglomerate; matrix is medium gray (N 5), clasts are light gray (N 7); weathers to dark yellowish orange (10 YR 6/6); matrix supported; clasts are micrite with average diameter of 0.3–0.5 cm (largest clast has 2.7-cm diameter); matrix contains fine quartz sandstone; graded bedding (coarsens upward).	0.8–1.8
7	Claystone; dark reddish brown (10 R 2/4); calcareous.	3.4
6	Limestone; same lithology and color as unit 2.	0.6
5	Siltstone; same lithology and colors as unit 1.	5.2
4	Sandstone; grayish red purple (5 RP 4/2); made of siltstone debris; calcareous.	0.6
3	Siltstone; same lithology and colors as unit 1.	1.5
2	Limestone; medium gray (N 5); silty.	2.3
1	Siltstone; dusky red (5 R 3/4), grayish red (10 R 4/2) and dark reddish brown (10 R 3/4); calcareous and sandy in places; contains nodules of medium dark gray (N 4) micrite.	10.0+

Section DEF

Measured in the SW1/4 NW1/4 NW1/4, sec. 18, T21S, R8W, the S1/2 NE1/4 NE1/4, sec. 13, T21S, R9W, the SE1/4 SE1/4 NE1/4 NW1/4 and NE1/4 NE1/4 SE1/4 NW1/4, sec. 13, T21S, R9W, and the E1/2 NW1/4 SW1/4 NE1/4 and W 1/2 NE1/4 SW1/4 NE1/4, sec. 13, T21S, R9W, Luna County. Strata dip 5–10° to N40°W–N87°E.

unit	lithology	thickness (m)
	Lobo Formation:	
23	Sandstone; grayish red purple (5 RP 4/2) and very dusky red purple (5 RP 2/2); arkosic; very coarse grained; angular to subrounded; poorly sorted; non-calcareous; trough crossbedded.	not measured
	Disconformity	
	Mancos Formation (upper member):	
22	Silty shale; dusky yellow (5 Y 6/4) and light olive gray (5 Y 5/2); calcareous.	1.8
21	Shale; light olive gray (5 Y 6/1) and olive gray (5 Y 4/1); weathers grayish yellow (5 Y 8/4); calcareous; contains two thin (0.1 m thick) silty beds 1.4 m and 1.8 m above base; a layer of septarian limestone nodules about 0.3–0.6 m in diameter 2.4 m above base.	3.9
20	Shale, olive gray (5 Y 4/1); calcareous.	9.1
19	Siltstone; light olive gray (5 Y 6/1); weathers dark yellowish orange (10 YR 6/6); fine sand in some beds; calcareous; bioturbated; two thin (0.1 m) massive siltstone beds are 0.3 and 1.4 m above base of unit (UNM locality 1374).	2.3
18	Siltstone; medium light gray (N 6) and grayish orange (10 YR 7/4); calcareous; laminar.	2.3
17	Siltstone; light olive gray (5 Y 6/1); weathers grayish orange (10 YR 7/4); calcareous; good marker bed; UNM locality 1367.	0.05
16	Shale; light olive gray (5 Y 5/2); calcareous; contains a silty calcarenite (oyster hardground) 0.5 m above base that is dark yellowish orange (10 YR 6/6) (matrix) and medium gray (N 5); fossils (UNM locality 1372).	7.9

Mancos Formation (Bridge Creek Member):

15 Limestone; medium dark gray (N 4); silty micrite; nodular; every nodule is an ammonite mold or cast (UNM locality 1366). 0.2

14 Silty shale; medium dark gray (N 4); calcareous; fossiliferous (UNM locality 1373). 0.5

13 Limestone; light olive gray (5 Y 6/1); weathers grayish orange (10 YR 7/4); silty micrite; fossiliferous (UNM locality 1370). 0.3

12 Silty shale; same lithology and color as unit 8; fossils; contains *Pycnodonte* hardground (UNM locality 1371). 0.6

11 Limestone; same lithology and colors as unit 9. 0.2

10 Silty shale; medium dark gray (N 4); slightly calcareous. 0.6

9 Limestone; medium dark gray (N 4); weathers grayish orange (10 YR 7/4); micrite; silty. 0.2–0.3

8 Shale; olive gray (5 Y 3/2); slightly silty; calcareous; top of unit is thin bentonite. 2.3

7 Limestone; medium dark gray (N 4); weathers grayish orange (10 YR 7/4); micritic; silty. 0.3

Mancos Formation (lower member):

6 Silty shale with some interbeds of siltstone; shale is light olive gray (5 Y 6/1) to medium gray (N 5); siltstones are medium gray (N 5) and weather grayish orange (10 YR 7/4); calcareous; siltstone beds are well indurated and form thin (0.1–0.3 m) resistant beds throughout the unit. 26.2

5 Siltstone; pale yellowish brown (10 YR 6/2) to pale yellowish orange (10 YR 8/6); weathers grayish orange (10 YR 7/4); slightly calcareous; fossiliferous (UNM locality 1365). 8.3

4 Sandstone; very light gray (N 8); weathers dark yellowish orange (10 YR 6/6); quartzose; medium grained; subangular to well rounded; well sorted; calcareous; fossiliferous; trough crossbedded. 1.1

3 Conglomerate; matrix is light gray (N 7) and weathers dark yellowish orange (10 YR 6/6); clasts are white (N 9), dark gray (N 3) and grayish orange (10 YR 7/4); matrix supported; clasts are chert, quartzite and limestone up to 2.0 cm in diameter; matrix is sandstone that is quartzose, medium-grained, angular to subrounded, well sorted and calcareous; base is bioturbated. 0.2–0.3

Disconformity

Sarten Formation:

2 Silty sandstone; same lithology and colors as unit 7 of section A; UNM locality 1364. 0.1

1 Sandy siltstone; medium dark gray (N 4) and dark yellowish orange (10 YR 6/6); calcareous; bioturbated. 1.5+

Section G

Measured in the NE¼ NW¼ SW¼ SE¼, sec. 29, T21S, R8W, Luna County. Strata dip 20° to S30°W.

unit	lithology	thickness (m)
	Sarten Formation:	
22	Sandstone; light olive gray (5 Y 6/1); weathers light brown (5 YR 5/6); quartzose; very fine grained; subangular to well rounded; well sorted; slightly calcareous; planar crossbedded.	3.0+
21	Sandy siltstone; same colors and lithology as unit 15.	1.2
20	Sandy siltstone; yellowish gray (5 Y 8/1); weathers moderate brown (5 YR 4/4) and grayish orange (10 YR 7/4); calcareous; laminar.	0.9
19	Silty shale; dark gray (N 3); weathers moderate yellowish brown (10 R 5/4); microfossils (UNM locality 1378).	0.6
18	Fossiliferous calcarenite; same colors, lithology and fossils as unit 10.	0.2
17	Silty sandstone; same color and lithology as unit 11.	0.6
16	Fossiliferous calcarenite; same colors, lithology and fossils as unit 10.	0.2
15	Sandy siltstone; mottled dark yellowish brown (10 YR 4/2) and olive gray (5 Y 3/2); calcareous (UNM locality 1382).	0.3
14	Fossiliferous calcarenite; same colors, lithology and fossils as unit 10.	0.2
13	Silty sandstone; same color and lithology as unit 11.	0.8
12	Fossiliferous calcarenite; same colors, lithology and fossils as unit 10.	0.1
11	Silty sandstone; moderate yellowish brown (10 YR 5/4) quartzose; silty to medium grained; subrounded; poorly sorted; hematite stained; bioturbated (UNM locality 1377).	0.6
10	Fossiliferous calcarenite; olive gray (5 Y 4/1); weathers pale olive (10 Y 6/2).	0.1
9	Sandy siltstone; pale olive (10 Y 6/2); weathers grayish orange (10 YR 7/4); very calcareous; contains 2 thin layers of limestone nodules like unit 7 (UNM locality 1376).	1.0
8	Fossiliferous limestone nodules (UNM locality 1358).	0.2
7	Sandy siltstone and silty sandstone with three thin (up to 0.1 m) layers of nodular limestone; siltstone is grayish olive green (5 GY 3/2), weathers to grayish orange (10 YR 7/4) and very calcareous; sandstone is greenish gray (5 G 6/4), weathers moderate yellowish brown (10 YR 5/4), quartzose, fine-grained, subangular to rounded, well sorted, slightly calcareous and massive (UNM locality 1375).	1.7
6	Sandy siltstone; pale olive (10 Y 6/2) and light olive gray (5 Y 5/2); weathers light olive brown (5 Y 5/6); slightly calcareous; locally hematitic.	0.9
5	Sandstone; yellowish gray (5 Y 8/1) and moderate yellowish brown (10 YR 5/4); weathers to mottles of light gray (N 7), dusky red (5 R 3/4), light brown (5 YR 5/6) and moderate red (5 R 5/4); quartzose; medium-grained; subangular to rounded; moderately sorted; non-calcareous; hematite stains; lower 0.9 m has trough crossbeds; remainder is massive to bioturbated; fossil wood (UNM locality 1383).	4.6
4	Sandstone; pale olive (10 Y 6/2) and moderate orange pink (5 YR 8/4); weathers to grayish orange (10 YR 7/4); quartzose; medium-grained; subangular to subrounded; poorly sorted; calcareous; planar and trough crossbedded.	8.2
	Disconformity	
	Abo Formation:	
3	Conglomerate; same colors and lithology as unit 1.	7.9
2	Sandy siltstone; moderate yellowish brown (10 YR 5/4); calcareous; metasomatized; has some trough-shaped scour surfaces.	1.8
1	Conglomerate of clast-supported limestone cobbles as much as 15 cm in diameter; clasts are medium light gray (N 6) to light bluish gray (5 B 7/1) micrite; matrix is grayish orange (10 YR 7/4); quartzose; very fine- to medium-grained; subrounded to very angular; poorly sorted; calcareous sandstone; massive.	1.1+

Section H

Measured in the NE¼ NE¼ SE¼ SW¼, sec. 29, T21S, R8W, Luna County. Strata dip 10° to N85°W.

unit	lithology	thickness (m)
	Sarten Formation:	
3	Silty sandstone; very light gray (N 8); weathers grayish orange (10 YR 7/4), moderate yellowish brown (10 YR 5/4) and dusky red (5 R 3/4); quartzose; silty to medium grained; subrounded to subangular; poorly sorted; non-calcareous; planar and trough crossbedded.	3.0+
	Disconformity	
	Abo Formation:	
2	Conglomerate of clast-supported limestone cobbles as much as 15 cm in diameter; clasts are medium light gray (N 6) to light bluish gray (5 B 7/1) micrite; matrix is grayish orange (10 YR 7/4), quartzose; very fine- to medium-grained, subrounded to very angular, poorly sorted, calcareous sandstone; generally massive but has scour surfaces every 0.3 (m) to 0.9 m, some trough crossbeds and some graded beds; some sandstone clasts.	16.6
1	Siltstone; grayish red (10 R 4/2); calcareous and, in some places, sandy; contains bluish gray (5 B 7/1) limestone nodules.	10.0+

Section I

Measured in the SE¼ SW¼ SE¼ SW¼, sec. 7, T21S, R8W and the NW¼ NW¼ NE¼ NW¼, sec. 18, T21S, R8W, Luna County. Strata dip 8° to S60°W.

unit	lithology	thickness (m)
	Mancos Formation (lower member):	
22	Sandstone; same colors and lithology as unit 13 of section A.	1.1
21	Silty sandstone; same colors and lithology as unit 12 of section A.	0.3
	Disconformity	
	Sarten Formation:	
20	Limestone septaria; same colors and lithology as unit 10 of section A.	0.5
19	Sandy siltstone; same colors and lithology as unit 9 of section A.	0.4
18	Limestone septaria; same colors and lithology as unit 8 of section A; fossiliferous.	0.4
17	Silty sandstone; same colors and lithologies as units 5, 6 and 7 of section A.	3.7
16	Siltstone and silty sandstsone; same colors and lithology as unit 4 of section A.	0.6
15	Sandstone; yellowish gray (5 Y 7/2) and grayish orange (10 YR 7/4); weathers to moderate brown (5 YR 3/4) and moderate yellowish brown (10 YR 5/4); same lithology as unit 14; bedforms begin with trough crossbeds (some isoclinally folded) grading upward to laminar and then bioturbated in the upper 1.5 m; *Ophiomorpha*.	7.9
14	Sandstone; yellowish gray (5 Y 8/1); weathers pale brown (5 YR 5/2); quartzose; fine to medium grained; subangular to subrounded; poorly sorted; limonitic cement; very slightly calcareous; some planar crossbeds but mostly bioturbated; much covered.	3.0
13	Sandstone; yellowish gray (5 Y 7/2); weathers moderate brown (5 YR 4/4) to light brown (5 YR 6/4); same lithology as unit 12; massive except for trough crossbeds and bioturbation in upper 1 m; unit forms a cliff.	3.0
12	Sandstone; very pale orange (10 YR 8/2) and light olive gray (5 Y 6/1); weathers moderate yellowish brown (10 YR 5/4); quartzose; very fine to fine grained; subangular-subrounded; moderately sorted; some silt; slightly calcareous; massive except bioturbated at base.	1.8
11	Sandstone; light gray (N 7); weathers dark yellowish orange (10 YR 6/6), moderate brown (5 YR 4/4) and dark red (5 R 2/6) in hematitic mottles and liesegang banding; quartzose; very fine to fine grained; subangular to subrounded; poorly sorted; very slightly calcareous; planar and low angle trough crossbeds.	6.7
10	Silty sandstone; pale yellowish brown (10 YR 6/2); weathers grayish orange (10 YR 7/4) and moderate yellowish brown (10 YR 5/4); quartzose; very fine to fine grained; subangular to subrounded; poorly sorted; very slightly calcareous; laminar.	0.2
9	Conglomerate; medium gray (N 5), grayish orange (10 YR 7/4) and white (N 9); weathers dark reddish brown (10 R 3/4), moderate brown (5 YR 4/4) and pale yellowish orange (10 YR 8/6); matrix supported; clasts are chert, quartz and lithic pebbles up to 1 cm in diameter; matrix is quartzose, fine- to coarse-grained, subrounded, poorly sorted, hematitic and non-calcareous sandstone; massive.	1.5
8	Silty sandstone; yellowish gray (5 Y 7/2); weathers in liesegang bands of dark yellowish orange (10 YR 6/6) grayish red (5 R 4/2) and moderate brown (5 YR 4/4); same lithology as unit 7; oxidized plant stems; much covered; ripple laminar.	6.6
7	Silty sandstone; yellowish gray (5 Y 7/2); weathers dark yellowish orange (10 YR 6/6) and light brown (5 YR 5/6); quartzose; fine to medium grained; subangular to subrounded; poorly sorted; hematitic; slightly calcareous; planar crossbedded; cliff former.	2.4
6	Siltstone and sandy siltstone; medium gray (N 5) and medium dark gray (N 4); weathers grayish orange (10 YR 7/4) to dark yellowish orange (10 YR 6/6); non-calcareous; siltstone is laminar; sandy siltstone is bioturbated; hematitic; much covered.	9.4
5	Silty sandstone; yellowish gray (5 Y 7/2); weathers grayish orange (10 YR 7/4); quartzose; very fine grained; subangular to rounded; moderately well sorted; slightly calcareous; hummocky trough crossbeds.	1.5
4	Silty sandstone; moderate yellowish brown (10 YR 5/4) and dark yellowish orange (10 YR 6/6); weathers pale brown (5 YR 5/2); quartzose; very fine grained; subangular-subrounded; moderately well-sorted, slightly calcareous; hematitic; low angle trough crossbeds.	0.6
3	Sandy siltstone; light gray (N 7), weathers light olive gray (5 Y 6/1) and grayish orange (10 YR 7/4); non-calcareous; low angle trough crossbeds and bioturbation.	0.3
2	Silty sandstone; olive gray (5 Y 4/1); quartzose; fine-grained; subrounded; poorly sorted; slightly calcareous; laminar.	0.2
1	Sandstone; light olive gray (5 Y 6/1); weathers moderate brown (5 YR 4/4) and dark yellowish orange (10 YR 6/6); quartzose; fine grained; subangular-subrounded; moderately well sorted; slightly calcareous; hematitic; massive.	0.5+



Playas Peak, Little Hatchet Mountains. View is N39°W. Slopes in foreground and hill on right composed of west- and south-dipping Mojado Formation. Small part of west end of Howell's Ridge visible to right of Playas Peak (distant center). Two low hills on left are capped by reef member of U-Bar Formation, thrust over Mojado. Vegetation in foreground includes shrubby mesquite, acacia, mariola, ocotillo and prickly pear cactus. Camera station is in SE¼ SW¼, sec. 15, T28S, R16W. Altitude about 1539 m. W. Lambert photograph No. 87L45. 24 July 1987, 5:57 p.m., MDT.