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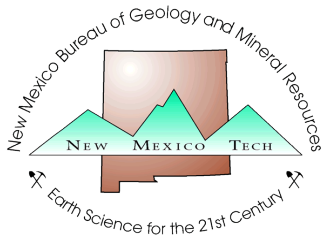

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The Upper Cretaceous (Turonian) Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale in central New Mexico and their relationship to the Juana Lopez Member of the Mancos Shale in the San Juan Basin

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Abstract

The distinctive rock types and faunas of the Juana Lopez Member of the Mancos Shale of the San Juan Basin can be recognized to the southeast in Socorro, Lincoln, and Otero Counties, New Mexico. Consequently, this lithostratigraphic name is extended formally into central New Mexico, where it is used as a bed-rank unit within the D-Cross Tongue of the Mancos Shale. The Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale in central New Mexico consist of thin calcarenites and sandstones interbedded with thicker, noncalcareous shales as much as 21.4 ft (6.5 m) thick. Just as in the San Juan Basin, the base of the Juana Lopez Beds can lie in the middle Turonian *Prionocyclus macombi* Zone and its top, in the upper Turonian *P. novimexicanus* Zone. However, the unit is less than half as thick in central New Mexico as it is in the San Juan Basin, suggesting it is condensed to the southeast. Reduced thicknesses in units below and within the Juana Lopez Member and Beds suggest erosional unconformities throughout its geographic extent in New Mexico. The most distinctive fossil in the Juana Lopez is the small, ribbed oyster *Cameleolopha lugubris* (Conrad 1857), which is abundant in the basal part of the unit.

The chronostratigraphy of the upper and lower contacts of the Juana Lopez in 11 outcrop sections extending from Mesa Verde National Park, Colorado, to northwest Otero County, New Mexico, indicate that neither contact represents a regional isochronous surface. An assemblage of three ammonite and two bivalve species from near the base of the Juana Lopez at four localities in New Mexico may provide the biostratigraphic resolution required for isochroneity. This assemblage includes the Boreal species *Prionocyclus macombi, Coilopoceras inflatum, Inoceramus dimidius,* and *Cameleolopha lugubris* along with the distinctive Tethyan ammonite *Hourcquia mirabilis,* described originally from Madagascar. However, this assemblage occurs in only three of the 11 profiled outcrop sections, although it is also known from the base of the Juana Lopez Member of the Carlile Shale in northeastern New Mexico.

Introduction

The basal portion of the D-Cross Tongue of the Mancos Shale—the noncalcareous shale tongue lying between the Tres Hermanos Formation and the Gallup Sandstone—contains interbedded, resistant, thin calcarenite beds in Socorro, Lincoln, and Otero Counties, New Mexico, that are lithologically and faunally similar to those in the Juana Lopez Member of the Mancos Shale in the San Juan Basin (Fig. 1). With publication of the measured sections below, the Juana Lopez terminology is extended from the Laguna–San Ysidro area (Cobban and Hook 1989, fig. 2) as far east as northwest Otero County, New Mexico, where it is used as a formal, bed-rank unit of interbedded noncalcareous shale and arenite within the lower part of the D-Cross Tongue of the Mancos Shale. The interbedded arenites and shale in northwest Otero County are the same age as and of similar faunal composition to the Juana Lopez Member of the Mancos Shale at its type section in Santa Fe County, New Mexico. In both areas, the basal part of the unit lies in the middle Turonian *Prionocyclus macombi* Zone and the top, in the upper Turonian *P. novimexicanus* Zone. In central New Mexico, the Juana Lopez Beds are less than one-quarter as thick as the Juana Lopez Member in the San Juan Basin, yet the arenites at the base and top of the bed-rank unit contain almost identical faunas, indicating that they were deposited penecontemporaneously. Therefore, the Juana Lopez Beds in central New Mexico represent condensed intervals.

In earlier publications the issue of formal (bed-rank) designation of these Juana Lopez-like rocks has been sidestepped in central New Mexico by referring to the calcarenites in the D-Cross Tongue informally as being of Juana Lopez aspect (Tabet 1979, p. 6; Hook and Cobban 2007, p. 93) or referring to them informally as Juana Lopez beds (with a small case "b", e.g. in Hook et al. 2012, figs. 6 and 7). Tabet (1979, p. 6), working in the Jornada del Muerto coal field of Socorro County, points out that there are two thin calcarenites just above the top of the Tres Hermanos Formation that are lithologically and faunally similar to the Juana Lopez Member. Fieldwork presented below indicates that the Juana Lopez Beds can be differentiated within the basal part of the D-Cross Tongue in Otero, Lincoln, and northern Socorro Counties, New Mexico. Rock types that can be assigned to the Juana Lopez Beds are not present in the D-Cross Tongue at the Carthage coal field, Socorro County, and to the south in Sierra and Doña Ana Counties, even though the basal D-Cross Tongue at these localities contains rocks of the appropriate age (Hook et al. 2012).

Background

Rankin (1944, pp. 12, 19, and 20) applied the name "Juana Lopez sandstone member" to 10 ft (3 m) of thin-bedded, brown-weathering, highly calcareous, very fossiliferous sandstone near the top of the Carlile Shale on the Mesita de Juana Lopez Grant near Cerrillos, Santa Fe County, New Mexico. The only fossils listed by Rankin (1944, p. 20) in the type section of the Juana Lopez (Fig. 1) were (with updated names in brackets) *Prionocyclus wyomingensis* [and/or *P. novimexicanus*] and *Inoceramus labiatus* [*I. perplexus*?]. A reexamination of the type section of the Juana Lopez Member by Hook and Cobban (1980a, fig. 5) showed that both *Prionocyclus wyomingensis* in association with *Inoceramus dimidius* and *P. novimexicanus* in association with *I. perplexus* occur in these calcarenites, which are now assigned to the upper part of the redefined Juana Lopez. The two ammonites are very close morphologically; according to Kennedy et al. (2001, p. 117), it was not until 1979 that *Prionocyclus wyomingensis elegans* Haas 1946 was recognized as a junior synonym of *Prionocyclus novimexicanus* (Marcou 1858). Therefore, Rankin (1944) could have been referring to either or both species of ammonites. However, Rankin (1944, p. 13) differentiates clearly among three species of *Inoceramus* (*I. dimidius*, *I. labiatus*, and *I. fragilis*) in the entire Carlile Shale. Neither of the latter two species occurs in the Juana Lopez. Therefore, it appears likely that he misidentified *I. perplexus* as *I. labiatus*.

Pike (1947, p. 22) was aware of Rankin's (1944) work, but did not use the term Juana Lopez in his pioneering work on intertonguing Upper Cretaceous in New Mexico, Arizona, and Colorado. Instead, he used a broadly defined "Carlile zone" and noted that "…*Scaphites warreni* and *Prionocyclus wyomingensis* occur together through a very limited vertical range near the top of the zone and form a very definite horizon marker, the best in the Mancos shale. *Inoceramus fragilis*, *Ostrea lugubris*, and often *Inoceramus dimidius* are associated with *Prionocyclus wyomingensis* and *Scaphites warreni*. In the north, this fossil assemblage is found in a highly calcareous sandy zone that, being harder than the enclosing Mancos shale, usually stands out as a separate lithologic unit and forms a cuesta in the

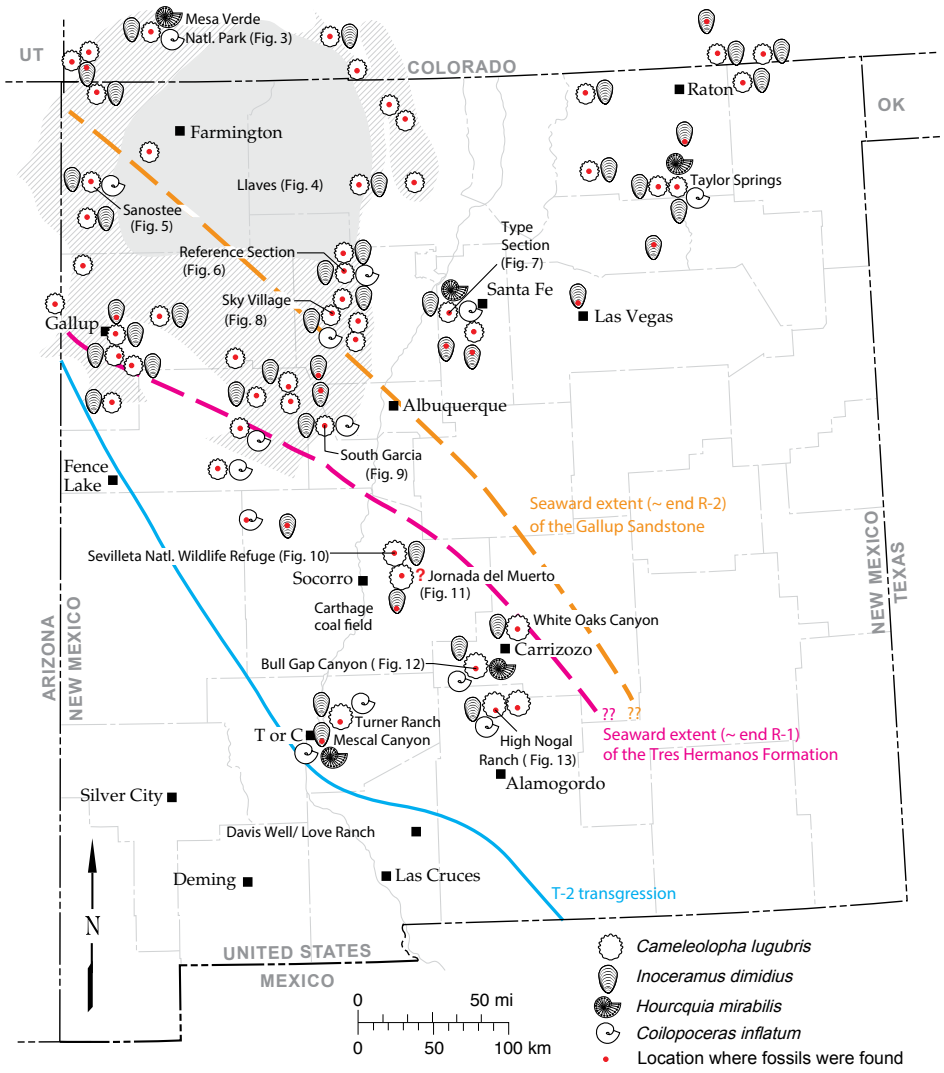


FIGURE 1—Map of New Mexico and portions of adjacent states showing San Juan Basin (gray) and marginal platforms (diagonal lines), cities, key outcrops, and the approximate position (blue line) of the transgressing (T-2) western shoreline of the Late Cretaceous seaway at the end of time during which *Cameleolopha lugubris* lived (late middle Turonian). The shoreline's position is virtually unchanged from that of the earlier (middle Turonian) *C. bellaplicata* shoreline (Hook and Cobban 2011, fig. 3). The locations where four invertebrate species were collected—primarily in calcarenites in the lower and middle portions of the Juana Lopez—are shown. Their widespread distribution indicates that the depositional conditions necessary for calcarenite formation were seaway-wide. The seaward extent of the Tres Hermanos Formation and Gallup Sandstone (red and orange lines) mark the approximate positions of the shoreline at the end of the R-1 and R-2 regressions, respectively (modified from Molenaar 1986, fig. 10).

slightly dipping strata. This calcareous zone contains abundant fossils, and many large slabs are made up almost entirely of them."

Dane et al. (1966) recognized that most of the highly calcareous sandstones of the Juana Lopez were actually calcarenites composed of bioclastic debris. They redefined the Juana Lopez Member by extending its lower boundary downward to the base of the lowest, ridge-forming calcarenite above the Semilla Sandstone Member of the Mancos Shale on the east side of the San Juan Basin, where they established a reference section (Fig. 1). Their redefinition lowered the base of the Juana Lopez approximately 100 ft (30 m) below the base of Rankin's type section. Biostratigraphically, the redefinition lowered the base of the member so that it included the upper part of the middle Turonian *Prionocyclus macombi* Zone. The characteristic oyster from the basal part of the redefined member is *Cameleolopha lugubris*.

Both Lamb (1968, p. 831, 836) and Woodward (1987, p. 40) misinterpreted Dane et al.'s (1966) redefinition of the Juana Lopez to include all the rock in the interval between the top the Semilla (or Codell?) Sandstone Member and the top of the calcarenitic ridge of Rankin's (1944) original definition of the Juana Lopez. They, therefore, used Rankin's restricted definition on the east side of the San Juan Basin because the Semilla is not developed everywhere in that area.

The distinctive and widespread nature of this very fossiliferous, arenaceous interval had been known long before Rankin (1944) named it formally and Dane et al. (1966) redefined it. Newberry (1861, p. 106), describing the geology along the Santa Fe Trail near Las Vegas, New Mexico, noted that the shales in the Upper Cretaceous "…include thin arenaceous bands, containing fragments of shells of *Inoceramus*, which at first sight resemble fish scales….We found these strata much better displayed further eastward, but even here they exhibit characters sufficient to distinguish them from any rocks we had before met with." Later, Newberry (1876, p. 87) referred to these ferruginous layers along the banks of the Red River as "…a clearly defined geological horizon throughout all the Cretaceous area of New Mexico; they contain here *Ostrea lugubris*…."

This reference by Newberry (1876, p. 87) to beds containing *Ostrea* [*Cameleolopha*] *lugubris* indicates that he was referring to calcarenites in the lower part of the Juana Lopez Member as redefined by Dane et al. (1966), not to the (upper) calcarenites defined originally by Rankin (1944) as the Juana Lopez sandstone member, which lacked plicate oysters. Meek (1876, p. 124) described Newberry's collections and stated that *C. lugubris* is "…usually found scattered about on the surfaces of calcareous and sandy slabs…." In addition, Meek (1876, pp. 132–133) described the new ammonite species *Prionocyclus*? *macombi* from these same collections. Today, *C. lugubris* and *P. macombi* are two of the most important guide fossils to the Upper Cretaceous in New Mexico.

Hook and Cobban (1980b, p. 47), working in Colfax County, New Mexico, concluded that the holotype of *P. macombi* "… probably came from the same outcrop of the Juana Lopez Member of the Carlile Shale that yielded the holotype of [*Cameleolopha*] *lugubris*." This faunal association points to the lower part of the [redefined] Juana Lopez. Historically, it is the lower ledge of calcarenites that seems to have been regarded as the widespread marker horizon, thus adding more credence to the suitability of Dane et al.'s (1966) redefinition.

The characteristic rock type of the Juana Lopez Member in New Mexico is calcarenite, which is usually thin, hard, dense, rusty brown weathering, slabby, and very fossiliferous. However, as redefined by Dane et al. (1966), the Juana Lopez is composed primarily of noncalcareous shale with thin interbeds of calcarenite, consisting primarily of inoceramid and oyster debris, or calcareous, quartzose sandstone. Resistant beds of arenite mark the top and bottom of the Juana Lopez; they stand in relief above the softer shales and create ridges (Fig. 2A). At several localities in the San Juan Basin and northeast New Mexico, the initial resistant bed of the Juana Lopez appears to have been deposited or formed on a submarine erosion surface that scoured into the top of the Semilla Sandstone Member

of the Mancos Shale. Submarine erosion of approximately the same age in northern Socorro County scoured the top of the Tres Hermanos Formation, concentrating oyster shells and phosphatized internal molds of bivalves as a lag deposit on the upper surface of the Fite Ranch Sandstone Member (Hook and Cobban 2007, pp. 91–92).

The base of the Juana Lopez in the San Juan Basin, deposited early in the T-2 transgression, lies in the upper part of the *Prionocyclus macombi* Zone; almost universally, the base coincides with the first appearance of the oyster *Cameleolopha lugubris*. The top of the Juana Lopez, deposited about the middle of the T-2 transgression, lies in either the *P. wyomingensis* Zone or the *P. novimexicanus* Zone.

The redefined type and reference sections of the Juana Lopez are almost identical in thickness, rock type, and faunal content (Figs. 2A, B; Hook and Cobban 1980a). The base of each section lies near the top of the middle Turonian *Prionocyclus macombi* Zone, and the top of each lies in the base of the upper Turonian *Prionocyclus novimexicanus* (= *Scaphites whitfieldi*) Zone. Fossils from the base, with specific names updated from Dane et al. (1966) and Hook and Cobban (1980a), include *Cameleolopha lugubris*, *Prionocyclus macombi* (Fig. 2F), *Coilopoceras inflatum* (Figs. 2F, G), *Hourcquia mirabilis* (Fig. 2H), and *Inoceramus dimidius*. This assemblage places the base in the *Coilopoceras inflatum* Subzone of the *P. macombi* Zone. Key fossils from the uppermost calcarenites include *P. novimexicanus, Scaphites whitfieldi*, and *I. perplexus*. *Cameleolopha lugubris* is not listed in this paper as a key fossil from the uppermost part of the Juana Lopez, even though Dane et al. (1966, fig. 3 and p. H11 and H13-H14) list a smooth variety of *C. lugubris* from the upper Juana Lopez. The key word is "smooth," which means these oysters do not have ribs, and, therefore, belong in a different genus and species.

Geographically, the Juana Lopez Member and Beds occupy a broad portion of the southern Western Interior. The distinctive lithologies of Juana Lopez extend as far north as the Colorado Springs area of El Paso County, Colorado (McLane 1982, p. 72) and southwestern Garfield County west of Glenwood Springs, Colorado (Merewether et al. 2006, fig. 1); as far east as Hamilton County, Kansas (Hattin 1975, text-fig. 3); as far south as the Three Rivers area, Otero County, New Mexico (this paper); and as far west as Carbon County, Utah (USGS Mesozoic locality D12017). Within New Mexico (Fig. 1), the Juana Lopez extends over most of the northern half of the state from the Four Corners area of San Juan County east to Union County, south to northern Otero County, and west to southwest McKinley County. To the southeast in Texas, Juana Lopez-like rock types and associated faunas have been reported in the Chispa Summit Formation in southwest Jeff Davis County by Kennedy et al. (1989, p. 46).

The calcarenites in the Juana Lopez are self-sourcing sediment beds composed of bioclastic debris derived primarily from the hard parts of organisms that lived on the sea floor. This debris is composed of the prismatic layers of inoceramid shells and fragments of oyster shells along with a minor component of abraded fish teeth, bones, and scales (Dane et al. 1966, p. H5). Aubrey (1991, p. B11), working in the northern San Juan Basin in southwestern Colorado, concluded that the "…Juana Lopez is a condensed section that marks a period of most rapid rise in relative sea level during the T-2 transgression…. During sea-level rise, lagoons and estuaries trapped sediment input in coastal areas, and the rate of sediment input to the shelf decreased. Sediment on the shelf was then reworked by storm waves and currents, and bioclastic debris was concentrated into calcarenite beds." This is an interesting interpretation, but does not appear to go far enough. It treats the entire Juana Lopez as a single calcarenite unit, not unlike Rankin's (1944) original concept, rather than as a series of related calcarenite units (i.e., condensed intervals) separated by several tens of feet of (non-condensed) shale.

The lithic and faunal characteristics of the Juana Lopez will be compared and contrasted through an examination of 11 measured sections (Table 1) extending southeastward from Mesa Verde National Park in the northwest part of the San Juan Basin to northwest Otero County, New Mexico (Fig. 1), a straight line distance of more than 300 mi (480 km). The Juana Lopez is a member-rank unit of the Mancos Shale at the principal reference section for the Mancos Shale at Mesa Verde National Park in Montezuma County, Colorado, at Llaves in Rio Arriba County, New Mexico, at the Sanostee section in San Juan County, at the reference section and the Sky Village section in Sandoval County, and at the type section in Santa Fe County.

TABLE 1—Summary of the lithic, faunal, and stratigraphic characteristics of the 11 measured sections of the Juana Lopez discussed in the paper. The alphanumeric code(s) shown in the "Zone(s)" column refer to the faunal content of the Juana Lopez at the specific locality, beginning with the lowest (3) through the highest (5) zone occurring in the Juana Lopez. Each zone is further subdivided into subzones and assemblage zones, indicated by the letters *a* (lowest) through *c* (highest). The specific content of each alphanumeric code is shown in Table 2. The "Key unit" column contains the formally named unit below the base of the Juana Lopez: BCLM = Bridge Creek Limestone Member of the Mancos Shale, SSM = the Semilla Sandstone Member of the Mancos Shale, and FRSM = the Fite Ranch Sandstone Member of the Tres Hermanos Formation.

Measured section	Thickness	Arenite	Shale	Bentonite	Zone(s)	Key unit	Distance above key unit
Juana Lopez Member northern New Mexico							
Mesa Verde Natl. Park, CO	139.6 ft (42.6 m)	13.3 ft (4.1 m) - 9.5%	123.4 ft (37.6 m) - 88.4%	14, 2.9 ft (89 cm), 2.1%	3*b*?, 3*c**, 4*a*, and 5*b*	BCLM	340.2 ft (103.7 m)
Llaves	135.7 ft (41.4 m)	2.7 ft (81 cm) - 2.0%	133.0 ft (40.5 m) - 98.0%	none observed	3*c*? and 4*a*	SSM	440 ft (134 m)
Sanostee	106.2 ft (32.4 m)	37.0 ft (11.3 m) - 34.9%	69.2 ft (21.1 m) - 65.1%	none observed	3*b*?, 3*c*, and 4*a*	BCLM	60 ft (18.3 m)
Reference section	106.9 ft (32.6 m)	5.5 ft (1.7 m) - 5.1%	100.3 ft (30.6 m) - 93.8%	7, 1.1 ft (34 cm), 1.1%	3*c* and 5*a*	SSM	12.5 ft (3.8 m)
Type section	106.1 ft (32.3 m)	5.5 ft (1.7 m) - 5.2%	98.2 ft (29.9 m) - 92.6%	12, 2.4 ft (72 cm), 2.2%	3*c**, 4*a*, and 5*a*	SSM	60 ft (18.3 m)
Sky Village	111.4 ft (33.9 m)	14.4 ft (4.4 m) - 12.9%	97.0 ft (29.6 m) - 87.1%	none observed	3*b*?, 3*c*, and 4*a*	SSM	15 ft (4.6 m)
Juana Lopez Beds central New Mexico							
South Garcia	57.1 ft (17.4 m)	3.1 ft (95 cm) - 5.5%	54.0 ft (16.5 m) - 94.5%	none observed	3*c* and 4*a*	SSM	0.0 ft (0.0 m)
Sevilleta Natl. Wildlife Refuge	5.5 ft (1.7 m)	0.7 ft (21 cm) - 12.8%	4.8 ft (1.5 m) - 87.2%	none observed	4*a*, *b*	FRSM	5.0 ft (1.5 m)
Jornada del Muerto	10.3 ft (3.1 m)	0.6 ft (18 cm) - 5.7%	9.7 ft (3.0 m) - 94.3%	none observed	5*a*	FRSM	8.5 ft (2.6 m)
Bull Gap Canyon	16.7 ft (5.1 m)	2.7 ft (81 cm) - 16.0%	14.0 ft (4.3 m) - 84.0%	none observed	3*c** and 4*a*?	FRSM	7.0 ft (2.1 m)
High Nogal Ranch	21.4 ft (6.5 m)	1.38 ft (42 cm) - 6.5%	20.0 ft (6.1 m) - 93.5%	none observed	3*c*, 4 , and 5*a*	FRSM	7.0 ft (2.1 m)

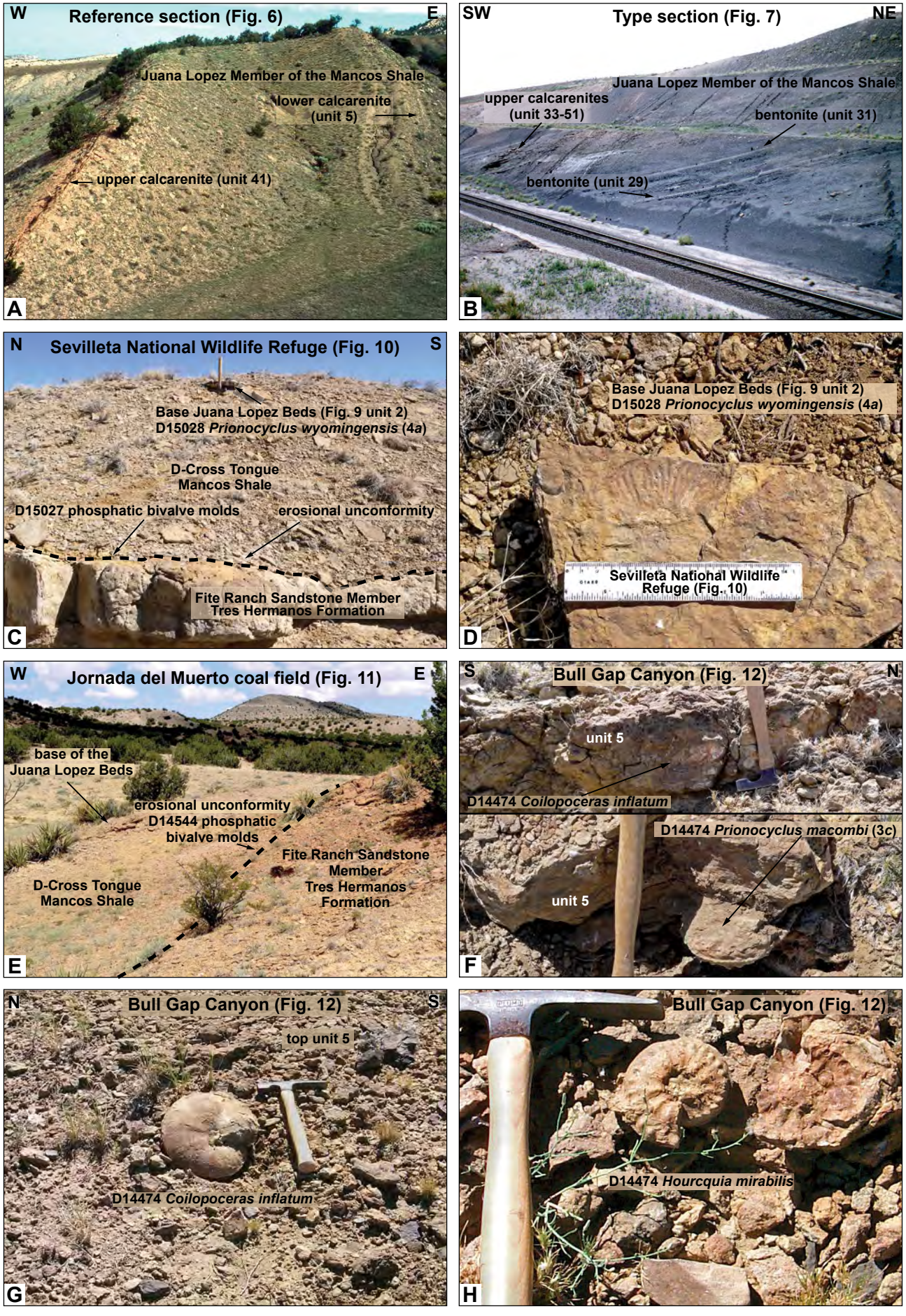

W
Reference section (Fig. 6)
E
Juana Lopez Member of the Mancos Shale
lower calcarenite (unit 5)
upper calcarenite (unit 41)
A
SW
Type section (Fig. 7)
NE
Juana Lopez Member of the Mancos Shale
upper calcarenites (unit 33-51)
bentonite (unit 31)
bentonite (unit 29)
B
N
Sevilleta National Wildlife Refuge (Fig. 10)
S
Base Juana Lopez Beds (Fig. 9 unit 2)
D15028 Prionocyclus wyomingensis (4a)
D-Cross Tongue
Mancos Shale
D15027 phosphatic bivalve molds
erosional unconformity
Fite Ranch Sandstone Member
Tres Hermanos Formation
C
Base Juana Lopez Beds (Fig. 9 unit 2)
D15028 Prionocyclus wyomingensis (4a)
Sevilleta National Wildlife Refuge (Fig. 10)
D
W
Jornada del Muerto coal field (Fig. 11)
E
base of the Juana Lopez Beds
erosional unconformity
D14544 phosphatic bivalve molds
Fite Ranch Sandstone Member
Tres Hermanos Formation
D-Cross Tongue
Mancos Shale
E
S
Bull Gap Canyon (Fig. 12)
N
unit 5
D14474 Coilopoceras inflatum
D14474 Prionocyclus macombi (3c)
unit 5
F
N
Bull Gap Canyon (Fig. 12)
S
top unit 5
D14474 Coilopoceras inflatum
G
Bull Gap Canyon (Fig. 12)
D14474 Hourcquia mirabilis
H

FIGURE 2—Photographic gallery of the rocks and fossils from the Juana Lopez in the study area. **A**—Outcrop view, looking north, of the 106.9-ft-(32.6-m-) thick reference section (Fig. 6) of the Juana Lopez Member of the Mancos Shale exposed in the SE¼ SW¼ sec. 14 T19N R1W La Ventana 7.5-min quadrangle, Sandoval County, New Mexico. **B**—View looking southeast at the south side of the railroad cut of the 106.1-ft- (32.3-m-) thick type section (Fig. 7) of the Juana Lopez Member of the Mancos Shale exposed in the NW¼ SE¼ sec. 33 (projected) T15N R7E Madrid 7.5-min quadrangle, Santa Fe County, New Mexico. The two bentonites (units 29 and 31) are separated by 10 ft (3 m) of section.**C**—Outcrop view, looking east, of the upper portion of the Tres Hermanos Formation and the lower part of the D-Cross Tongue of the Mancos Shale, including the basal calcarenite of the Juana Lopez Bed on Sevilleta National Wildlife Refuge (Fig. 10). An erosion surface separates the Fite Ranch Sandstone Member from the overlying D-Cross Tongue. A lag deposit on this surface contains phosphatized internal molds of bivalves and corroded valves of *Cameleolopha bellaplicata* (D15027). The basal calcarenite of the Juana Lopez Beds, 5 ft (1.5 m) above this contact, litters the slope with debris. The outcrop is 1.07 mi (1.8 km) N51°W of the southeast corner of the La Joya 7.5-min quadrangle, Socorro County, New Mexico. **D**—Typical preservation of ammonites in calcarenites is shown by this specimen of *Prionocyclus wyomingensis* (D15028, USNM 593441), preserved as an impression in the basal calcarenite of the Juana Lopez Beds on Sevilleta National Wildlife Refuge (Fig. 10). Same location as Fig. 2C. **E**—Outcrop view, looking south, of the upper portion of the Tres Hermanos Formation and the lower part of the D-Cross Tongue of the Mancos Shale, including the basal calcarenite of the Juana Lopez Beds at the Jornada del Muerto coal field (Fig. 11). An erosion surface separates the Fite Ranch Sandstone Member from the overlying D-Cross Tongue. A lag deposit on this surface contains phosphatized internal molds of bivalves (D14544). The calcarenites of the Juana Lopez Beds, 5 ft (1.5 m) above this contact at this locality, form a minor ridge. Only the lower part of the Juana Lopez is exposed here. The outcrop is in the NW¼ SW¼ sec. 5 T3S R3E Bustos Well 7.5-min quadrangle, Socorro County, New Mexico. **F**—Outcrop view, looking east, of the basal arenite (unit 5) of the Juana Lopez Beds of the D-Cross Tongue at Bull Gap Canyon (Fig. 12) showing in situ positions of two key Juana Lopez ammonites. The disk-shaped, involute ammonite *Coilopoceras inflatum* (upper view, D14474, USNM 593442) occurs 4 inches (10 cm) above the base of unit 5, whereas the evolute, keeled ammonite *Prionocyclus macombi* (lower view, D14474, USNM 593443) occurs at the base of unit 5. Both specimens were collected in the SW¼ NW¼ sec. 19 T9S R9E Bull Gap 7.5-min quadrangle, Lincoln County, New Mexico. Hammer is 13 inches (33 cm) long. **G**—Outcrop view, looking east, of a specimen of *Coilopoceras inflatum* (D14474, USNM 593444) that has weathered from the top of the basal arenite (unit 5) of the Juana Lopez Beds at Bull Gap Canyon (Fig. 12). *Coilopoceras inflatum* is a large, robust, very involute ammonite with foldlike primary ribs and a narrow sharp venter on early whorls that becomes well rounded on later whorls. *Coilopoceras inflatum* is an uncommon ammonite, known from only 14 localities, 13 of which are in the study area. Same locality as Fig. 2F. Hammer is 13 inches (33 cm) long. **H**—A specimen of *Hourcquia mirabilis* (D14474, USNM 593445), hammer for scale, that was collected in situ from 4 inches (10 cm) below the top of the basal arenite (unit 5) of the Juana Lopez Beds at Bull Gap Canyon (Fig. 12). *Hourcquia mirabilis* is a Tethyan ammonite, described from Madagascar. In the Western Interior it is known from five localities, all within the study area, four in New Mexico and one in Colorado. It is a keeled, ribbed, involute ammonite that has a trapezoidal whorl section with umbilical bullae and blunt ventrolateral nodes. This specimen was collected in the SW¼ NW¼ sec. 19 T9S R9E Bull Gap 7.5-min quadrangle, Lincoln County, New Mexico.

TABLE 2—Content by species of the middle through upper Turonian ammonite zones of *Prionocyclus hyatti* (zone 2), *P. macombi* (3), *P. wyomingensis* (4), and *P. novimexicanus* (5) that characterize the Juana Lopez in the Western Interior. Subdivisions within the zones, designated by the letters *a*, *b*, and *c* are based on various species of: the ammonite genera *Scaphites* and *Coilopoceras*; the pelecypod genus *Inoceramus*; and the oyster genus *Cameleolopha*. (*Hoplitoides sandovalensis*, shown at the base of the *Coilopoceras* column, is the ancestral species for the genus *Coilopoceras*.) The 3*b* assemblage that contains *P. macombi*, *C. colleti*, *I. dimidius*, and *Cameleolopha lugubris* is extremely rare, occurring at only one locality in the Western Interior, the Llaves, New Mexico, measured section (Fig. 4).

Turonian	Zonal index	Alphanumeric code	*Scaphites*	*Coilopoceras*	*Hourcquia*	*Inoceramus*	*Cameleolopha*
upper	*P. novimexicanus*	5*b*	*S. whitfieldi*	none	none	*I. dakotensis*	none
upper	*P. novimexicanus*	5*a*	*S. whitfieldi*	none	none	*I. perplexus*	none
middle	*P. wyomingensis*	4*b*	*S. ferronensis*	none	none	*I. dimidius*	*C. lugubris*
middle	*P. wyomingensis*	4*a*	*S. warreni*	none	none	*I. dimidius*	*C. lugubris*
middle	*P. macombi*	3*c*	none	*C. inflatum*	*mirabilis**	*I. dimidius*	*C. lugubris*
middle	*P. macombi*	3*b*	none	*C. colleti*	none	*I. dimidius*	*C. lugubris*
middle	*P. macombi*	3*a*	none	*C. colleti*	none	*I. dimidius*	*C. bellaplicata*
middle	*P. hyatti*	2*b*	none	*C. springeri*	none	*I. howelli*	*C. bellaplicata*
middle	*P. hyatti*	2*a*	none	(*H. sandovalensis)*	none	*I. howelli*	*C. bellaplicata*

In the remaining area to the south and southeast, the Juana Lopez is a bed-rank unit in the D-Cross Tongue of the Mancos Shale, which lies between Gallup Sandstone above and either the Tres Hermanos Formation or Semilla Sandstone Member of the Mancos Shale below. The bed-rank terminology has been used previously southeast of the San Juan Basin; this area is represented by South Garcia in Cibola County. The formal "Juana Lopez Beds" terminology is extended southeastward into Socorro County, where it is used at Sevilleta National Wildlife Refuge and the Jornada del Muerto coal field. From there it is extended to Bull Gap Canyon, Lincoln County, and finally to High Nogal Ranch in northwest Otero County. This formal bed-rank terminology has not been used previously in this area.

In the six northern measured sections (Figs. 3–8), the Juana Lopez ranges from 106.1 ft (32.3 m) to 139.6 ft (42.6 m) thick (Table 1). Arenites, primarily calcarenites, comprise from 2% to 34.9% of the member by thickness; the bulk of the unit is composed of shale, limestone concretions, and bentonite (Table 1). In the area southeast of the San Juan Basin (Figs. 9–13), the Juana Lopez is considerably thinner, ranging from 5.5 ft (1.6 m) to 57.1 ft (17.4 m) thick. Arenites comprise from 5.5% to 16% of the total thickness. At High Nogal Ranch (Fig. 13), where the Juana Lopez is less than 20% the thickness of the Mesa Verde National Park section (Fig. 3), it nonetheless encompasses the same three ammonite zones.

The top of the Juana Lopez Member has long been considered a time marker in the San Juan Basin (Pentilla, 1964, p. 10). Molenaar (1973, 1974, 1983a, b), in important papers on the correlation of the Gallup Sandstone in New Mexico, treated the top of the Juana Lopez Member as an isochronous surface. The Upper Cretaceous biostratigraphy available in 2013 has a higher resolution than that available to 1983 and permits this hypothesis to be tested. The biostratigraphic refinement for the Juana Lopez requires the use of assemblage zones in the middle and upper Turonian that include not only the index ammonite species, but also four other genera of co-occurring ammonites, along with four species of *Inoceramus*, and two species of *Cameleolopha*. For ease of comparison, each ammonite index species in the middle through the

upper Turonian has been assigned a whole number that increases upward from 1 for *Collignoniceras woollgari* at the base of the middle Turonian to 8 for *Forresteria peruana* at the top of the upper Turonian. Each recognizable subzone or assemblage zone is assigned a letter from *a* (at the base) to *b* or *c* (at the top) within its respective zone. The entire set (zones 1 through 8) of middle to upper Turonian assemblage zones is presented graphically (Fig. 14) in the Summary at the end of this paper. Only zones 2 through 5 are shown in Table 2. These four zones encompass the stratigraphic interval between the top of the Juana Lopez and the top of the underlying key stratigraphic unit, either the Semilla Sandstone Member of the Mancos Shale in the San Juan Basin or the Fite Ranch Sandstone Member of the Tres Hermanos Formation to the southeast.

This assemblage zone scheme (Table 2) is based on a combination of the ammonite zones proposed last by Hook and Cobban (2011, p. 92) and the inoceramid zones proposed by Walaszczyk and Cobban (2000, p. 22, table 2). The alphanumeric scheme shown in the "Zone(s)" column in Table 1 is from Table 2.

Based on these 11 well-documented sections (Table 1), each of which is discussed in detail in the next section of the paper, neither the top nor the base of the Juana Lopez is an isochronous surface. The top varies from as high as zone 5*b* at Mesa Verde National Park to as low as zone 4*a* in at least five sections (Llaves, Sanostee, Sky Village, South Garcia, and Bull Gap Canyon); but it is in zone 5*a* in four sections (the reference and type sections, Jornada del Muerto, and High Nogal Ranch), and in zone 4*b* in one section (Sevilleta).

The base of the section comes closer to being isochronous; it is definitely in zone 3*c* in six sections (the reference and type sections, Sky Village, South Garcia, Bull Gap Canyon, and High Nogal Ranch), probably in zone 3*c* in one section (Llaves), but may be as low as the top of zone 3*b* in three sections (Mesa Verde, Sanostee, and Sky Village). However, in northern Socorro County (Sevilleta and Jornada del Muerto), where the Juana Lopez is less than 6 ft (2 m) thick, the Juana Lopez spans only a single ammonite zone (4) or a portion of a zone (5*a*), from bottom to top. Therefore, neither the upper nor the lower contact appears to be an isochronous surface over the entire area.

In three sections (Mesa Verde, the type section, and Bull Gap Canyon), the rare ammonite *Hourcquia mirabilis*, which is known from only five localities in the southern Western Interior, with only one or a few specimens per locality, makes an appearance in a single bed in zone 3*c* along with *Prionocyclus macombi* and *Coilopoceras inflatum*. This assemblage is marked with an asterisk (*) on Table 1. *Hourcquia mirabilis* is known to occur high in the *P. macombi* Zone (3*c*) in New Mexico and may range into the base of the overlying *P. wyomingensis* Zone (4*a*) (Kennedy et al. 1988, 1989). This assemblage is rare enough that it may represent a nearly isochronous event and is discussed in detail below.

Therefore, the lower contact appears to be closer to an isochronous surface, especially where it contains the ubiquitous ammonite *P. macombi*, which has a long vertical range, along with the much less common ammonites *Coilopoceras inflatum* and *H. mirabilis,* which are generally restricted to a single bed. These three species have been collected at Bull Gap Canyon both in situ and as float from an l1 to 24-inch- (28 to 61-cm-) thick calcareous sandstone at the base of the Juana Lopez Beds. *Prionocyclus macombi* occurs in place, near the top of its range, at the base of unit 5 (Fig. 2F); *Coilopoceras inflatum* occurs approximately 4 inches (10 cm) above the base (Fig. 2F) and ranges to the top of unit 5 where it weathers out ready for collecting on the sandstone's dip slope (Fig. 2G). *Hourcquia mirabilis* (Fig. 2H) has been collected in place, 3 inches (8 cm) below the top. Internal molds of *Prionocyclus wyomingensis*, from the overlying zone, occur as float specimens on the shale beneath this basal arenite at four locations in the Bull Gap Canyon area. The lithology of these specimens indicates that they weathered from the basal arenite. They, therefore, had to come from somewhere above the base, but below the top, where they have not been found on the bed's dip slope. These occurrences suggest that *C. inflatum* ranges from the top of the *P. macombi* Zone into the base of the *P. wyomingensis* Zone and that *H. mirabilis* occurs at or near the top of the *P. macombi* Zone. At Mesa Verde National Park, *H. mirabilis* occurs with *P. macombi* and *C. inflatum* approximately 25 ft (7.6 m) below the first occurrence of *P. wyomingensis*.

Mesa Verde National Park, Colorado

Description

The Juana Lopez Member of the Mancos Shale at Mesa Verde National Park (Fig. 3) is 139.6 ft (42.6 m) thick and occurs 465 ft (141.6 m) above the top of the Dakota Sandstone and 340.2 ft (103.7 m) above the top of the Bridge Creek member of the Mancos Shale; it has a sharp basal contact with the Blue Hill Member of the Mancos Shale and a sharp upper contact with the Montezuma Valley Member of the Mancos Shale. The member is composed primarily of dark-gray, noncalcareous shale (90.5%) with interbedded, thin, orange-weathering calcarenites (9.5%). The base of the Juana Lopez is drawn at the base of a 2.4-inch- (6-cm-) thick calcarenite (unit 224), the first calcarenite above shale typical of the Blue Hill Member. The top is drawn at a 1.2-inch- (3-cm-) thick calcarenite (unit 304), the last calcarenite below calcareous shale typical of the Montezuma Valley Member. The base of the member is at least as low as the *Coilopoceras inflatum* Subzone (3*c*) of the *Prionocyclus macombi* Zone, and its top is in the upper part of the *P. novimexicanus* Zone (5*b*). The Juana Lopez Member was measured in the SW¼ NE¼ sec. 29, the NW¼ SE¼ sec. 29, the SW¼ SE¼ sec. 29, and the SW¼ NE¼ sec. 31 T36N R14W Point Lookout 7.5-min quadrangle, Montezuma County, Colorado, during the summers of 1988 and 1989 by Leckie et al. (1997). Leckie et al.'s (1997) unit numbers are shown on the left side of the column in Figure 3.

Discussion

The Mancos Shale exposed in and around Mesa Verde National Park, Colorado, in the northwestern part of the San Juan Basin, was established as the principal reference of the Mancos Shale by Leckie et al. (1997) for the following reasons: 1) the outcrop lies within the type area of the Mancos Shale; 2) the entire section of the Mancos Shale from the top of the Dakota Sandstone to the base of the Point Lookout Sandstone is exposed; and 3) this entire section of Mancos Shale was trenched, then described and collected in centimeter detail from fresh exposures.

The first fossils in the Juana Lopez occur in the second calcarenite (unit 226), 1.9 ft (58 cm) above the base; they include *Prionocyclus macombi*, *Inoceramus dimidius*, and *Cameleolopha lugubris*, an assemblage indicative of the middle or upper part of the middle Turonian *P. macombi* Zone (3*b* or 3*c*) and characteristic of the basal Juana Lopez Member regionally. This assemblage probably represents 3*c* because the 3*b* is known from only one locality, the Llaves measured section discussed below. This assemblage continues through unit 266, an 11.4-inch- (29-cm-) thick calcarenite, 73 ft (22.2 m) above the base of the member. Fossils indicative of the middle Turonian *P. wyomingensis* Zone (4) appear first in unit 280, a 2.8-inch- (7-cm-) thick shale, approximately 95 ft (29 m) above the base of the member; fossils characteristic of the *Scaphites warreni* Subzone (4*a*) appear in unit 283, a 1.0-ft- (29-cm-) thick calcarenite that is 96.8 ft (29.5 m) above the base. The fossils include *S. warreni*, *P. wyomingensis*, *I. dimidius*, and *C. lugubris*. Fossils indicative of the upper Turonian *P. novimexicanus* Zone appear in unit 293, a 1.9-ft- (59-cm-) thick calcarenite, 131 ft (39.9 m) above the base; the assemblage consists of *P. novimexicanus*, *S. whitfieldi*, and *I. dakotensis*, the latter indicating that the top is in the upper part of the *P. novimexicanus* Zone (5*b*).

The USGS Mesozoic invertebrate collections in Denver house three outcrop collections from the Juana Lopez Member at Mesa Verde National Park made by W. A. Cobban and C. M. Molenaar in the area where Leckie et al. (1997) trenched and measured their section (Fig. 3). These collections—D11860, D11861, and D13417—have been projected into Figure 3. D13417 contains *Scaphites whitfieldi* and was collected from the upper ledge of the Juana Lopez Member; it fits stratigraphically and faunally with Leckie

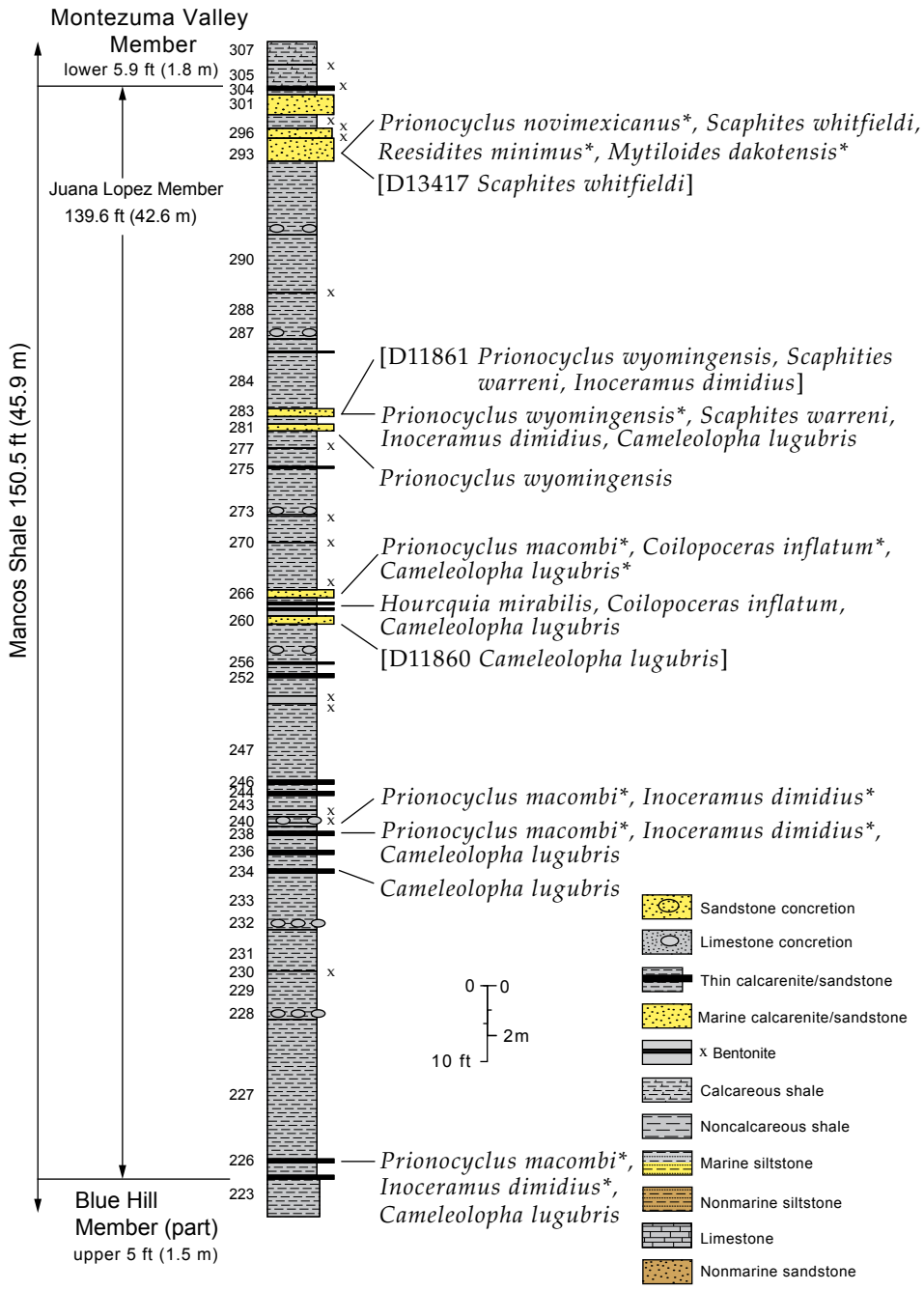


FIGURE 3—The Mesa Verde National Park measured section shows rock types and positions and compositions of fossil collections in the Juana Lopez Member of the Mancos Shale at the principal reference section of the Mancos Shale at Mesa Verde National Park, Montezuma County, Colorado. Fossil names have been updated from Leckie et al. (1997); USGS Mesozoic invertebrate collections [shown in brackets] have been projected into the section. An asterisk (*) following a fossil name indicates that specimen was illustrated by Leckie et al. (1997). At 139.6 ft (42.6 m) thick the Juana Lopez at Mesa Verde National Park is the thickest in the study area; it is also the most detailed in the study area because the entire Juana Lopez was trenched, then described from fresh samples. This section was measured in the SW¼ NE¼sec. 29, the NW¼ SE¼ sec. 29, the SW¼ SE¼ sec. 29, and the SW¼ NE¼ sec. 31 T36N R14W Point Lookout 7.5-min quadrangle, Montezuma County, Colorado, by Leckie et al. (1997). Lithologic key applies to Figures 3–13.

et al.'s (1997) collection from unit 293 at the base of the upper ledge of the Juana Lopez.

The placement of the other two collections requires some explanation because they are linked stratigraphically to each other. D11861 is from a calcarenite that contains a *Prionocyclus wyomingensis* fauna; it has been projected into Figure 3 at unit 283, the only calcarenite with a *P. wyomingensis* fauna. Units 281 and 283 are two, thin, closely spaced calcarenites that undoubtedly form a minor ledge. D11860 was recorded as being from the base of the Juana Lopez and contains *Cameleolopha lugubris*. Logically, this collection should project into unit 226, a thin calcarenite 1.9 ft (58 cm) above the base that also contains *C. lugubris*. This projection, based on its outcrop position at the base of the Juana Lopez, places the collection approximately 100 ft (30 m) below D11861. However, when these two collections were made in June 1982, the stratigraphic thickness between them was a measured 32 ft (9.8 m). A better fit for D11860 on Figure 3 based on this stratigraphic separation is unit 260, which is at the base of a series of four thin calcarenites and interbedded shale that is 4.7 ft (1.4 m) thick and carries the *Coilopoceras inflatum-Hourcquia mirabilis* fauna, including *C. lugubris*. Unit 260 is 26 ft (7.9 m) below the projected position of D11681, much closer to the measured field position.

This projection exercise suggests that the base of the Juana Lopez in the trench, where Leckie et al. (1997) measured their section, is considerably lower than the outcrop or topographic (=mapping) base of the Juana Lopez. This discrepancy suggests that the calcarenites in the trench below unit 281 are less resistant than those above, have little or no topographic expression, and end up covered on the outcrop.

Two ammonites of particular importance in correlating this northwestern, very detailed section with those to the southeast are *Coilopoceras inflatum* (Fig. 2F, G) and *Hourcquia mirabilis* (Fig. 2H) that occur with *Prionocyclus macombi* and *Cameleolopha lugubris* in unit 264, a thin calcarenite approximately 72 ft (21.9 m) m above the base of the member. *Hourcquia mirabilis* is a very rare ammonite in the Western Interior that is restricted to single bed in every known occurrence in New Mexico including the Juana Lopez at Taylor Springs, Colfax County (Hook and Cobban 1980b, fig. 4), the type section in Santa Fe County (Fig. 7), and Bull Gap Canyon (Fig. 12). In each instance, it occurs in association with *Coilopoceras inflatum*, *Prionocyclus macombi*, and *Cameleolopha lugubris*. Therefore, it is regarded as a species that can be used to establish a penecontemporaneous if not isochronous correlation from section to section. If so, then the 72 ft (21.9 m) of fossiliferous Juana Lopez section at Mesa Verde National Park below unit 264 suggests (1) that depositional conditions necessary for calcarenite formation began at Mesa Verde well before they did at all but one of the sections of the Juana Lopez to the south and southeast, most of which were probably farther offshore, or (2) that submarine erosion has removed most or all of this earlier calcarenitic section to the southeast.

The lone exception to (1) above is the Sanostee section (Fig. 5), where *Coilopoceras inflatum*, (D11247-8), but not *H. mirabilis*, occurs in a single bed 66 ft (20.1 m) above the base of the Juana Lopez. However, the shale unit below the topographic base of

the Juana Lopez is well exposed at Llaves (Fig. 4) and the type section (Fig. 7), but does not contain calcarenites. At Llaves this unnamed shale member contains concretions bearing the 3*b* assemblage in which *Cameleolopha lugubris* occurs with *Coilopoceras colleti*. At the type section, this shale contains fossils from the *Prionocyclus hyatti* Zone (2*b*). So, the presence of zone 3*b* at the Llaves section appears to support hypothesis (1) above, that calcarenite deposition commenced earlier at Mesa Verde National Park. The absence of zones 3*a* and 3*b* at the type section appears to support hypothesis (2) above, that erosion below the present-day base of the Juana Lopez has removed the older calcarenitic section.

Llaves, New Mexico

Description

The Juana Lopez Member of the Mancos Shale at Llaves (Fig. 4) is almost as thick as that of Mesa Verde at 135.7 ft (41.4 m) thick, has a sharp basal contact with Blue Hill Member of the Mancos Shale below, and a concealed, but topographically sharp, upper contact with the Montezuma Valley Member of the Mancos Shale above. It is composed primarily of dark-gray, noncalcareous shale (98%) with interbedded, thin, orange-weathering calcarenites (2%). The base of the Juana Lopez is drawn at the base of a 2-inch- (5-cm-) thick calcarenite (unit 6), the first calcarenite above a thin sandstone (unit 2) interpreted to be the feather edge of the Semilla Sandstone Member, which is 3.5 ft (1.1 m) below. The top is drawn at a 1.0-inch- (3-cm-) thick calcarenite (unit 20), that forms the top of a resistant ridge below a concealed shale valley. *Cameleolopha lugubris* and *Inoceramus dimidius* (D14617) at the base of the Juana Lopez, just above a concretionary bed with *Prionocyclus macombi* and *Coilopoceras colleti* (D14567), suggest that the base of the Juana Lopez is in the *Coilopoceras inflatum* Subzone (3*c*) of the *Prionocyclus macombi* Zone, even though *C. inflatum* was not collected from the section. *Scaphites warreni* from the uppermost calcarenite (D14630) indicates the top is in the *S. warreni* Subzone (4*a*) of the *P. wyomingensis* Zone. The section was measured in the NE¼ SW¼ sec. 15 T25N R1E Llaves 7.5-min quadrangle, Rio Arriba County, New Mexico, by S. C. Hook on June 1 and 19, 2007.

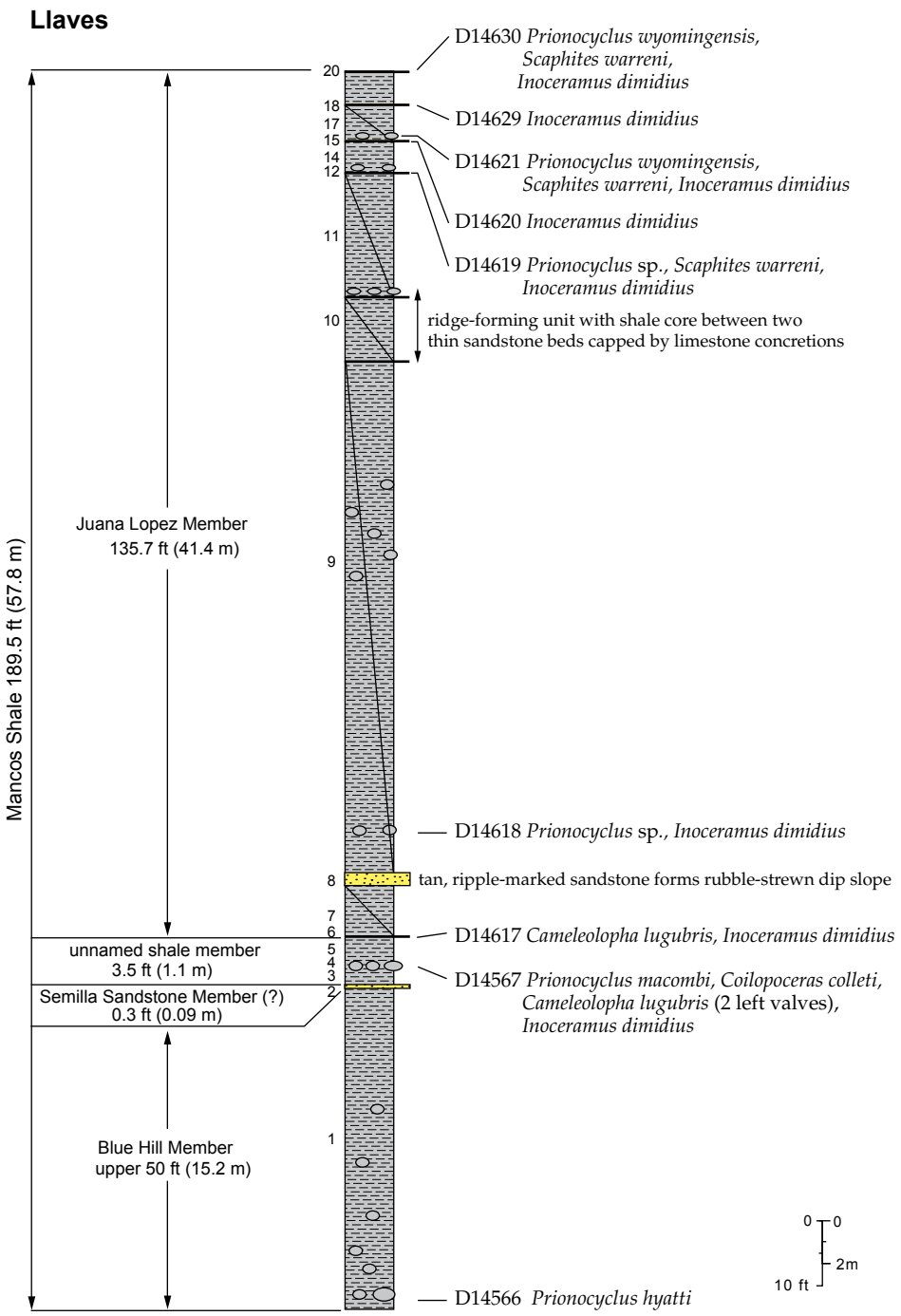


FIGURE 4—The Llaves measured section shows the positions of fossil collections from the Juana Lopez and underlying members of the Mancos Shale on the west side of the San Juan Basin, Rio Arriba County, New Mexico. This is the only known area where *Cameleolopha lugubris* occurs with *Coilopoceras colleti* (D14567); elsewhere it occurs with the younger *C. inflatum*. This section was measured in the NE¼ SW¼ sec. 15 T25N R1E Llaves 7.5-min quadrangle, Rio Arriba County, New Mexico.

Discussion

The first fossils in the Juana Lopez occur in the lowest calcarenite (unit 6), at the base of the member; they include *Inoceramus dimidius* and *Cameleolopha lugubris*, indicative of the upper part of the middle Turonian *P. macombi* Zone (3*c*) and characteristic of the basal Juana Lopez Member. This assemblage continues upward approximately 17 ft (5.2 m) into the base of unit 9, an 80-ft- (24.4-m-) thick shale. The 100 ft (30 m) of shale overlying D14618 is barren of fossils although it contains scattered concretions. *Scaphites warreni* (D14619) appears in unit 12, a thin calcarenite, 120 ft (36.6 m) above the base of the Juana Lopez. *Prionocyclus wyomingensis* and *S. warreni* (4*a*) are found in calcarenites and concretions all the way to the top of the Juana Lopez, unit 20 (D14630). Unit 16, a 1-ft- (30-cm-) thick concretion bed, 10 ft (3 m) below the top of the Juana Lopez, contained scores of specimens of *S. warreni* (D14621). Most of these internal molds had weathered out of the matrix and were lying on the ground.

Unit 4, the 1.5-ft- (46-cm-) thick bed of limestone concretions that is 4 ft (1.2 m) below the base of the Juana Lopez is one of the great invertebrate fossil treasure chests in New Mexico. This bed has produced scores of beautifully preserved internal molds of *Prionocyclus macombi*, *Inoceramus*

dimidius, and *Coilopoceras colleti* (D14567). Specimens of these three species are now reposited in the Mesozoic invertebrate collections of the U.S. Geological Survey at the Federal Center in Denver, Colorado. Some of the best specimens from this bed along strike were chosen to illustrate typical (1) *Coilopoceras colleti* in Cobban and Hook (1980) and (2) *I. dimidius* in Walaszczyk and Cobban (2000). In addition, two—and only two—valves of *Cameleolopha lugubris* were recovered from this level, making this the stratigraphically lowest, therefore, oldest, known occurrence of *C. lugubris.* In addition, this is the only known occurrence in which *C. lugubris* occurs with *Coilopoceras colleti*. Usually, *C. lugubris* occurs with *Coilopoceras inflatum*, whereas, the older oyster *C. bellaplicata* occurs with *Coilopoceras colleti*. This occurrence (D14567) was used to determine the lower limit of the range of *C. lugubris* in Hook and Cobban (2012, fig. 3).

Cobban and Hook (1980, table 1, locality 4) and Walaszczyk and Cobban (2000, p. 10, locality 76) interpret the *Coilopoceras colleti* concretions (Fig. 4, unit 4, D14567 level) to be the base of the Juana Lopez at Llaves. Their D4395 collection, which contains *Prionocyclus macombi, Coilopoceras colleti,* and *Inoceramus dimidius,* is from the same level as D14567, but at a different locality. The present interpretation places the base of the Juana Lopez at the lowest calcarenite in the section (Fig. 4, unit 6), which is 4 ft (1.2 m) above these limestone concretions. The thin sandstone (unit 2), 3.5 ft (1.1 m) below the D14567 concretions, is interpreted as the feather edge of the Semilla Sandstone Member.

Sanostee section, New Mexico

Description

The Juana Lopez Member is 106.2 ft (32.4 m) thick at a section measured about a mile (1.0–1.4 km) south of the Navajo settlement of Sanostee, 30 mi (48 km) southwest of Shiprock, New Mexico (Fig. 5). The member consists of thin beds of crossbedded and ripple laminated, rusty-brown, quartz-rich calcarenite interbedded with dark-gray, noncalcareous shale. It has a sharp contact with both the underlying and overlying unnamed shale members. Although shale is the dominant lithology, comprising 65.1% of the member, the hard, platy weathering arenites form cliffs and litter the slopes with debris. The base of the Juana Lopez is drawn at the base of a 6-inch- (15-cm-) thick calcarenite (unit 4), the first resistant, nonconcretionary bed in more than 90 ft (27.4 m) of soft, slope-forming shale measured in the underlying lower shale member (Fig. 5). The top of the member is drawn at the top of a 6-inch- (15-cm-) thick calcarenite (unit 16), the last resistant, nonconcretionary bed in more than 290 ft (88.4 m) of soft, slope-forming shale measured in the overlying upper shale member beneath the Gallup Sandstone (Fig. 5).

The Juana Lopez at Sanostee is composed primarily of dark-gray, noncalcareous shale (at least 65%) with interbedded, thin, rusty-brown-weathering calcarenites (35%). The percentage of calcarenite at Sanostee is the highest in the study area primarily because the section was not measured in the same detail as the other ten sections. The cliff-forming nature of unit 13 (Fig. 5) made it difficult to separate out individual beds of calcarenite. In calculating lithologic percentages for Table 1, both unit 13 and unit 14, totaling 71 ft (21.6 m) of section, were assumed to 50% shale and 50% calcarenite.

The base of the member is in the *Prionocyclus macombi* Zone (3), perhaps as low as the upper part of the *Coilopoceras colleti* Subzone (3*b*) and its top is in the *Scaphites warreni* Subzone (4*a*) of the *P. wyomingensis* Zone (4). The Juana Lopez section (units 4–16) was measured and collected along a prominent L-shaped ridge approximately 1 mi (1.0–1.4 km) south of the settlement of Sanostee on the Sanostee East 7.5-min quadrangle, San Juan County, New Mexico by S. C. Hook and W. A. Cobban on August 6, 1980.

Discussion

This measured and biostratigraphically dated section of the Juana Lopez Member at Sanostee is important historically and stratigraphically. Historically, Newberry (1876, p. 107) described its outcrop pattern along the San Juan River rather poetically as "…a band of brown, shelly, sandy limestone, which forms a projecting ledge in the face of the cliffs, giving cornices and capitals to the castles and palaces into which they have been worn. This ferruginous stratum marks a distinct horizon, and may be traced over an immense area in New Mexico. It is the same that I have referred to in my notes on the banks of the Dolores, Camp 21, the Pagosa, the ford of the Chama, Galisteo, and the banks of the Canadian. This stratum is characterized by

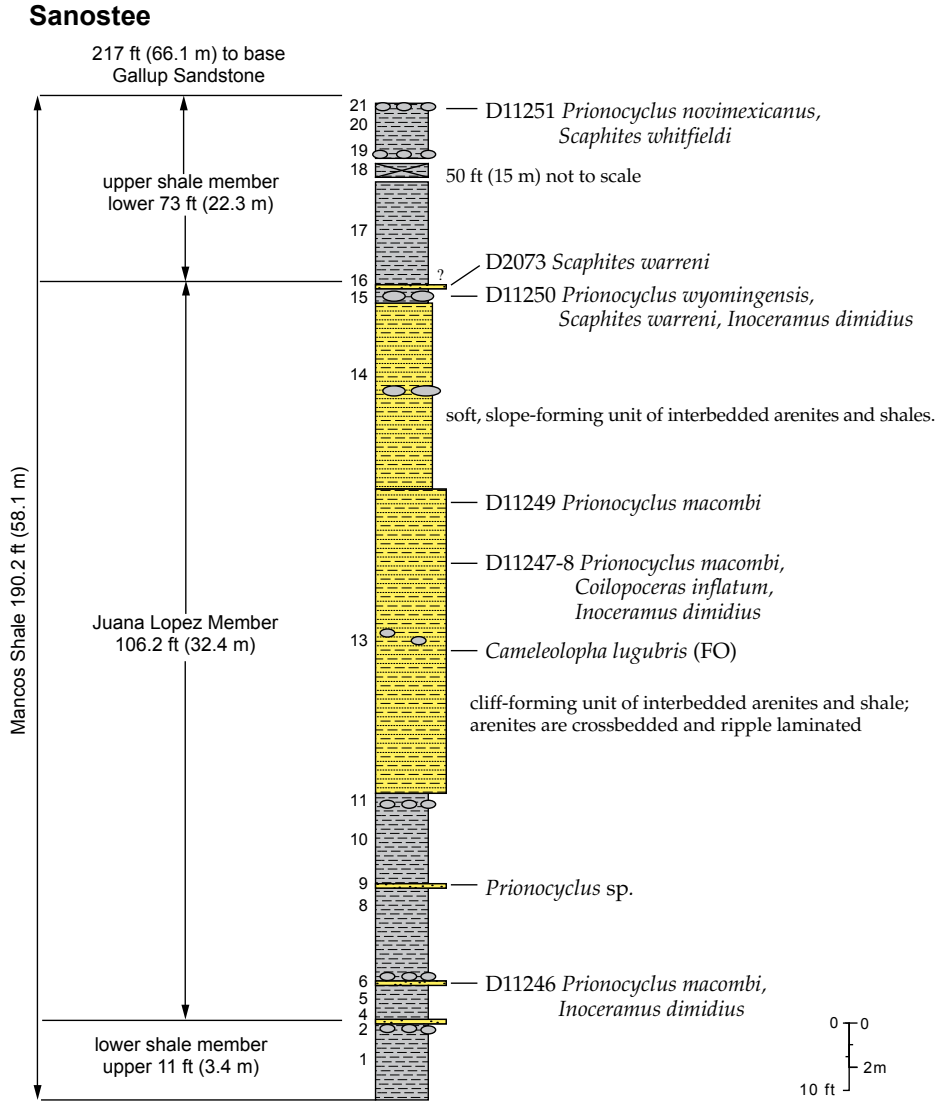


FIGURE 5—The Sanostee measured section shows the positions of fossil collections from the Juana Lopez and underlying and overlying members of the Mancos Shale on the west side of the San Juan Basin, San Juan County, New Mexico. This section was measured in the NE¼ SW¼ sec. 15 T25N R1E Sanostee East 7.5-min quadrangle, San Juan County, New Mexico.

the following fossils: *Inoceramus problematicus* [*dimidius*], *Ostrea* [*Cameleolopha*] *lugubris*, *Scaphites larvaformis* [*warreni*], *Ptychodus whipplei*, &c." Stratigraphically, this section helps establish the correlation of the earlier, formally named Juana Lopez Member (Rankin, 1944) with the later, informally named Sanostee (or Sanastee) Sandstone Member (Di Giambattista 1952, p. 6; Lilly 1952, p. 101). The earliest use of the name Sanastee Sandstone Member appears to be in a roadlog of Smith and Silver (1951, p. 46), which states that "…the unit has not been named except informally and W. B. Hoover of the Humble Oil and Refining Company suggests 'Sanastee sandstone member' because of the prominent development of this unit around Sanastee Trading Post." O'Sullivan et al. (1972, p. E20) rejected the name Sanastee for use in the San Juan Basin and noted that "[a]lthough the name has been used by geologists in the San Juan Basin since 1951, the Sanastee has never been formally defined."

The stratigraphic position of the calcarenite unit at Sanostee, 440 ft (134 m) above the limestone unit of Greenhorn age (O'Sullivan et al. 1972, p. E21) and 290 ft (88.4 m) below the Gallup Sandstone (Fig. 5), suggests correlation with the Juana Lopez. The fossil content—*Prionocyclus macombi*, *Coilopoceras inflatum*, *Inoceramus dimidius*, and *Cameleolopha lugubris* in the lower and middle parts, and *P. wyomingensis* and *Scaphites warreni* in the upper part—cements that correlation. The only other published, biostratigraphically well-documented measured section of rocks formerly referred to the Sanostee is 13 mi (21 km) south at Toadlena (Molenaar et al. 1996, section A–A', control point 18). There, the Juana Lopez is approximately 100 ft (30 m) thick; the lower part contains *Cameleolopha lugubris* (D11493-4); the middle part contains *Prionocyclus wyomingensis* and *Scaphites warreni* (D11495); and the uppermost ledge contains *Inoceramus perplexus* (D11496). At Toadlena, the top of the Juan Lopez is one faunal zone higher than at Sanostee, lying in the lower part of the *P. novimexicanus* Zone (5*a*).

The arenites in the Juana Lopez at Sanostee have a higher (apparent) quartz content in hand specimen than those from most of the other sections in this study. This prompted the authors to label them as highly calcareous sandstones on the outcrop and in field notes. O'Sullivan et al. (1972, p. E21) measured a section of Juana Lopez not far from Sanostee in the NE¼ sec. 3 T24N R19E. Their section includes only the upper ledges of the Juana Lopez as used in this paper (Fig. 5) and is therefore considerably thinner at 35 ft (12 m) thick, but "…consists of slope-forming shale beds ranging in thickness from 4 to 18 feet and intercalated ledge-forming limestone beds from 3 inches to about 1 foot. The insoluble residues in the limestone range from 7½ to 44 percent and average 26 percent. The insoluble residues consist of grains that range in size from medium sand to silt and clay, but are primarily of the very fine sand size and smaller." Inasmuch as the shales in the Juana Lopez are noncalcareous, the insoluble residue analysis suggests that limestones are composed of comminuted shell fragments and that calcarenite is the correct name to apply to the limestones.

The absence of recognizable shells of *Cameleolopha lugubris* in the lower third of the Juan Lopez is somewhat puzzling. However, the three thin, yellowish-brown to reddish-brown weathering calcarenites in the basal part of the section (Fig. 5, units 4, 6, and 9) are composed of unrecognizable oyster and inoceramid debris with a considerable amount of carbonaceous material. All three calcarenites have wavy bedding and are burrowed.

The presence of *Coilopoceras inflatum* in a single bed (D11247-8) just above the middle of a 44-ft- (14-m-) thick, cliff-forming calcarenite/shale unit (Fig. 5, unit 13), suggests that conditions for calcarenite formation existed here earlier than they did to the south and east and that they are more similar to conditions at Mesa Verde (Fig. 3) and Llaves (Fig. 4).

The name "Sanostee" can be translated as "rocks around it," or "tilted strat[a]," or "criss-cross rock extending out" (Julyan 1996, p. 323).

Reference section, New Mexico

Description

The Juana Lopez Member is 106.9 ft (32.6 m) thick at the reference section (Figs. 2A, 6), consists of thin beds of rusty-brown to orange, highly fossiliferous calcarenite interbedded with dark-gray, noncalcareous shale; it has a sharp contact with the underlying unnamed shale member and a sharp upper contact with the concealed shale valley above. Although shale is the dominant lithology, comprising 94.9% of the member, the hard, platy-weathering calcarenites are more conspicuous, forming ridges and littering the slopes with debris.

The Member lies 12.5 ft (3.8 m) above the top of the Semilla Sandstone Member of the Mancos Shale; its base is in the *Coilopoceras inflatum* Subzone (3*c*) of the *Prionocyclus macombi* Zone, and its top is in the lower part of the *P. novimexicanus* Zone (5*a*). The Juana Lopez section (units 1–45) was measured in the SE¼ SW¼ sec. 14 T19N R1W La Ventana 7.5-min quadrangle, Sandoval County, New Mexico by Dane et al. (1966). The remainder of the section (units A–G) was measured at the same location by S. C. Hook on August 7, 1979.

Discussion

The reference section of the Juana Lopez Member of the Mancos Shale (Fig. 6) is the most influential section of the 11 discussed in this report. Beyond being well exposed and very fossiliferous, it establishes the standard stratigraphic and biostratigraphic foundations for what constitutes the Juana Lopez in the San Juan Basin.

From the standpoint of correlation, the most important collection made at the reference section is from a calcarenite 3 ft (90 cm) above the base that contains *Prionocyclus macombi*, *Coilopoceras inflatum*, *Inoceramus dimidius*, and *Cameleolopha lugubris* (D4408). This assemblage occurs at or near the base of the Juana Lopez at eight of the 11 sections profiled in this report, and its first occurrence is regarded as an isochronous event, especially when the ammonite *Hourcquia mirabilis* is also present. Although the section ranges from the *Prionocyclus macombi* Zone (3) at the base to the *P. novimexicanus* Zone (5) at the top, no definitive fossils for the *P. wyomingensis* Zone (4) have been found anywhere in between. *Prionocyclus macombi* ranges through the basal 9.7 ft (3 m) of the section (D4408 and D3671) in association with *Cameleolopha lugubris* and *Inoceramus dimidius*. *Cameleolopha lugubris* continues upward, making its last definite appearance 47.4 ft (14.4 m) above the base (D4410). Although there are at least six hard beds (calcarenites and concretions) above that level that could preserve impressions or internal molds of fossils from the *P. wyomingensis* Zone, none have been found. *Prionocyclus novimexicanus*, *Scaphites whitfieldi*, and *Inoceramus perplexus* (D3672) are common in the 2.2-ft- (66-cm-) thick, ledge-forming calcarenite 102.8 ft (29.3 m) above the base.

The absence of the *Prionocyclus wyomingensis* fauna is puzzling, especially considering how common the associated scaphites are elsewhere in the San Juan Basin (see Molenaar et al. 1996), and in light of the Llaves section (Fig. 4), where a concretion at the D14621 level contained hundreds of specimens of *S. warreni*. Hook recently (3/23/2012) measured and collected a well-exposed section of the Juana Lopez Member approximately 2.3 mi (3.9 km) north of the reference section and was unable to find direct evidence for the *Prionocyclus wyomingensis* Zone, even though that was a specific objective of the field work. *Prionocyclus macombi* (D15036) was collected from a concretion bed 55.5 ft (16.9 m) above the base and *Cameleolopha lugubris* (D15037) from a 2-inch- (5-cm-) thick calcarenite directly on top of it. The next collection, 25 ft (7.6 m) higher, from a thin calcarenite was of *Inoceramus perplexus* (D15038), indicative of the *P. novimexicanus* Zone (5*a*). The intervening interval, which probably represents the *P. wyomingensis* Zone, is a shale without concretions.

Ball et al. (2009), working in west-central Colorado, have shown conclusively that fresh shale exposures, especially those in core samples, can be spectacularly fossiliferous. Their work has a direct bearing on the lack of the *Prionocyclus wyomingensis* fauna at the reference section. They examined 537 ft (164 m) of 2.5-inch (6.4-cm) core through the

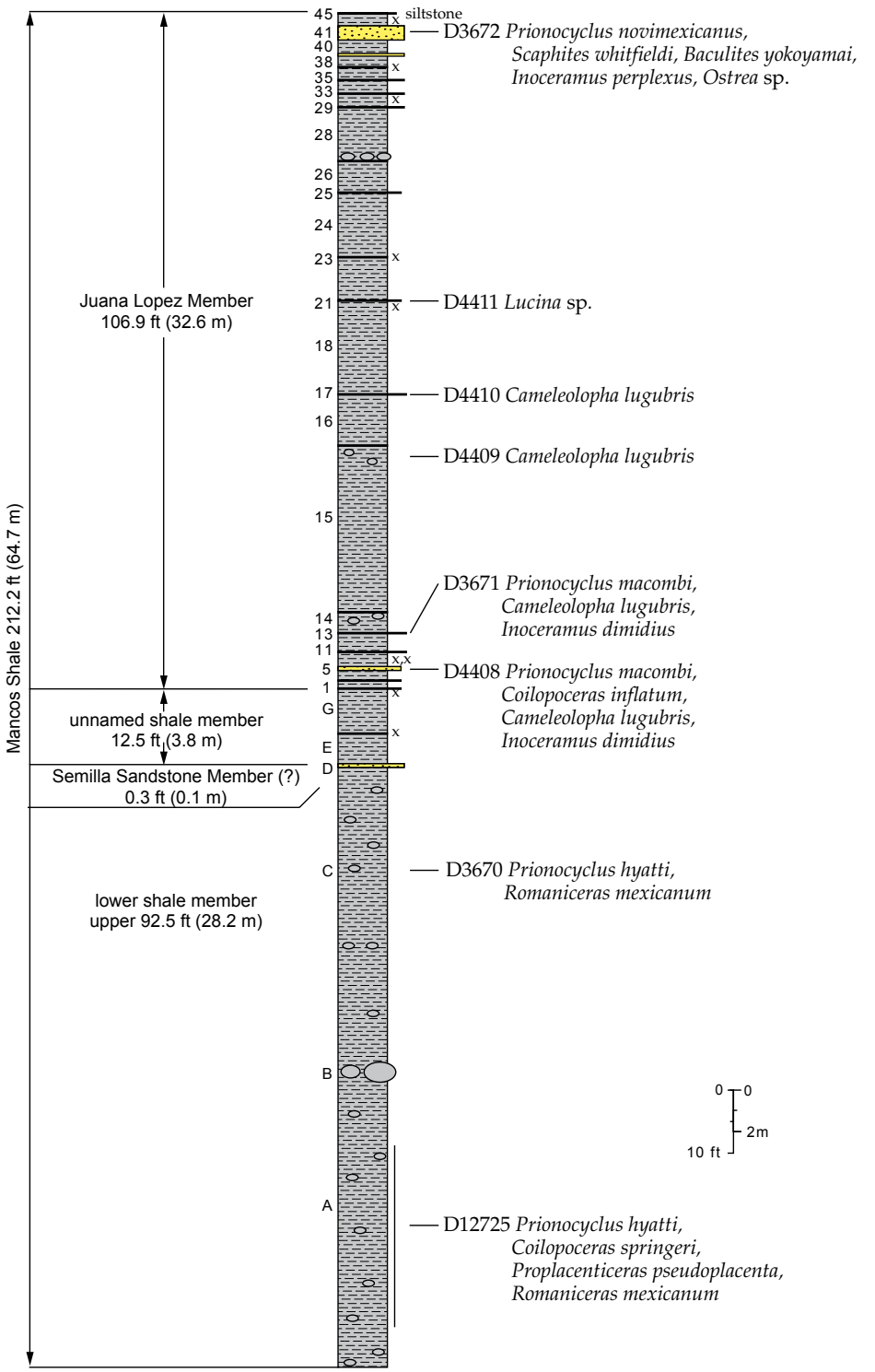


FIGURE 6—The reference section of the Juana Lopez Member of the Mancos Shale shows the positions of fossil collections from the Juana Lopez and underlying members of the Mancos Shale on the east side of the San Juan Basin, Sandoval County, New Mexico. The absence of the *Prionocyclus wyomingensis* fauna in the middle and upper parts of the Juana Lopez is puzzling but typical of the area. This section was measured in the SE¼ SW¼ sec. 14 T19N R1W La Ventana 7.5-min quadrangle, Sandoval County, New Mexico, by Dane et al. (1966).

Mancos Shale in Montrose County, southeast of Grand Junction, Colorado. They determined that the Juana Lopez Member of the Mancos Shale extended in depth from 240 to 378 ft (73.1–115.2 m), was 138 ft (42.1 m) thick, and was composed primarily of calcarenitic shale. Fossils were generally flattened internal molds that retained original shell material. Those from the basal calcarenitic shale unit, 76 ft (23.2 m) thick, included *Prionocyclus macombi*, *Inoceramus dimidius*, and *Cameleolopha lugubris*, probably representing zone 3*c*; fossils from the middle shale unit, 28 ft (8.5 m) thick, included *P. wyomingensis* and *I. dimidius*, representing zone 4; and fossils from the upper silty to calcarenitic shale, 34.4 ft (10.5 m) thick, included *P. novimexicanus*, *Scaphites whitfieldi*, and *Inoceramus perplexus*, representing zone 5*a*. *Mytiloides ratonensis* from the top of this interval may represent zone 5*b* because *P. novimexicanus* continues upward into the overlying calcareous shale of the Montezuma Valley Member.

The reference section for the Juana Lopez Member of the Mancos Shale (Dane et al. 1966) is in one of the most beautiful areas in New Mexico (Fig. 2A). It is on the east side of the San Juan Basin, tucked up against the very steeply dipping west flank of the Sierra Nacimiento.

Type section, New Mexico

Description

The Juana Lopez Member is 106.1 ft (32.3 m) thick at its (reestablished) type section (Figs. 2B, 7)—almost exactly the same thickness as the reference section—and consists of thin beds of rusty-brown, highly fossiliferous calcarenite interbedded with dark-gray, noncalcareous shale. Although shale is the dominant lithology, comprising 94.8% of the member, the hard, platy-weathering calcarenites are more conspicuous, even at a fresh railroad cut. Its contacts with both the underlying and overlying shale members are sharp. The member lies 60 ft (18.3 m) above the top of the Semilla Sandstone Member of the Mancos Shale; its base is in the *Coilopoceras inflatum* Subzone (3*c*) of the *Prionocyclus macombi* Zone, and its top is in the lower part of the *P. novimexicanus* Zone (5*a*). The section was measured in the NW¼ SE¼ sec. 33 (projected), T15N R7E Madrid 7.5-min quadrangle, Santa Fe County, New Mexico, by S. C. Hook on July 16–18, 1979.

Discussion

The type section of the Juana Lopez, like most of those in the San Juan Basin, can be subdivided into three informal units: a lower calcarenite and interbedded shale unit, 8 ft (2.5 m) thick; a middle shale unit with scattered calcarenite lens and septarian limestone concretions, 86 ft (26.2 m) thick; and an upper calcarenite and interbedded shale unit, 12 ft (3.7 m) thick. The contacts between the Juana Lopez and the underlying (unnamed) shale and the overlying Montezuma Valley Member appear to be conformable (Hook and Cobban 1980a, p. 19).

The fauna in the lower calcarenitic unit is dominated by *Cameleolopha lugubris* and *Prionocyclus macombi*. A 12-inch- (30-cm-) thick calcarenite (unit 11) that is 1.9 ft (58 cm) above the base contains the key *Prionocyclus macombi-Coilopoceras inflatum-Hourcquia mirabilis* ammonite fauna (D10811) that

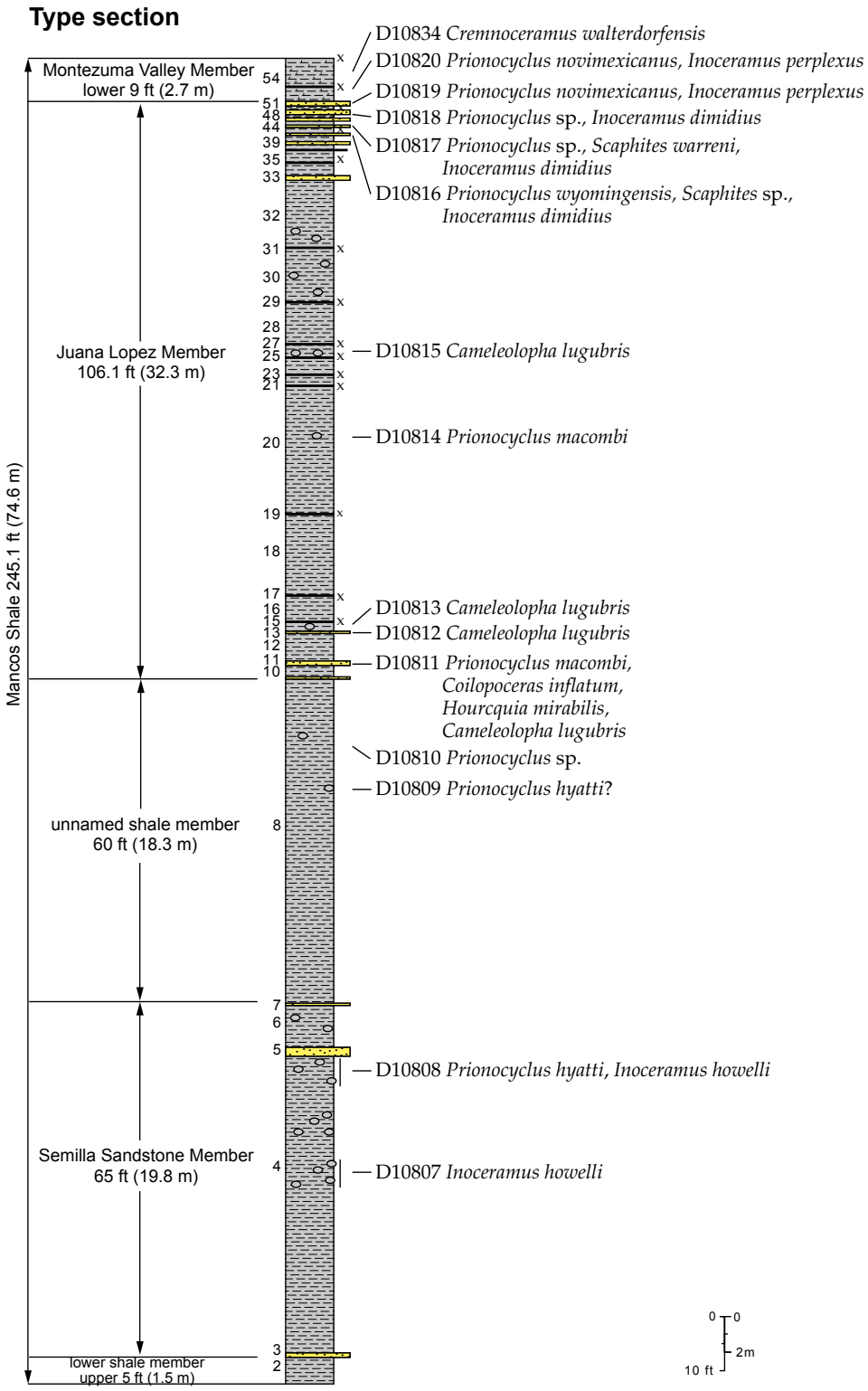


FIGURE 7—The type section of the Juana Lopez Member of the Mancos Shale shows the positions of fossil collections from the Juana Lopez and underlying and immediately overlying members of the Mancos Shale, Santa Fe County, New Mexico. This section at 106.1 ft (32.3 m) thick is almost the identical thickness of the reference section (Fig. 6). This section was measured in the NW¼ SE¼ sec. 33 (projected) T15N R7E Madrid 7.5-min quadrangle, Santa Fe County, New Mexico.

appears to mark the start of depositional conditions that led to calcarenite formation over much of the southern Western Interior. This fauna places the base of the Juana Lopez in the *Coilopoceras inflatum* Subzone (3*c*) of the *P. macombi* Zone.

Prionocyclus macombi ranges into the upper half of the middle shale unit but is replaced in the lower part of the upper calcarenite (units 41–44) by *P. wyomingensis*, *Scaphites warreni*, and *Inoceramus dimidius* (D10816–10817), delimiting the much thinner *S. warreni* Subzone (4*a*) of the *P. wyomingensis* Zone. The upper part of the *P. wyomingensis* Zone, the *S. ferronensis* Subzone (4*b*), is not represented, nor is there much stratigraphic room for it. The uppermost calcarenite bed (unit 51) of the Juana Lopez contains the first appearance of *P. novimexicanus* in association with *Inoceramus perplexus* (D10819). The lower part of the *P. novimexicanus* Zone (5*a*) continues upward a foot or so into the overlying calcareous shale member, where *P. novimexicanus* and *I. perplexus* occur (D10820).

The reinterpreted type section of the Juana Lopez Member (Hook and Cobban 1980a, pp. 20–21) is a 1965 railroad cut made by the Atchison, Topeka, and Santa Fe Railroad Company. It is presently inaccessible on foot or by vehicle but can be seen from the New Mexico Rail Runner. The type section is on the Mesita de Juana Lopez Grant, approximately 50 mi (80 km) southeast of the reference section and 5.4 mi (8.6 km) northwest of Cerrillos, New Mexico. According to Hook and Cobban (1980a, p. 19), the Mesita de Juana Lopez has been a place name since 1746, but there is not much known about the historical person or why the area bears her name. She may have been Juana Lopez del Castillo, whose family helped found Albuquerque about 1706.

Sky Village, New Mexico

Description

The Juana Lopez Member of the Mancos Shale at Sky Village (Fig. 8) is 111.4 ft (33.9 m) thick; it is 15 ft (4.6 m) above the top of the Semilla Sandstone Member of the Mancos Shale and has a sharp contact with the underlying (unnamed) shale member. The Juana Lopez is composed primarily of dark-gray, noncalcareous shale (87%) with interbedded, thin, dark-weathering calcarenites (13%). The base of the Juana Lopez is drawn at the base of a 1.0-inch- (3-cm-) thick calcarenite (unit 5), the first calcarenite in the shale above the Semilla Sandstone. The top is drawn at a 14-ft- (4.3-m-) thick, ledge-forming calcarenite and interbedded shale unit (unit 13). The base of the Juana Lopez lies in the *Coilopoceras inflatum* Subzone (3*c*) of the *Prionocyclus macombi* Zone, and its top is in the lower part of the *P. wyomingensis* Zone (4*a*). The Sky Village section was measured in the SE¼ SE¼ sec. 32 T15N R1E Sky Village NE (now Cerro Conejo) 7.5-min quadrangle, Sandoval County, New Mexico, by S. C. Hook on February 3, 1981.

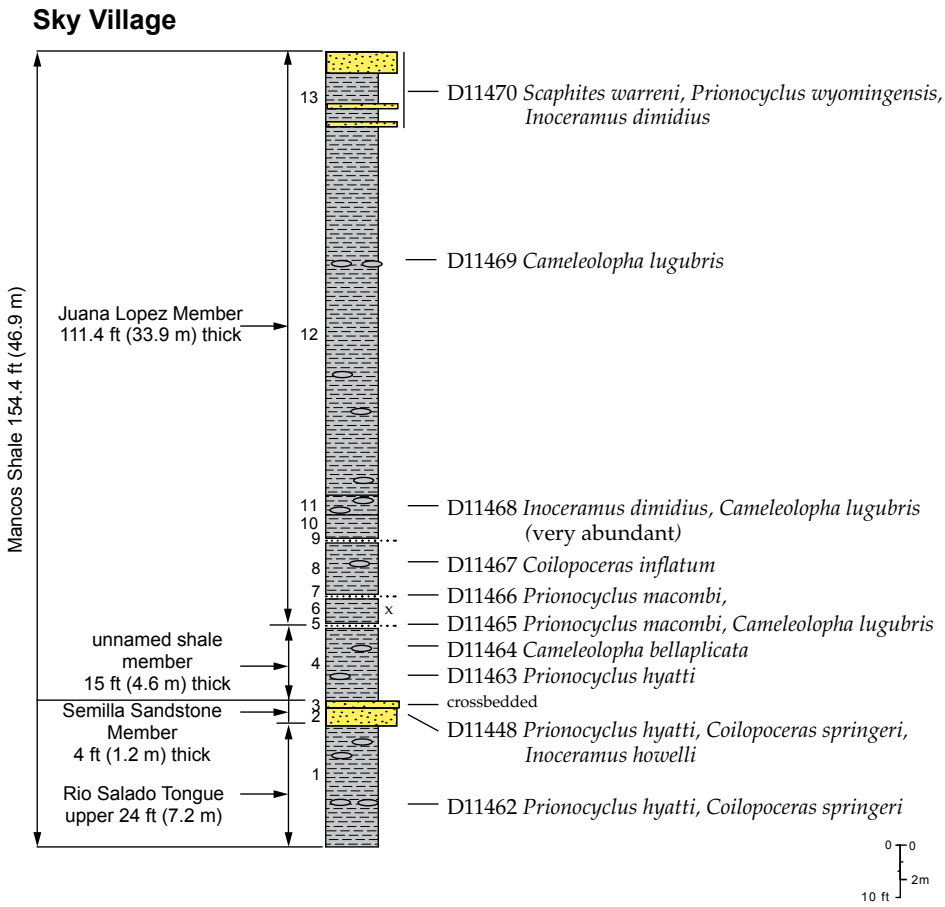


FIGURE 8—The Sky Village measured section of the Juana Lopez Member of the Mancos Shale shows the positions of fossil collections from the Juana Lopez and underlying members of the Mancos Shale in the Acoma Basin, Sandoval County, New Mexico. The presence of *Prionocyclus hyatti* (D11463) in the shale between the Juana Lopez Member and the Semilla Sandstone Member indicates that the T-2 transgression began in late *Prionocyclus hyatti* time. This section was measured in the SE¼ SE¼ sec. 32 T15N R1E Sky Village NE (now Cerro Conejo) 7.5-min quadrangle, Sandoval County, New Mexico.

Discussion

The base of the Juana Lopez at Sky Village contains abundant valves of *Cameleolopha lugubris* and impressions of *Prionocyclus macombi* (D11465). Body fossils of the key ammonite *Coilopoceras inflatum* (D11467) occur in concretions approximately 12 ft (3.7 m) higher, placing the basal Juana Lopez in zone 3*c*, the same zone as the base at the type and reference sections. This rather high occurrence of *C. inflatum* is reminiscent of the Mesa Verde National Park section, where it occurs 72 ft (22) m above the base of the member (Fig. 3).

The uppermost ledges of calcarenite at Sky Village carry a *Prionocyclus wyomingensis-Scaphites warreni* fauna (D11470) that places the top in the *Scaphites warreni* Subzone (4*a*), a full zone lower than at the type or reference sections. However, at 111.4 ft (33.9 m) thick, the Sky Village section is a little thicker than either of those two sections.

The entire measured section at Sky Village (Fig. 8) consists of 154.4 ft (46.9 m) of Mancos Shale, beginning with a *Prionocyclus hyatti-Coilopoceras springeri* collection (D11462) from concretions in noncalcareous shale in the Rio Salado Tongue and ending with a collection containing *Prionocyclus wyomingensis* and *Scaphites warreni* (D11470) from the last exposed calcarenite in the Juana Lopez Member. This measured section is near the seaward limit of the Semilla Sandstone Member, which is only 4 ft (1.2 m) thick, contains a *P. hyatti* fauna (D11448), and is separated from the Juana Lopez by 15 ft (4.6 m) of an unnamed shaly unit of the Mancos Shale that also contains a *P. hyatti* fauna. The upper 15 inches (38 cm) of the Semilla is more resistant and coarser grained than the lower part; it is also crossbedded. The contact of the Semilla with the overlying shale is sharp, but there is no direct evidence of an erosional unconformity. A limestone concretion 5 ft (1.5 m) above the contact contained *P. hyatti* (D11463), and another concretion 5 ft (1.5 m) higher contained the first and only occurrence of *Cameleolopha bellaplicata* (D11464) here. These occurrences of *P. hyatti* both above and below the Semilla indicate that the seaway changed from regressive (R–1) to transgressive (T–2) within the span of time represented by upper part of the *P. hyatti* Zone (2*b*).

South Garcia, New Mexico

Description

The Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale at South Garcia (Fig. 9) are 57.1 ft (17.4 m) thick and rest disconformably on the Semilla Sandstone Member of the Mancos Shale. The lower arenite of the Juana Lopez is topographically indistinguishable from the upper part of the Semilla Sandstone. Faunally, however, it contains the *Prionocyclus macombi-Coilopoceras inflatum-Cameleolopha lugubris-Inoceramus dimidius* fauna (zone 3*c*) that is so prominent at the base of the Juana Lopez elsewhere in the San Juan Basin. *Prionocyclus wyomingensis* (D11455) occurs in unit 27 in a limestone concretion, 24 ft (7.3 m) above the base of the Juana Lopez. The upper calcarenites, units 28 and 30, at the top of the beds contain *P. wyomingensis* and *Scaphites warreni* from zone 4*a*. Lithologically, the Juana Lopez is dominantly noncalcareous shale (94.5%) with subsidiary amounts of calcarenitic and quartzose sandstone (4.5%). The South Garcia section was measured 1 mi (1.6 km) due south of the intersection of I–40 and Cañoncito School Road, South Garcia 7.5-min quadrangle, Cibola County, New Mexico, by S. C. Hook on January 16, 1981.

Discussion

When compared directly with the Sky Village section, 50 mi (80 km) to the north, the South Garcia section is missing a minimum of 15 ft (4.6 m) of shale that is present at Sky Village between the top of the Semilla and the base of the Juana Lopez. The unnamed shale unit at Sky Village (Fig. 8, unit 4) that contains *Prionocyclus hyatti* (D11463) and *Cameleolopha bellaplicata* (D11464) is gone. If the first occurrence of *Coilopoceras inflatum* (D11467) at Sky Village represents the same event as the first occurrence of *C. inflatum* (D11451) at South Garcia, then the amount of missing section almost doubles to 28 ft (8.5 m). This is the first published, direct evidence of an erosion surface at the base of the Juana Lopez.

The entire South Garcia section (Fig. 9) consists of 286 ft (87.2 m) of Mancos Shale, beginning with a *Collignoniceras woollgari woollgari* collection (D11449) from concretions in noncalcareous shale in the Rio Salado Tongue and ending with a collection containing *Prionocyclus wyomingensis* and *Scaphites warreni* (D11456) from the last exposed calcarenite in the Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale. The Semilla Sandstone Member, 23 ft (7.0 m) thick, separates the Rio Salado Tongue from D-Cross Tongue. The contact of the Semilla with the Rio Salado is gradational; its contact with the Juana Lopez is interpreted as an erosional disconformity, with the basal, 4-inch- (10-cm-) thick quartzose, ripple-marked sandstone of the Juana

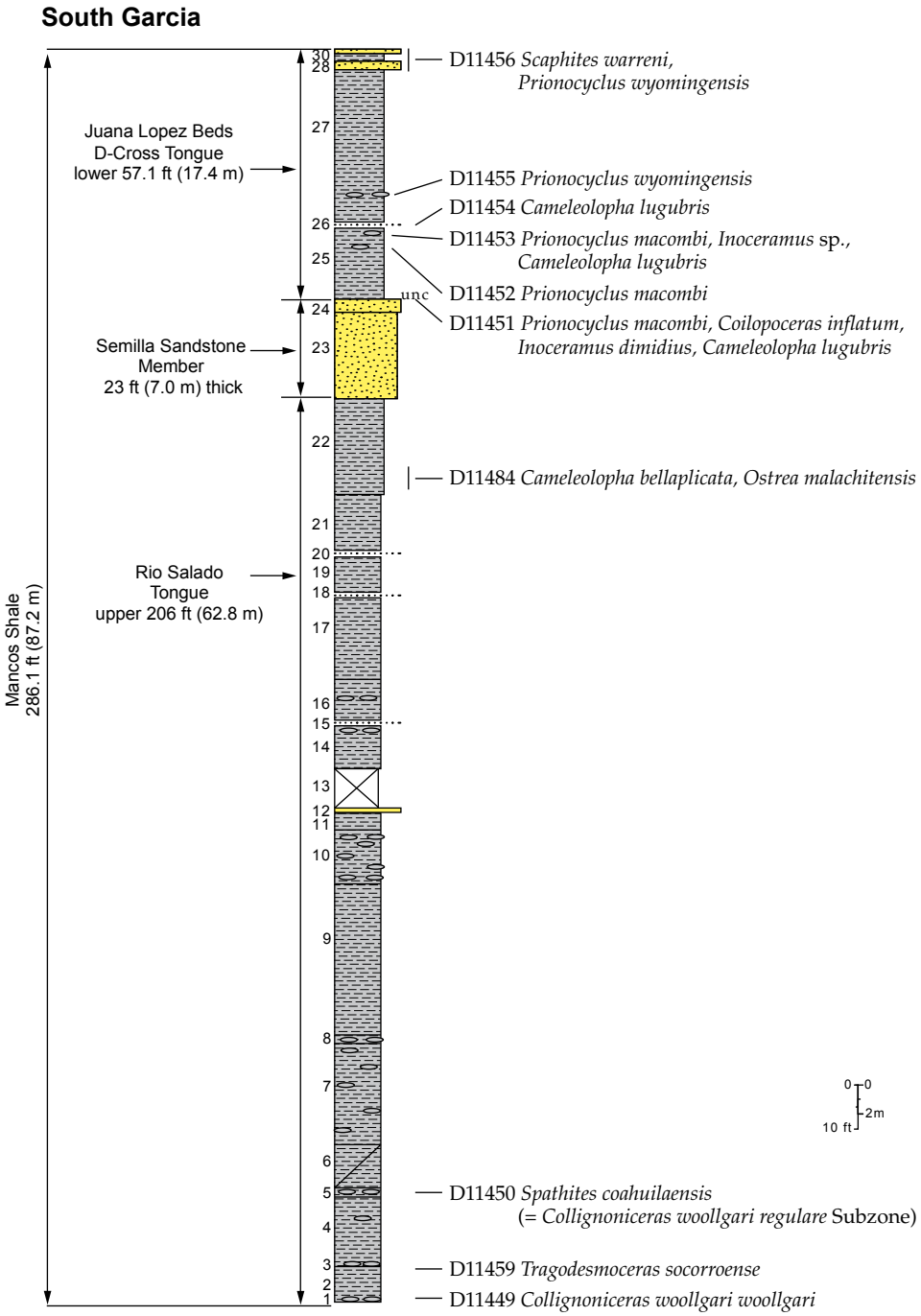


FIGURE 9—The South Garcia measured section of the Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale shows the positions of fossil collections from the Juana Lopez and underlying members of the Mancos Shale in the Acoma Basin, Cibola County, New Mexico. The unconformity at the base of the Juana Lopez rests on the top of the Semilla Sandstone Member. This section was measured 1 mi (1.6 km) due south of the intersection of I–40 and Cañoncito School Road, South Garcia 7.5-min quadrangle, Cibola County, New Mexico.

Lopez containing phosphate granules and *Cameleolopha lugubris*, *Inoceramus dimidius*, *Coilopoceras inflatum*, and *Prionocyclus macombi* (D11451) in contact with Semilla Sandstone, which is barren of fossils in this area.

The presence of the Semilla Sandstone, the offshore equivalent of the Tres Hermanos Formation, above, and the Twowells Tongue of the Dakota Sandstone below (not measured, but present in the area) dictates use of the term "Rio Salado Tongue of the Mancos Shale" between the two sandstones.

Sevilleta National Wildlife Refuge, New Mexico

Description

The Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale on Sevilleta National Wildlife Refuge (Figs. 2C, D and 10), Socorro County, New Mexico, consist of two thin calcarenites separated by a medial, noncalcareous shale. The beds are 5.5 ft (1.7 m) thick, lie 5 ft (1.5 m) above the top of the Tres Hermanos Formation, and encompass only one ammonite zone, the *Prionocyclus wyomingensis* Zone (4*a*, *b*). The lower calcarenite is 6.5 inches (17 cm) thick and is very fossiliferous. The upper calcarenite is 2 inches (5 cm) thick and just as fossiliferous. Both beds contain *Prionocyclus wyomingensis* (Fig. 5D), *Inoceramus dimidius*, and scaphites: the lower bed has *Scaphites warreni* (4*a*); the upper, *S. ferronensis* (4*b*). The calcarenites are separated by 4.8 ft (1.5 m) of noncalcareous gray shale that comprises 87.2% of the unit by rock type. The section was measured 1.1 mi (1.8 km) N51°W of the southeast corner of the La Joya 7.5-min quadrangle, Socorro County, New Mexico, and 0.6 mi (1 km) north of hill 5405 by S. C. Hook, on March 15, 2012.

Discussion

The Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale on Sevilleta National Wildlife Refuge (Figs. 2C, D and 10) are the thinnest in the study area at 5.5 ft (1.7 m); they are unusual in that they encompass only one ammonite zone, the *Prionocyclus wyomingensis* Zone (4*a*, *b*). Yet, the two sets of rusty- to orange-brown-weathering calcarenites composed primarily of comminuted *Inoceramus* prisms are unmistakable.

The top of the Tres Hermanos Formation is interpreted as an erosion surface because of the concentration of many worn oyster shells and phosphatic internal molds of small bivalves that appear to have accumulated on it as a lag deposit (Fig. 10, D15027). The oysters are the disarticulated valves of *Cameleolopha bellaplicata*, many of which have sandstone matrix attached to the spaces between ribs. The amount of section missing here and the magnitude of the unconformity are difficult to assess. The *Prionocyclus macombi-Coilopoceras inflatum-Cameleolopha lugubris* assemblage (3*c*) is not here. Representatives of both subzones (4*a*, *b*) of the *P. wyomingensis* Zone are present in the calcarenites of the Juana Lopez beds, and *P. novimexicanus* occurs in concretions 73 ft (22.3 m) above the base of the D-Cross Tongue (Hook et al. 2012, fig. 6).

Cameleolopha lugubris and *Scaphites warreni* were not collected from the basal calcarenite (unit 2) at the Figure 10 locality, but have been projected into the section from a nearby locality on Sevilleta National Wildlife Refuge (D11349).

Jornada del Muerto coal field, New Mexico

Description

The Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale at the Jornada del Muerto coal field (Figs. 2E and 11) are

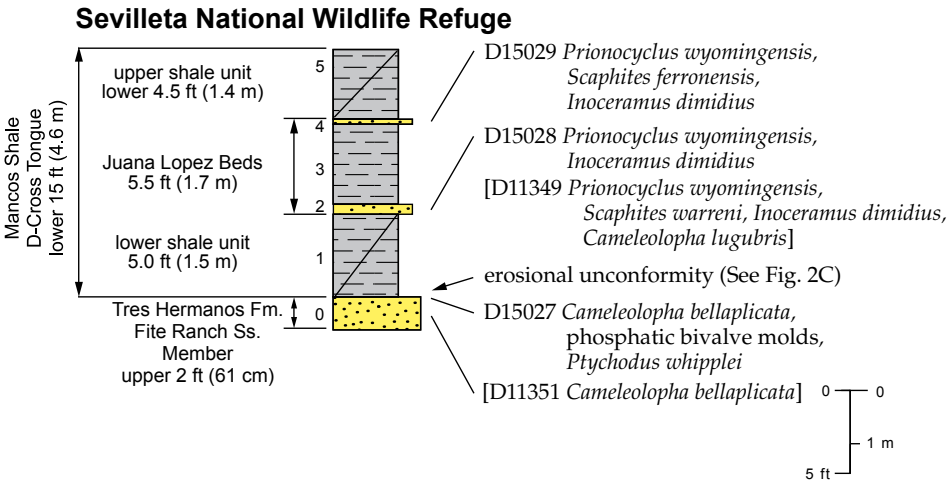


FIGURE 10—The Sevilleta National Wildlife Refuge measured section of the Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale shows the positions of fossil collections from the Juana Lopez and underlying Fite Ranch Sandstone Member of the Tres Hermanos Formation, Socorro County, New Mexico. The Juana Lopez is only 5.5 ft (1.7 m) thick, making it the thinnest in the study area; it lies entirely within the *Prionocyclus wyomingensis* Zone. This section was measured 1.07 mi (1.8 km) N51°W of the southeast corner of the La Joya 7.5-min quadrangle, Socorro County, New Mexico.

10.3 ft (3.1 m) thick, lie 8.5 ft (2.6 m) above the top of the Tres Hermanos Formation, and are composed of two sets of thin-bedded calcarenites separated by as much as 9.7 ft (3.0 m) of noncalcareous gray shale, which comprises 94.3% of the total thickness. These beds encompass a single ammonite zone just as they do at Sevilleta National Wildlife Refuge, but it is the next higher zone of *Prionocyclus novimexicanus* (5*a*). The lower calcarenite is 4 inches (10 cm) thick, weathers rusty brown, and is very fossiliferous. The upper calcarenite is also 4 inches (10 cm) thick but weathers brownish orange and is poorly fossiliferous. The section was measured in the NW¼ sec. 5 T3S R3E Bustos Well 7.5-min quadrangle, Socorro County, New Mexico, by S. C. Hook, G. Massingill, B. Robinson, and D. Tabet on September 15, 1978 (see Tabet, 1979, pp. 13–14).

Discussion

The Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale in the Jornada del Muerto coal field, Socorro County, New Mexico (Figs. 2E and 11), are the second thinnest in the study area. They encompass only one ammonite zone (5*a*), the uppermost of the three zones that make up the Juana Lopez Member at Mesa Verde National Park and at the principal and reference sections. Yet, the rusty-brown- to orange-weathering calcarenites, here composed primarily of comminuted *Inoceramus* prisms, are unmistakable.

The Juana Lopez crops out sporadically in the Jornada del Muerto coal field primarily because the D-Cross Tongue is almost entirely covered by alluvium in the area. Generally, only the basal calcarenitic unit crops out (Fig. 2E). In some places, both the upper and lower calcarenites are exposed by channeled erosion along the traces of small displacement, east-west faults that form (dry) water gaps through the lower D-Cross Tongue and Tres Hermanos Formation.

The thickness of the lower ridge-forming calcarenite (Fig. 2E) varies considerably along strike from 4 to 18 inches (10 to 46 cm). The composition of this ridge-forming unit varies from 100% calcarenite to two thin calcarenites separated by as much as 1 ft (30 cm) of shale. At the locality of Figure 2E, the lower of these two calcarenites is as much as 6 inches (15 cm) thick, weathers rusty brown, and is very fossiliferous. The upper calcarenite varies from 2 to 8 inches (5 to 20 cm) thick, weathers brownish orange, and is poorly fossiliferous. The base of the upper calcarenite appears to be an erosion surface; in places it rests directly on the lower calcarenite.

Where the upper ridge-forming calcarenite (Fig. 11, unit 18) crops out, it varies from approximately 6 to 10 ft (1.8 to 3.0 m) above the lower calcarenite. This variation suggests that the upper calcarenite was deposited on an erosion surface. The interval between the two calcarenites is generally covered.

The section presented in Figure 11 is from Tabet (1979) and is regarded by the authors as representative of the coal field. All fossils shown on the section were collected and identified by the authors of the present study. The Juana Lopez lies 8.5 ft (2.6 m) above the base of the D-Cross Tongue of the Mancos Shale, which is interpreted to rest unconformably on the top of the Fite Ranch Sandstone Member of the Tres Hermanos Formation (Fig. 2E). Fossils collected from the base of the D-Cross (Fig. 11, D14544) include phosphatic internal molds of small bivalves and the teeth of the shell-crushing shark *Ptychodus whipplei*. The top of the Fite Ranch Sandstone is poorly fossiliferous yielding only a single internal mold of the infaunal bivalve *Pholadomya* sp. (D14543), which is interpreted to be from the *Prionocyclus macombi-Cameleolopha bellaplicata-Pholadomya* sp. assemblage common in the Fite Ranch farther to the south at the Carthage coal field (see Hook and Cobban, 2011). This assemblage occurs in the *Coilopoceras colleti* Subzone (3*a*) of the middle Turonian *Prionocyclus macombi* Zone. In support of this interpretation, Tabet (1979, p. 14) reports *Cameleolopha bellaplicata* (D10603) from concretions high in the Carthage Member, approximately 40 ft (12 m) below the top of the Tres Hermanos Formation.

Both the basal and upper calcarenites of the Juana Lopez Beds contain fairly abundant impressions of *Prionocyclus novimexicanus* and *Scaphites whitfieldi* along with many internal molds and impressions of *Inoceramus perplexus* (D14545 and D10466),

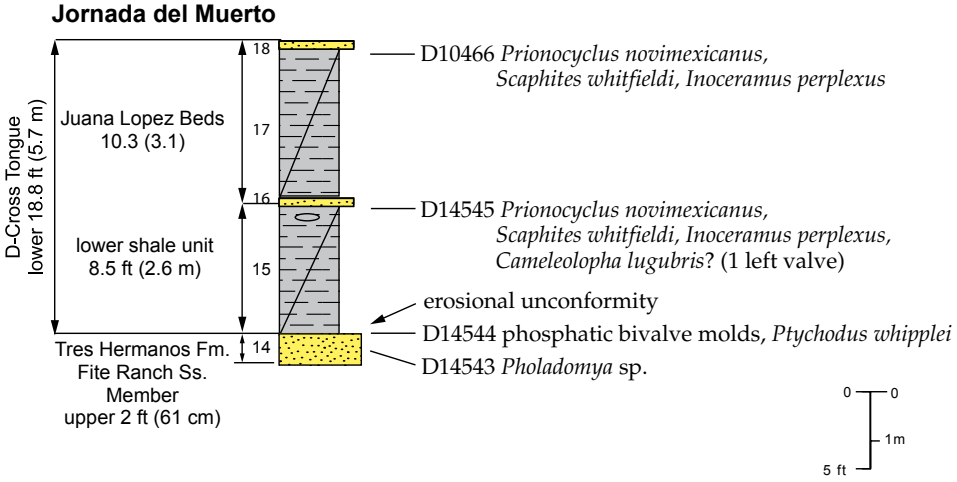


FIGURE 11—The Jornada del Muerto coal field measured section of the Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale shows the positions of fossil collections from the Juana Lopez and underlying Fite Ranch Sandstone Member of the Tres Hermanos Formation, Socorro County, New Mexico. The Juana Lopez is only 10.3 ft (3.1 m) thick—the second thinnest in the study area—and lies entirely within the *Prionocyclus novimexicanus* Zone. This section was measured in the SW¼ sec. 5 T3S R3E Bustos Well 7.5-min quadrangle, Socorro County, New Mexico. Modified from Tabet 1979, pp. 13–14.

all indicative of the lower part of the upper Turonian *P. novimexicanus* Zone (5*a*). In addition, recent collecting (July 2012) yielded one left valve of a small, coarsely ribbed oyster with a large attachment scar from the lower calcarenite. This specimen is referred questionably to *Cameleolopha lugubris* (D14545). The presence of this single ribbed oyster suggests that the base of this calcarenite was deposited at or very near the end of the time represented by the underlying middle Turonian *P. wyomingensis* Zone. The *Prionocyclus novimexicanus* Zone extends at least 42.5 ft (12 m) above the top of the Juana Lopez Beds, where *P. novimexicanus* (D10604) has been collected from a zone of limestone concretions (Tabet, 1979, p. 14, recorded as *Prionocyclus* sp.).

The 8.5 ft (2.6 m) of shale at the base of the D-Cross appears to represent the *Coilopoceras inflatum* Subzone (3*c*) of the *Prionocyclus macombi* Zone and both subzones of the *Prionocyclus wyomingensis* Zone (4*a*, *b*). How much of those zones is represented by the erosional unconformity between the Tres Hermanos and the D-Cross is impossible to determine. However, the two calcarenites from Sevilleta National Wildlife Refuge that carry the *Scaphites warreni* and *S. ferronensis* faunas (Fig. 10), respectively, are not developed here.

Bull Gap Canyon, New Mexico

Description

At this Bull Gap Canyon measured section (Figs. 2F, G, H, and 12), the Juana Lopez Beds are 16.7 ft (5.1 m) thick, lie 7 ft (2.1 m) above the top of the Fite Ranch Sandstone Member, and consist of two thin arenite beds—comprising 16% of beds' rock types—separated by 14 ft (4.3 m) of gray, concretion-bearing, noncalcareous shale (84%). The basal arenite (unit 5) contains the zone 3*c* *Prionocyclus macombi-Coilopoceras inflatum-Inoceramus dimidius-Cameleolopha lugubris* fauna (D14474) typical of the Juana Lopez in much of New Mexico. It also contains *Hourcquia mirabilis*. The upper calcarenite contains *P. wyomingensis*, *I. dimidius*, and *C. lugubris* (D14476) that probably represent zone 4*a*. This composite section occupies a spatial position between the two sections presented in Hook and Cobban (2012, figs, 2 & 4). Units A–D were measured in the NE¼ SE¼ sec. 24 T9S R9E on March 13, 2011; units 2–7, in the SW¼ SW¼ sec. 18 T9S R9E on September 14, 2005. Both sections are on the Bull Gap 7.5-min quadrangle, Lincoln County, New Mexico, and were measured by S. C. Hook.

Discussion

The Bull Gap Canyon composite section (Fig. 12) documents a 100% exposed outcrop of Juana Lopez Beds as well as highlighting the evolutionary sequence of four species of the *Cameleolopha lugubris* group present in the Fite Ranch Sandstone and the basal part of the D-Cross Tongue (Hook and Cobban 2012). The basal bed of the Juana Lopez is a medium-brown, resistant, 2.0-ft- (61-cm-) thick, highly calcareous quartz arenite that tends to be concretionary. The upper arenite is a dark-brown, calcarenite 8 inches (20 cm) thick that forms a minor ridge and litters the underlying slope with platy debris. Although both arenites are fossiliferous, the lower one (D14474 level) contains many well-preserved internal molds of at least five species of ammonites, prompting Hook and Cobban (2012, p. 81) to call it "…one of the most fossiliferous, ammonite-bearing beds in the Upper Cretaceous of New Mexico." Most of these ammonites are found as float on the shale below the arenite. However, a single in-place specimen of the important ammonite *Hourcquia mirabilis* (Fig. 2H) was collected from 3 inches (8 cm) below the top of this unit.

Hourcquia mirabilis (Fig. 2H) is the key ammonite in this bed because it also occurs near the base of the Juana Lopez at its type section (Fig. 7) as well as at Mesa Verde National Park (Fig. 3) and Taylor Springs (Fig. 1). *Hourcquia mirabilis* is among the rarest ammonite species in the Western Interior (Kennedy et al., 1988), known only from New Mexico and southwest Colorado. It occurs in association with *P. macombi* (Fig. 2F), *Coilopoceras inflatum* (Fig. 2F, G), and *Cameleolopha lugubris*. This faunal association, always in a single bed, suggests that the basal portion of the Juana Lopez at these four widespread localities was deposited at least penecontemporaneously, if not synchronously.

The 14 ft (4.3 m) of noncalcareous shale above the *Hourcquia mirabilis* bed contains scattered pancake limestone concretions. One of these concretions, 2 ft (60 cm) below the top of the unit is the internal mold of *Prionocyclus wyomingensis* (D14475). The top of the 16.7-ft- (5.1-m-) thick Juana Lopez is an 8-inch- (20-cm-) thick, dark-brown, slabby calcarenite containing *Cameleolopha lugubris* and *Inoceramus dimidius* along with impressions of *P. wyomingensis* (D14476). Whether this assemblage represents zone 4*a* or 4*b* cannot be determined because scaphitids have not been found this high in the section in east-central New Mexico.

If there are higher calcarenites in the Juana Lopez here, they are covered by alluvium along the outcrop belt. The next higher exposures of the D-Cross to the east of the measured section are of the shales beneath the Gallup Sandstone, which contain a zone of large, resistant limestone concretions (Hook et al. 2012, fig. 7) containing a lower Coniacian fauna.

High Nogal Ranch, New Mexico

Description

The Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale at the High Nogal Ranch (Fig. 13) are 21.4 ft (6.5 m)

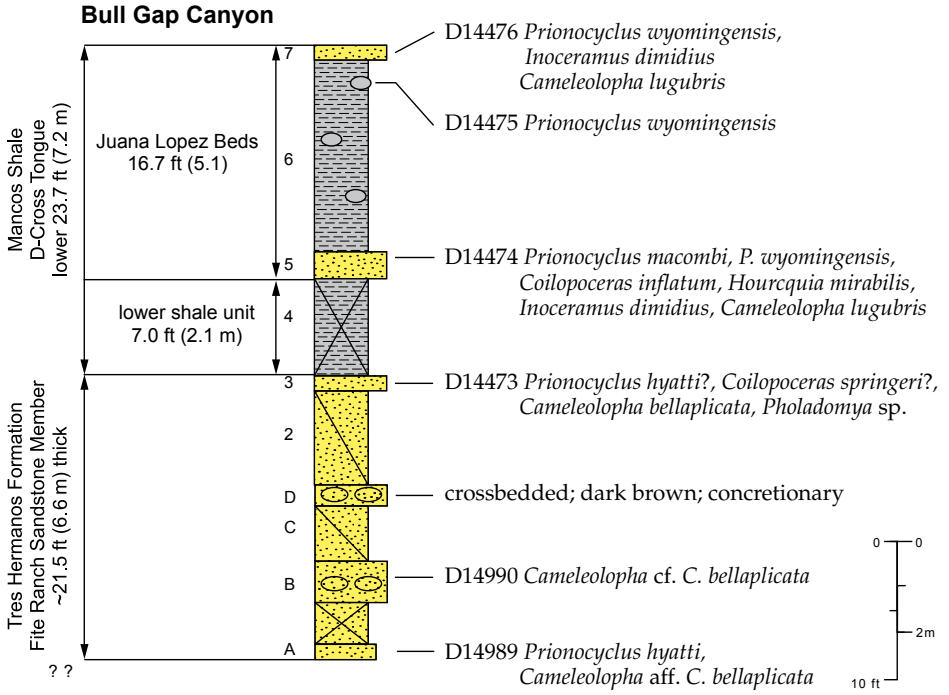


FIGURE 12—The Bull Gap Canyon composite section of the Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale shows the positions of fossil collections from the Juana Lopez and underlying Fite Ranch Sandstone Member of the Tres Hermanos Formation, Lincoln County, New Mexico. The basal arenite of the Juana Lopez (unit 5) is one of the most fossiliferous ammonite beds in New Mexico, yielding several well-preserved specimens of *Prionocyclus macombi* (Fig. 2F), *Coilopoceras inflatum* (Fig. 2F, G), and *Hourcquia mirabilis* (Fig. 2H). This composite section was measured in the NE¼ SE ¼ sec. 24 T9S R9E and in the SW¼ SW¼ sec. 18 T9S R9E on the Bull Gap 7.5-min quadrangle, Lincoln County, New Mexico.

thick, lie 6.6 ft (2.0 m) above the top of the Tres Hermanos Formation, have sharp upper and lower contacts, and consist of three arenites (6.5%) separated by two noncalcareous, concretion-bearing shales (93.5%). The basal arenite, a concretionary sandstone bed (unit 19) contains the typical 3*c* assemblage zone of *Prionocyclus macombi*, *Coilopoceras inflatum*, and *Cameleolopha lugubris*. The upper calcarenite (unit 23) contains *P. novimexicanus* and *Inoceramus perplexus*, typical of zone 5*a*. The High Nogal Ranch section was measured in the NE¼ NE¼ sec. 15 T12S R10E Golondrina Draw 7.5-min quadrangle, Otero County, New Mexico, by S. C. Hook on March 16, 2010.

Discussion

The complete High Nogal Ranch measured section (Fig. 13) consists of approximately 150 ft (45 m) of strata extending from the upper part of the lower tongue of the Mancos Shale (45 ft [13.7 m] thick), through the Tres Hermanos Formation (70 ft [21.3 m] thick), and into the basal part of the D-Cross Tongue of the Mancos Shale (28 ft [8.5 m] thick). It is the easternmost known outcrop in New Mexico containing both the Tres Hermanos Formation and the Juana Lopez Beds, although these units may be present to the east on the Mescalero Apache Indian Reservation. Moore et al. (1988) mapped the northwest part of the reservation and indicated that their undivided Kmmv map unit contained Tres Hermanos Formation along with D-Cross Tongue and Gallup Sandstone.

The High Nogal Ranch section documents a 100% exposure of the thickest Juana Lopez Beds in central New Mexico, although they are only about 20% as thick as the type or reference sections of the Juana Lopez Member to the northwest. In addition, the Juana Lopez Beds contain the full suite of ammonite zones found in these much thicker sections. Both the Tres Hermanos Formation and the Juana Lopez Beds at High Nogal Ranch are condensed relative to their reference sections. Here, the Tres Hermanos is approximately 70 ft (21.3 m) thick—a quarter of the thickness of its reference section at Carthage, 65 mi (104 km) to the northwest. The base of the Tres Hermanos is probably in the *Collignoniceras woollgari* Zone (D14985) and the top is in the *Prionocyclus macombi* Zone (D14921), just as it is at Carthage. The oyster *Crassostrea* aff. *C. subtrigonalis* (D14985), which occurs near the base of the Atarque Sandstone here, is known only from the *C. woollgari* Zone in New Mexico. However, no ammonites have been recovered from the base of the Tres Hermanos. A rare occurrence of *Cibolaites molenaari* (D14927), 35 ft (10.7 m) below the base, suggests that the base could lie one zone lower in the *Mammites nodosoides* Zone. The Tres Hermanos here consists of a marine, regressive sandstone at the base (the Atarque Sandstone Member), a nonmarine core of carbonaceous shale, siltstone, and sandstone (the Carthage Member), and an upper, transgressive marine sandstone unit (the Fite Ranch Sandstone Member), just as it does elsewhere in New Mexico. The upper few inches of the Fite Ranch and the lower few inches of the D-Cross contain the only occurrence of the oyster *Cameleolopha* aff. *C. lugubris* (D14922-23), a species transitional between the older *C. bellaplicata* and the younger *C. lugubris* (Hook and Cobban 2012, appendix 2).

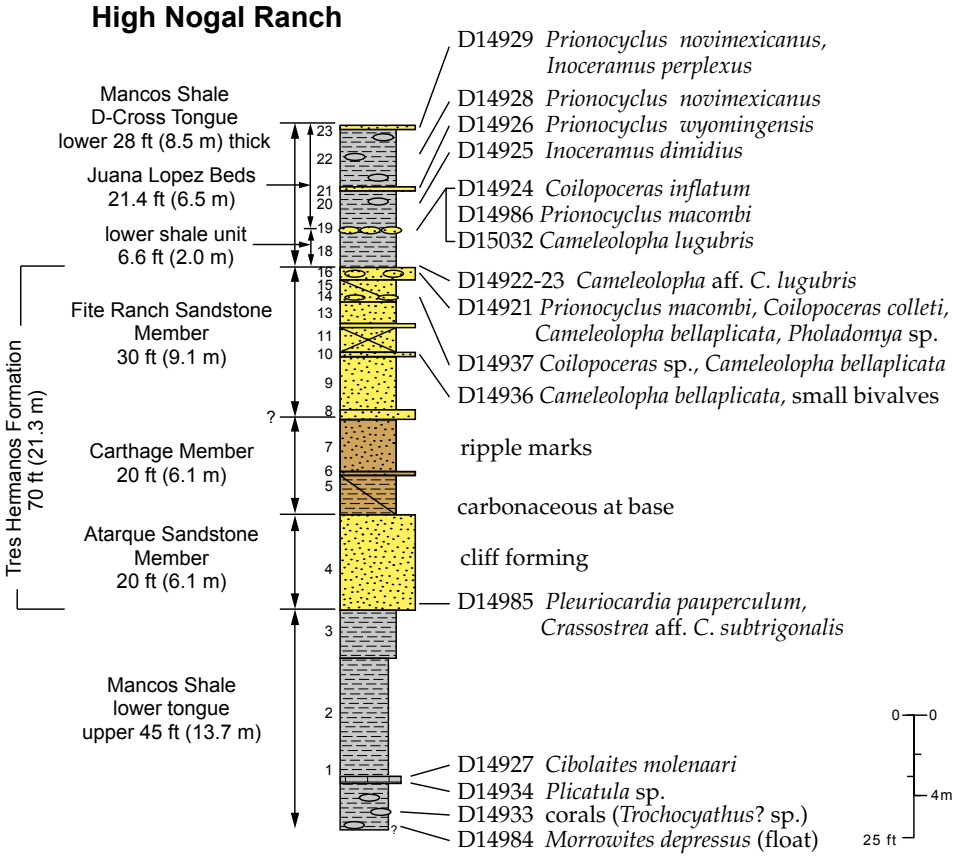


FIGURE 13—The High Nogal Ranch section of the Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale shows the positions of fossil collections from the Juana Lopez and underlying Tres Hermanos Formation and upper part of the lower tongue of the Mancos Shale, Otero County, New Mexico. This section is the easternmost in New Mexico known to contain the Tres Hermanos Formation. Although the Juana Lopez Beds are only 21.4 ft (6.5 m) thick, they span three ammonite zones: the *Prionocyclus macombi*, *P. wyomingensis*, and *P. novimexicanus* Zones. This section was measured in the NE¼ NE¼ sec. 15 T12S R10E Golondrina Draw 7.5-min quadrangle, Otero County, New Mexico.

The Juana Lopez Beds, which are 21.4 ft (6.5 m) thick, attain their greatest measured thickness in central New Mexico here. The basal unit of the Juana Lopez is a 1-ft- (3-cm-) thick bed of sparsely fossiliferous, sandy limestone concretions. Collections from three different, but nearby, localities were necessary to get the typical zone 3*c* fossils of *Coilopoceras inflatum* (D14924), *Prionocyclus macombi* (D14986), and *Cameleolopha lugubris* (D15032).

Limestone concretions in the overlying 8 ft (2.4 m) of noncalcareous shale (unit 20) contain well-preserved *Inoceramus dimidius* (D14925). The 1.5-inch- (4-cm-) thick, thin-bedded calcarenite (unit 21) above this shale contains impressions of *P. wyomingensis* (D14926). Body fossils (internal molds) of *P. novimexicanus* (D14928) occur in concretions in the overlying 12-ft- (3.7-m-) thick shale. The upper dark-brown calcarenite bed, 3 inches (8 cm) thick, contains impressions of *P. novimexicanus* and *Inoceramus perplexus* (D14929). Above the calcarenite, which represents zone 5*a*, the section is concealed.

T-2 transgression

Shoreline positions

Molenaar (1983a) recognized five major cycles of transgression and regression of the Late Cretaceous seaway across the Four Corners area into New Mexico, which he labeled T-1/R-1 (oldest) through T-5/R-5 (youngest). This labeling scheme for the shorelines has been used by many authors since then; e.g., Aubrey (1991) and Hook and Cobban (2011). Using this scheme, the Juana Lopez was deposited during the early and middle parts of the T-2 transgression.

The T-2/R-2 cycle is unique to New Mexico and eastern Arizona. In central New Mexico this cycle was responsible for deposition of the upper half of the Tres Hermanos Formation, the D-Cross Tongue

of the Mancos Shale (including the Juana Lopez Beds), the Gallup Sandstone, and the lower part of the Crevasse Canyon Formation. Figure 1 shows the approximate position of the shoreline of the Late Cretaceous seaway in New Mexico at the end of deposition of the middle portion of the Juana Lopez, about the end of the time represented by the *Prionocyclus wyomingensis* Zone, near the middle of T-2. This shoreline is based on positions of USGS Mesozoic invertebrate collections containing *Cameleolopha lugubris* and *Inoceramus dimidius*. The key control point among the isolated Upper Cretaceous outcrops in south-central New Mexico that determines the landward limit of this shoreline is Davis Well/Love Ranch (Fig. 1). There, the top member of the Tres Hermanos Formation, which was deposited on nonmarine strata of the Carthage Member of the Tres Hermanos Formation shortly after the T-2 shoreline arrived, contains *Scaphites whitfieldi*, representing zone 5*a* (Hook et al. 2012, fig. 3). Therefore, the position of the *C. lugubris* shoreline (Fig. 1) has to be north (seaward) of Davis Well/Love Ranch, but south (landward) of Mescal Canyon and High Nogal Ranch, where rocks above the nonmarine Carthage Member contain the older *P. macombi* fauna representing zone 3.

The inferred position of this *Cameleolopha lugubris* shoreline (middle T-2) is virtually the same as that presented for the older *C. bellaplicata* shoreline (early T-2) presented in Hook and Cobban (2011, fig. 3). If *Coilopoceras inflatum* and *Hourcquia mirabilis* were short lived, penecontemporaneous species as interpreted above, then faunal evidence from Sierra County indicates that the T-2 shoreline had stalled or was moving slowly in the Truth or Consequences area. At Reynolds Canyon on the Turner Ranch (Fig. 1), *C. inflatum* (D14676) occurs 50 ft (15 m) above the base of the D-Cross Tongue just above concretions containing *Cameleolopha lugubris* and *Inoceramus dimidius* (D14675). At Mescal Canyon, 12 mi (20 km) to the southwest, *I. dimidius* (D14608) and *C. inflatum* and *H. mirabilis* (D14591) occur in sandy concretions in the basal 5 ft (1.5 m) of the D-Cross Tongue (Hook et al. 2012, fig. 4).

Although there is virtually no difference between the landward positions of these two T-2 shorelines, there is a tremendous difference in the distribution of oysters relative to each shoreline. On the *Cameleolopha bellaplicata* map (Hook and Cobban 2011, fig. 3) the oyster localities cluster in a belt within 100 mi (160 km) of the shoreline, in nearshore, high-energy sandstones, more or less parallel to the shoreline. Those collections that are farther offshore are from older rocks, generally the Semilla Sandstone Member of the Mancos Shale, zone 2*b*. Those that are closer to the shoreline are from younger rocks, either the Fite Ranch Sandstone Member of the Tres Hermanos Formation or the basal part of the D-Cross Tongue of the Mancos Shale, zone 3*a*. In contrast, on the *C. lugubris* map (Fig. 1), the oyster localities are distributed throughout the seaway, primarily in the Mancos Shale, in medium-energy, low-sediment environments that created calcarenites in zones 3*c* through 5*b*. For comparison, note that the straight line distance from the shoreline southwest of T or C to fossil collections in southeast Colorado is approximately 350 mi (560 km) and that the fossils are fairly evenly distributed throughout the seaway.

If the position of the shoreline were at a stillstand, but the energy within the offshore environment increased, then the implication is that either the seaway became shallower (over at least the Four Corners states) or offshore currents intensified. The evolutionary picture of the genus *Cameleolopha* presented in Hook and Cobban (2012) appears to favor the shallower water interpretation. Hook and Cobban (2012) collected the four species of *Cameleolopha* ancestral to *C. lugubris* from nearshore, relatively high energy sandstones in the Fite Ranch Sandstone Member of the Tres Hermanos Formation from Bull Gap Canyon (Fig. 12) and High Nogal Ranch (Fig. 13).

Exactly how these calcarenites formed over such an immense area of the Western Interior while the position of the western shoreline remained more-or-less stationary is beyond the scope of the present paper. However, calcarenite formation in far offshore environments is not unique to the deposition of the Juana Lopez. Two older, equally widespread, thin calcarenitic units (interbedded with shale) similar to the Juana Lopez are present lower in the Upper Cretaceous in the study area. The older of the two was formed during the time represented by the middle Cenomanian *Acanthoceras amphibolum* Zone, early in the T-1 transgression, about the time the x-bentonite was deposited. The younger formed during the time represented by lower Turonian *Mammites nodosoides* Zone, early in the R-1 regression. The older one is more similar to the Juana Lopez depositionally and faunally than the younger. It was formed in a transgressing seaway, and its fauna is dominated by the oyster *Ostrea beloiti* but contains numerous inoceramids (*Inoceramus arvanus* and *I. rutherfordi*) and occasional ammonite molds (*A. amphibolum*) and impressions (*Tarrantoceras* spp.). Sageman and Johnson (1985, p. 107), working in the Pueblo, Colorado, area, regard what they call the "*O. beloiti* biostrome" as being "… indicative of agitated benthic environments with deeper water (about 100 m), firm, well-oxygenated substrates."

The younger calcarenite unit, which forms the upper part of the Bridge Creek Limestone Beds of the Mancos Shale in central New Mexico, contains a less diverse invertebrate fauna that is dominated overwhelmingly by the bivalve *Mytiloides mytiloides*; there are no oysters and only local molds of *Mammites nodosoides*. All four of the outcrop sections in south-central New Mexico profiled in this report (Sevilleta National Wildlife Refuge, Jornada del Muerto, Bull Gap Canyon, and High Nogal Ranch, Figs. 10–13) contain one or both of these lower calcarenite units. Additional information and sections containing these calcarenites in south-central New Mexico can be found in Hook et al. (2012).

Timing

The exact biostratigraphic timing for the initiation of the T-2 transgression has been a little uncertain, but must be near the end of the *Prionocyclus hyatti* Zone (2*b*), when the Semilla Sandstone was deposited, or near the beginning of the *P. macombi* Zone (3*a*), when the uppermost part of the Carthage Member of the Tres Hermanos Formation was deposited (Hook and Cobban 2011). Two sections from this study help pinpoint this timing.

At the type section of the Juana Lopez (Fig. 7) near Cerrillos, New Mexico, the base of the Juana Lopez Member, which is in zone 3*c*, is separated from the Semilla Sandstone Member (2*b*) by 60 ft (18.3 m) of unnamed shale containing an ammonite that is probably *Prionocyclus hyatti* (D10809). At Sky Village (Fig. 8), this unnamed shale is 15 ft (4.6 m) thick and contains an undoubted specimen of *P. hyatti* (D11463). This unnamed shale is interpreted to have been deposited in deeper water than the Semilla Sandstone at the beginning of the T-2 transgression. Based on the interpretation of these two sections, the T-2 transgression began during the latter part of the time represented by the *Coilopoceras springeri* Subzone (2*b*) of the *P. hyatti* Zone.

Unconformities

Calcarenites in the Juana Lopez consist primarily of bioclastic debris formed by abrasion of marine bivalve shells in offshore environments under medium- to high-energy conditions with little clastic input. By definition, a calcarenite represents a condensed interval at a minimum. The medium- to high-energy processes required to reduce bivalve shells to sand-sized particles could intensify during storms to the point that erosion occurred that removed some of the underlying soft, offshore clay. Of the 11 sections discussed above, only one contains direct evidence for erosion beneath a Juana Lopez calcarenite. In the Jornada del Muerto coal field (Fig. 11) the stratigraphic interval between the lower and upper calcarenites varies from 0 to 1 ft (0 to 30 cm) over a lateral distance of less than 100 ft (30 m). Both calcarenites are high in the section, in the lower part of the *Prionocyclus novimexicanus* Zone (5*a*).

The varying thickness of the stratigraphic interval between the base the Juana Lopez and the top of the underlying Semilla Sandstone on the east side of the San Juan Basin east into the Hagan Basin (reference

and type sections, Sky Village, and South Garcia) suggests that there is an erosional surface at the base of the Juana Lopez (Table 1, last column). In Figures 6–9, this interval is referred to the "unnamed shale member." Where it contains fossils, this member lies in the upper part of the *Prionocyclus hyatti* Zone (2*b*). At the reference section (Fig. 6) the unnamed shale is 12.5 ft (3.8 m) thick; at Sky Village (Fig. 8), 15 ft (4.6 m); at South Garcia (Fig. 9), 0 ft (0 m); at the type section (Fig. 7), 60 ft (18.3 m). Assuming that the unnamed shale member is full thickness at the type section, which is the farthest offshore (Fig. 1), the magnitude of the unconformity increases to the west and southwest, where the erosion surface has cut into the Semilla Sandstone at South Garcia.

Comparison of the section at Sky Village (Fig. 8) with South Garcia (Fig. 9) permits interpretation that this erosional unconformity at the base of the Juana Lopez Beds at South Garcia has removed a minimum of 15 ft (4.6 m) of section. This interval (Fig. 8, unit 4) is in the *Prionocyclus hyatti* Zone (zone 2*b*). This interpretation relies on the first occurrence of the *Prionocyclus macombi-Coilopoceras inflatum-Cameleolopha lugubris* assemblage (3*c*) in a thin phosphate-bearing, quartzose sandstone to identify the base of the Juana Lopez at South Garcia. Based on stratigraphic position, this sandstone, the upper 3 inches (7.5 cm) of unit 24, would be the uppermost bed in the Semilla Sandstone Member; yet, the fossil assemblage indicates it formed during the early part of the second major transgression (T-2) of the Late Cretaceous seaway, well after deposition of the Semilla ceased at the end of the initial regression (R-1). This timing places the thin phosphatic sandstone in the Juana Lopez at South Garcia and allows the base of the Juana Lopez to be placed at the bottom of a quartzose sandstone bed containing the same faunal assemblage in Lincoln and Otero Counties. A similar erosion surface, i.e., one between the Codell (=Semilla) Sandstone and the Juana Lopez, was interpreted at Taylor Springs, Colfax County, by Hook and Cobban (1980b, fig. 4). There, the Juana Lopez Member of the Carlile Shale is only 10 ft (3 m) thick, but spans three ammonite zones, including fossils from 3*c*, 4*a*, and 5*a*. The basal assemblage there contains *Hourcquia mirabilis*.

The observationally verifiable erosion surface in Socorro and Lincoln Counties (Figs. 10–12) is not within or at the base of the Juana Lopez Beds, but lower in the section at the base of D-Cross Tongue. At both Sevilleta National Wildlife Refuge and the Jornada del Muerto coal field, the top of the Fite Ranch Sandstone appears to be an erosion surface on which phosphatic, abraded internal molds of bivalves, corroded and eroded oyster shells (*Cameleolopha bellaplicata*), and shark teeth accumulated as a lag deposit. At Bull Gap Canyon erosion at this level has removed as much as 25 ft of the Fite Ranch Sandstone (Hook and Cobban 2012, fig. 3, p. 78). An erosion surface may be present in these sections at the base of the Juana Lopez Beds, as well, but cannot be verified by the present observations.

On Sevilleta National Wildlife Refuge (Fig. 10), 5 ft (1.5 m) of shale separates the abraded shells and phosphatic molds, which represent zone 3*a*, from the base of the Juana Lopez, which carries *Scaphites warreni* from zone 4*a*. At the Jornada del Muerto coal field (Fig. 11), 10 ft (3 m) of shale separates these 3*a* molds from the base of the Juana Lopez, which lies a full zone higher at the base of the *Prionocyclus novimexicanus* Zone (5*a*). In both cases, the *Coilopoceras inflatum* assemblage zone (3*c*) is missing, although it is present to the northwest in the San Juan Basin and to the southeast in Lincoln and Otero Counties. At the Jornada del Muerto section, the entire *P. wyomingensis* Zone (4) is not represented by fossils.

Bentonites

Description

Only three of the 11 measured sections in the study area are well enough exposed that bentonite beds (= ash falls) were noted and measured (Table 1). Those three sections are Mesa Verde National Park, the reference section, and the type section.

At Mesa Verde (Fig. 3), which was trenched, there are 14 bentonite beds within the Juana Lopez that have an aggregate thickness of 2.9 ft (89 cm)—2.1% of the member—and an average thickness of 2.5 inches (6.3 cm). The thickest bentonite (unit 240) occurs 44.3 ft (13.5 m) above the base and is 1.1 ft (33 cm) thick, but consists of "multiple bentonites with large concretions" (Leckie et al. 1997, p. 210). The thickest single bentonite (unit 297) occurs 135 ft (41.2 m) above the base and is 5.1 inches (13 cm) thick. Six bentonites (units 230, 240, 272, 277, 297, and 302) exceed 2 inches (5 cm) in thickness; none are less than 0.4 inch (1 cm) thick.

At the type section (Fig. 7), a fresh railroad cut when measured (Fig. 2B), there is also 100% exposure; the white bentonite seams are unmistakable, standing in stark contrast to the dark-gray shale (Fig. 2B). The 12 bentonites at the type section have an aggregate thickness of 2.4 ft (72 cm)—2.2% of the member—and an average thickness of 2.4 inches (6.1 cm). The thickest bentonite (unit 49) occurs 104.5 ft (31.9 m) above the base and is 9 inches (23 cm) thick. Four bentonites (units 15, 23, 35, and 49) exceed 2 inches (5 cm) in thickness; the thinnest (unit 27) is 0.5 inch (13 mm) thick.

The section with the poorest bentonite exposure of the three is the reference section (Fig. 6), where Dane et al. (1966) measured seven bentonites, about half as many as at the lithologically and faunally similar type section, that have an aggregate thickness of 1.1 ft (34 cm)—1.1% of the member—and an average thickness of 1.9 inches (4.8 cm). The thickest bentonite (unit 43) occurs 105.4 ft (30.1 m) above the base and is 6 inches (15 cm) thick. One bentonite (unit 31) is 4 inches (10 cm) thick, two (units 23 and 37) are 1 inch (2.5 cm) thick, and three (units 7, 9, and 19) are 0.5 inch (13 mm) thick.

Discussion

The presence of 14 bentonites with an aggregate compacted thickness of 2.9 ft (89 cm) at Mesa Verde National Park (Fig. 3) and 12 bentonites with an aggregate compacted thickness of 2.4 ft (72 cm) at the type section (Fig. 7) indicates that the western highland bordering the seaway was volcanically active during the deposition of the Juana Lopez Member of the Mancos Shale in the San Juan Basin. However, correlating individual bentonites between Mesa Verde (Fig. 3) and the type section (Fig. 7) is extremely difficult. First, there is the difference in thickness of the Juana Lopez: at Mesa Verde it is 140 ft (42.6 m) thick, whereas at the type section it is 106 ft (32.3 m) thick. Then, there is the difference in age between the contacts at each section. Although, the bases of both sections lie in the same zone (3*c*), the base at Mesa Verde appears to be slightly older because of the 72 ft (22 m) of section below the first occurrence of *Hourcquia mirabilis* (Fig. 3). The top of the Juana Lopez at Mesa Verde is in zone 5*b*; at the type section it is lower, in zone 5*a*. If the first occurrence of *Hourcquia mirabilis* represents an isochronous event as postulated above, then the 106.1 ft (32.3 m) of Juana Lopez at the type section is the temporal equivalent of only the upper 68 ft (21 m) of the Juana Lopez at Mesa Verde.

The thickest individual bentonite at each of the three sections seems to correlate well from section to section because it is very close to the top of the member at each location. However, there is a difference in biostratigraphic age. At the type and reference sections, this bentonite lies in the lower part of the *Prionocyclus novimexicanus* Zone (5*a*), but at Mesa Verde it is in the upper part of the zone (5*b*).

At Mesa Verde, the first five bentonites in the Juana Lopez lie below the *Hourcquia mirabilis/Coilopoceras inflatum* bed, including unit 240, which consists of several bentonites that are an aggregate 1.1 ft (33 cm) thick. At the type section, no bentonites were observed below the *Hourcquia mirabilis/Coilopoceras inflatum* bed. At the type section (Fig. 7) there are nine bentonites between the *Hourcquia mirabilis/Coilopoceras inflatum* bed (lower ledge-forming calcarenites) and the upper ledge-forming calcarenites. At Mesa Verde (Fig. 3), there are five bentonites in this interval.

One very plausible explanation for the difficulty in correlating bentonite beds in the Juana Lopez is that the fossil preservation and biostratigraphic resolution are not great enough to be able to compare bentonites of the same age from one section to another. Another explanation is that

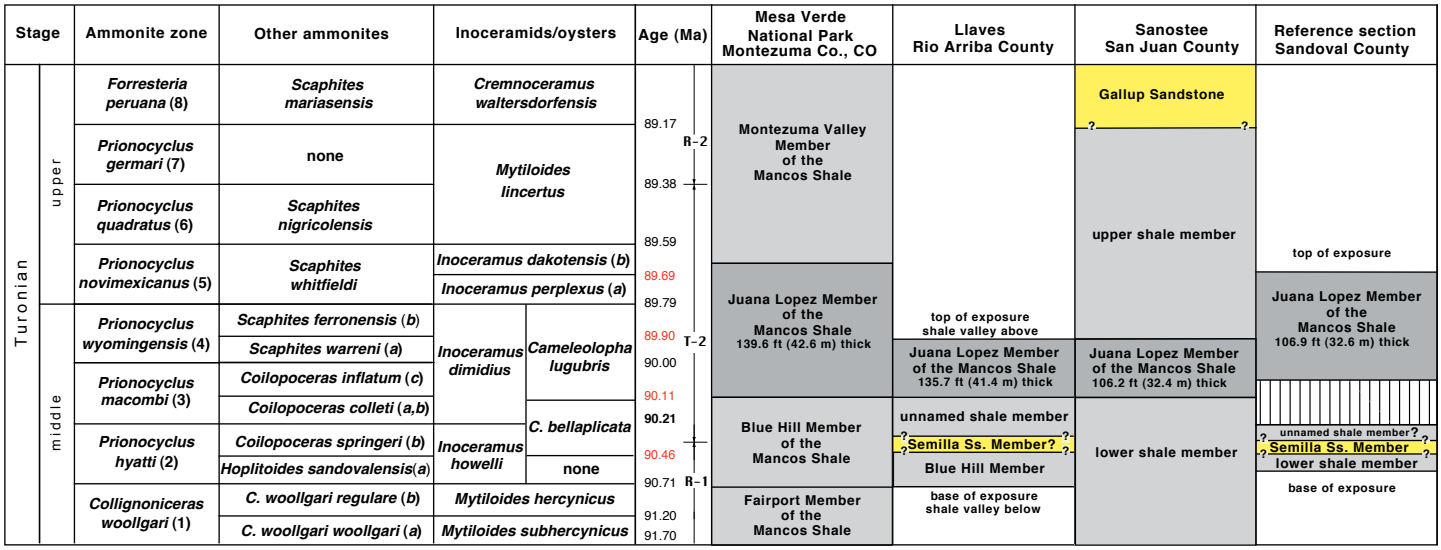


FIGURE 14—Chronostratigraphic diagram of the middle and upper Turonian showing biostratigraphic zones (vertically) and the correlation (horizontally) of the Juana Lopez and related rock units at the 11 measured sections highlighted in this report. Both the top and base of the Juana Lopez move up and down from section to section. Although the top has often been treated as an isochronous surface in the literature (see, e.g., Molenaar 1973 and 1974), its base seems to be the more consistent of the two surfaces in relationship to the ammonite zones. Neither axis is to scale. (Zones and ages modified from Hook and Cobban 2012, fig. 3. The emboldened age is from a dated bentonite assumed to be at the base of a zone; black age dates are interpolated between dated bentonites by assuming all subzones between two zonal ages are of equal duration; red age dates are interpolated between subzonal ages by assuming all assemblage zones between two subzonal ages are of equal duration.)

different suites of bentonite beds have been preserved at each location because erosion occurred at different times in different parts of the basin. If so, there would not be a one-to-one correspondence between individual bentonite beds from section to section. The sea floor conditions that resulted in calcarenite formation appear not to have been synchronous across the basin based on position, age, and thickness of the calcarenites in the 11 sections profiled above. Sea floor conditions with enough energy to create bioclastic debris from clam and oyster shells would certainly have been strong enough to remove ash beds. Leckie et al. (1997, p. 175) report that calcarenites in the Juana Lopez at Mesa Verde can have basal scour and upper rippled surfaces; many contain low-angle crossbeds along with broken and abraded shells of ammonites and oysters. Therefore, it is entirely possible that different bentonites or suites of bentonite beds would be eroded (or preserved) at different locations at different times.

Summary

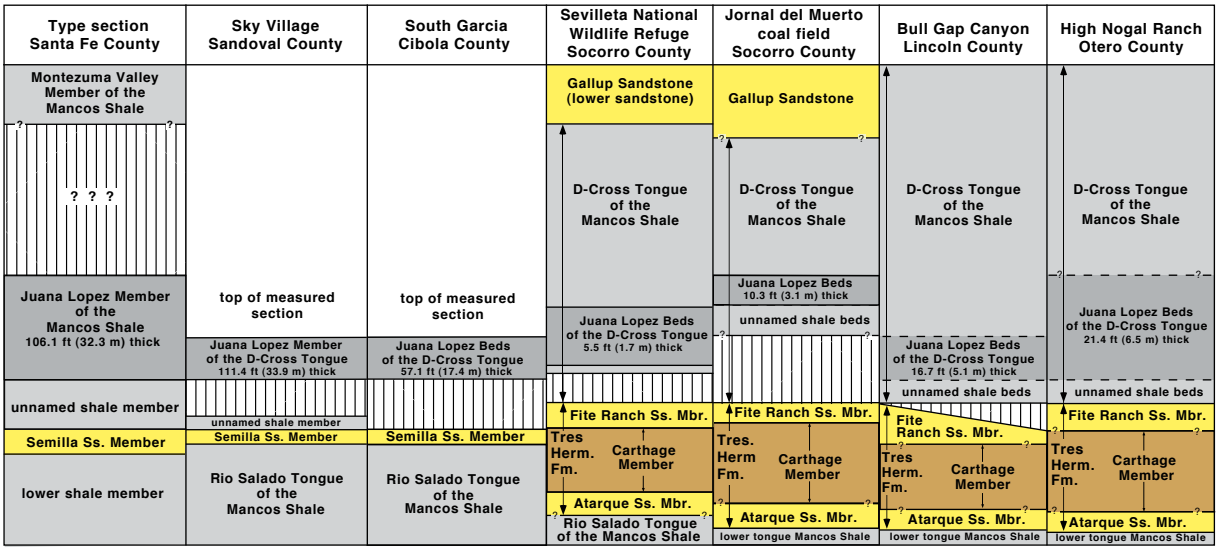
The chronostratigraphic/correlation diagram (Fig. 14) summarizes most of the pertinent information presented about the 11 biostratigraphically well-documented surface sections of the Juana Lopez discussed in the preceding portions of the paper. This diagram shows that the Juana Lopez in the study area was deposited during the early and middle portions of the T-2 transgression, where it is a member-rank or a bed-rank unit in the Mancos Shale, and how thick it is at each location. The vertical scale of the diagram is in time, both (1) relative time in terms of ammonite zones and subzones as well as faunal assemblages, and (2) absolute time in terms of radiometric ages of bentonites within those zones. Younger is toward the top of the diagram, but is not to scale. The horizontal scale is distance, although it, too, is not to scale. Unconformities discussed in the text are shown by vertical lines. Environments of deposition are color-coded: offshore shales are gray; nearshore sandstones are yellow; nonmarine rocks are brown; and the marine Juana Lopez, which is composed primarily of offshore shale, is dark gray. The informal, alphanumeric zonal terminology and faunal composition of middle through upper Turonian assemblages used throughout the paper are shown in the faunal columns. These assemblage zones have applicability outside New Mexico and the Juana Lopez.

The unevenness of the upper contact of the Juana Lopez across the diagram reveals at a glance that it is not suitable to be used either as a chronostratigraphic surface or as a surface to hang a cross section on. The basal contact is more even, but has some undulations. With minor reservations it can be used as a chronostratigraphic surface, especially in the northern and western San Juan Basin.

Where fully developed, although not necessarily thickest, the Juana Lopez spans parts of three ammonite zones: the upper *Prionocyclus macombi* (3*c*) through the lower half of the upper *P. novimexicanus* (5*b*) Zones. Sections in the southeast portion of the study are condensed relative to those in the northwest. In Socorro County, the Juana Lopez is not only quite thin, less than 11 ft (3.3 m) thick, but also spans only a single ammonite zone, either all of the *P. wyomingensis* Zone (4) or the lower portion of the *P. novimexicanus* Zone (5*a*).

Preparation of this chronostratigraphic diagram (Fig. 14) led to the realization that there was an anomaly at High Nogal Ranch (Fig. 13), where, originally, the base of the Juana Lopez was interpreted to rest on an erosional surface that had cut into the top of the Fite Ranch Sandstone Member of the Tres Hermanos Formation. A reexamination of the fossil collections from this interval (Fig. 13, D14922–23) revealed that there was an oyster species transitional between *Cameleolopha bellaplicata* and *C. lugubris* preserved in the Fite Ranch Sandstone at High Nogal Ranch (see Hook and Cobban 2012, appendix 2, p. 95) that had been misidentified as *C. lugubris*.

Using the mostly interpolated absolute ages shown on Figure 14 for the beginning of each zone, subzone, or assemblage zone, we estimated the amount of time the Juana Lopez interval represents at each measured section (Table 3). Based on these admittedly gross approximations, it took from one to a few hundred thousand years for the strata we now call the Juana Lopez to accumulate on the Late Cretaceous sea floor in the study area. The shortest and generally shorter duration accumulation times are in the southeast portion of the study area (Sevilleta, Jornada del Muerto, Bull Gap Canyon, and High Nogal Ranch); the longest and generally longer times, in the seven sections to the northwest. The thinnest sections are also in the southeast, where the (compacted) accumulation rate is less than 1.3 inches/thousand years (3.3 cm/thousand years); the thickest sections are in the northwest, where the (compacted) accumulation rate is more than 2.5 times greater, ranging from 3.49 to 8.62 inches/ thousand years (8.85 to 21.87 cm/thousand years). These lower accumulation rates in the southeast underscore the



(more) condensed nature of the Juana Lopez there relative to the northwest. The variability of the accumulation rates within each of the two regions suggests erosion intervals within the Juana Lopez.

The average section of the Juana Lopez in the study area (Table 3) is 74.3 ft (22.6 m) thick and accumulated over 251 k.y. at a rate of 3.73 inches/k.y. (9.46 cm/k.y.). Its base is high in the *Coilopoceras inflatum* Subzone (3*c*) of the *Prionocyclus macombi* Zone; its top lies low in the *P. novimexicanus-Scaphites whitfieldi-Inoceramus perplexus* assemblage zone (5*a*) of the *P. novimexicanus* Zone. Except for the thickness value, which is too thin, these average values describe the type and reference sections of the Juana Lopez. Note, however, that the standard deviation for each average value is generally quite large. All of which indicate that there is significant regional variation within the Juana Lopez.

Conclusions

The Turonian Juana Lopez is one of the most distinctive, widespread, and easily recognized lithostratigraphic units in the Upper Cretaceous of New Mexico and adjacent Colorado. The following general conclusions can be drawn about the Juana Lopez in the study area.

1. The distinctive platy-weathering, thin calcarenites of the Juana Lopez that carry an abundant middle to late Turonian, mollusk-dominated, low-diversity fauna can be recognized over a wide swath of the southern Western Interior into Trans-Pecos Texas.

2. Lithologically, however, the Juana Lopez is composed primarily of dark-gray, noncalcareous shale that comprises 65% to 98% of the unit.

3. The Juana Lopez accumulated on the Late Cretaceous sea floor over a period from one to a few hundred thousand years, averaging an estimated 251 k.y. in the study area.

4. Neither the top nor the base of the Juana Lopez is an isochronous surface. The top can be as high as the upper part (5*b*) of the *Prionocyclus novimexicanus* Zone or as low as the lower part (4*a*) of the underlying *P. wyomingensis* Zone. The base could be as low as the middle part (3*b*?), but is certainly as low as the upper part (3*c*) of the *P. macombi* Zone or as high as the lower part (5*a*) of the *P. novimexicanus* Zone, which is two zones higher.

5. A thin bed containing both of the rare ammonites *Hourcquia mirabilis* and *Coilopoceras inflatum* in the upper part (3*c**) of the *P. macombi* Zone at or near the base of the Juana Lopez (or near the base of the

TABLE 3—Quantification of the Juana Lopez at the 11 measured sections in terms of age of the base and top of the unit (in millions of years before the present); total duration of deposition at each section (in thousands of years), thickness (in feet and meters), and rate of (compacted) accumulation (in inches and cm per thousand years). The measured sections that come closest to being average; i.e., being typical of the study area (southern Western Interior), for these parameters are the type (Fig. 7) and reference (Fig. 6) sections.

Measured section	Age top (Ma)	Age base (Ma)	Duration (k.y.)	Thickness (ft)	Thickness (m)	Rate (inches/k.y.)	Rate (cm/k.y.)
Juana Lopez Member northern New Mexico							
Mesa Verde Natl. Park, CO	89.64	90.11	470	139.6	42.6	3.56	9.06
Llaves	89.90	90.11	210	135.7	41.4	7.75	19.71
Sanostee	89.90	90.11	210	106.2	32.4	6.07	15.43
Reference section	89.69	90.06	365	106.9	32.6	3.51	8.93
Type section	89.69	90.06	365	106.1	32.3	3.49	8.85
Sky Village	89.90	90.06	155	111.4	33.9	8.62	21.87
Juana Lopez Beds central New Mexico							
South Garcia	89.90	90.06	155	57.1	17.4	4.42	11.23
Sevilleta Natl. Wildlife Refuge	89.79	90.00	210	5.5	1.7	0.31	0.81
Jornada del Muerto coal field	89.69	89.79	100	10.3	3.1	1.24	3.10
Bull Gap Canyon	89.90	90.06	155	16.7	5.1	1.29	3.29
High Nogal Ranch	89.69	90.06	365	21.4	6.5	0.70	1.78
Average	**89.79**	**90.04**	**250.91**	**74.26**	**22.64**	**3.73**	**9.46**
Standard deviation	**0.11**	**0.09**	**119.35**	**52.67**	**16.06**	**2.81**	**7.15**

D-Cross Tongue) at five widely separated localities may have been deposited more or less contemporaneously across the area.

6. As a rule of thumb, the base of the Juana Lopez is at or near the first occurrence of the small, but abundant and easily recognized, oyster *Cameleolopha lugubris*.

7. Erosion surfaces appear to be common beneath calcarenites at both the base of the Juana Lopez and within it. In the San Juan Basin, the base of the Juana Lopez varies from as low as the top of the Semilla Sandstone Member of the Mancos Shale to 60 ft (18.3 m) above it. Lack of one-to-one correspondence between bentonites in the northwest and lateral loss of shale between two closely spaced calcarenites elsewhere in the southeast suggest erosion within the Juana Lopez.

8. The Juana Lopez in Socorro, Lincoln, and Otero Counties is condensed relative to sections to the northwest. The thickest section in these southern counties is less than half as thick as the thinnest section in the San Juan Basin, yet it contains faunas from the same three standard ammonite zones.

9. The type section and the reference section of the Juana Lopez, which are virtually identical in thickness, lithology, and fossil content, are typical of the unit; they approach the quantitative average Juana Lopez section within the study area.

10. The Juana Lopez changes stratigraphic rank within the study area. In northern New Mexico and southern Colorado, the Juana Lopez is a formal member-rank unit in the (a) Mancos Shale in the northwest (San Juan Basin area) and (b) Carlile Shale in the northeast (Raton Basin area); in south-central New Mexico, it is a bed-rank unit in the D-Cross Tongue of the Mancos Shale (Cibola, Socorro, Lincoln, and Otero Counties).

11. The Juana Lopez in New Mexico was deposited during the early and middle portions of the second major transgression (T-2) of the western shoreline of the Late Cretaceous seaway. The lower and middle parts of the Juana Lopez in this area appear to have been deposited when the shoreline was more or less at a stillstand with a northwest-southeast trend and a maximum landward position just south of Truth or Consequences. During deposition of the upper Juana Lopez, the southern portion of the shoreline moved landward (southwestwardly) over the Davis Well/Love Ranch area, the southernmost outcrop in New Mexico and adjacent west Texas to record marine strata deposited during T-2.

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Cover description continued.

The flexuous, looping ribs and single, clavate, ventrolateral tubercles of the large planispiral ammonite help identify it as *Prionocyclus novimexicanus*, the first fossil to be named for the Territory of New Mexico (Marcou 1858, p. 35). The species has a Western Interior-wide distribution and has been found in Trans-Pecos Texas and Tunisia (Kennedy et al. 2001, p. 121). *Prionocyclus novimexicanus* is common in rocks of early late Turonian age in New Mexico (Hook and Cobban, 1979), where it occurs in concretions in the Mancos Shale and in the uppermost calcarenites in the Juana Lopez Member or Beds of the Mancos Shale (see article by Hook and Cobban, this volume, p. 59). *Scaphites whitfieldi* is the common and generally more numerous associate of *P. novimexicanus* throughout much of its geographic range. Missing from the pictured faunal assemblage, but observed on the outcrop, is the small, smooth oyster referred to *Ostrea* sp. by Hook and Cobban (this volume, Fig. 6, p. 68) at the reference section of the Juana Lopez Member of the Mancos Shale, on the east side of the San Juan Basin, Sandoval County. Dane et al. (1966, p. H9) referred this oyster to *Lopha lugubris* (smooth form) and implied that it was derived from an earlier *L. lugubris* with very fine ribs.

The cover photograph (X 1.5) is cropped from an image of the irregularly shaped polygonal slab of calcarenite that has a height of 20 cm, a width of 26 cm, and a thickness of 4 cm. Juana Lopez outcrops throughout New Mexico are characterized by thin, platy- to slabby-weathering calcarenite beds that shed debris that often obscures the shale slopes below them. The weathering color of the calcarenites varies from yellowish brown to reddish brown.

The slab (Jemez Pueblo fossil locality JP-21) was collected from the uppermost bed of the Juana Lopez Member of the Mancos Shale in SE¼ NE¼ sec. 30, T16N, R3E, Jemez Pueblo 7.5 min quadrangle, Sandoval County, New Mexico, as part of a reconnaissance geologic trip by S. C. Hook and K. Madalena on July 10, 2013. There, the Juana Lopez Member consists of 6 ft of lower calcarenite ledges, at least 50 ft of light-gray, fissile, slightly calcareous shale with concretions, and 5 ft of upper calcarenite ledges. The lower ledges and middle shale contain abundant valves of the ribbed oyster *Cameleolopha lugubris*.

References can be found on pp. 80–81.

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