The type section of the Upper Cretaceous Tokay Tongue of the Mancos Shale (new name), Carthage coal field, Socorro County, New Mexico

S. C. Hook and W.A. Cobban

New Mexico Geology, v. 37, n. 2 pp. 27-46, Online ISSN: 2837-6420.
https://doi.org/10.58799/NMG-v37n2.27

This page is intentionally left blank to maintain order of facing pages.

The type section of the Upper Cretaceous Tokay Tongue of the Mancos Shale (new name), Carthage coal field, Socorro County, New Mexico

Stephen C. Hook, Atarque Geologic Consulting, LLC, 411 Eaton Avenue, Socorro, NM 87801
bellaplicata@gmail.com and *William A. Cobban*, 70 Estes Street, Lakewood, CO 80226
(December 31, 1916–April 21, 2015)

Abstract

The Tokay Tongue of the Mancos Shale (new name) is that portion of the Mancos Shale lying between the undifferentiated or main body of the Dakota Sandstone and the Tres Hermanos Formation (or offshore equivalent). Its type locality is in the Carthage coal field, Socorro County, New Mexico. At its type section the Tokay Tongue is 575 ft (175 m) thick and consists of the following five bed–rank units (in ascending order): 1) the shale and sandstone unit, 182 ft (55 m) thick; 2) the calcareous shale and bentonite unit, 120 ft (36 m) thick; 3) the Bridge Creek Limestone Beds, 72 ft (22 m) thick; 4) the calcareous shale unit, 113 ft (34 m) thick; and 5) the noncalcareous shale unit, 88 ft (27 m) thick. The Tokay Tongue was deposited during the initial depositional cycle of the Late Cretaceous Seaway in New Mexico: units #1 and #2 as the western shoreline transgressed southwestward (T-1); unit #3 at maximum transgression (end T-1); and units #4 and #5 as the shoreline regressed northeastward (R-1). The Tokay Tongue at Carthage ranges in age from middle Cenomanian to middle Turonian; both its base and top are diachronous across its outcrop belt in southern New Mexico. There are more than 70 discrete bentonite beds in the tongue at its type locality, ranging in thickness from a fraction of an inch to 14 inches (36 cm); a 12 inch- (30 cm-) thick bentonite near the base of the tongue that lies just above strata containing the middle Cenomanian ammonite *Acanthoceras amphibolum* is correlated with the "x" or marker bentonite that occurs throughout the Western Interior. A thin, white limestone near the middle of the Bridge Creek Limestone Beds contains the bivalve *Mytiloides puebloensis*, which marks the base of the Turonian Stage at the Global Boundary Stratotype section and point for the Turonian Stage at Pueblo, Colorado.

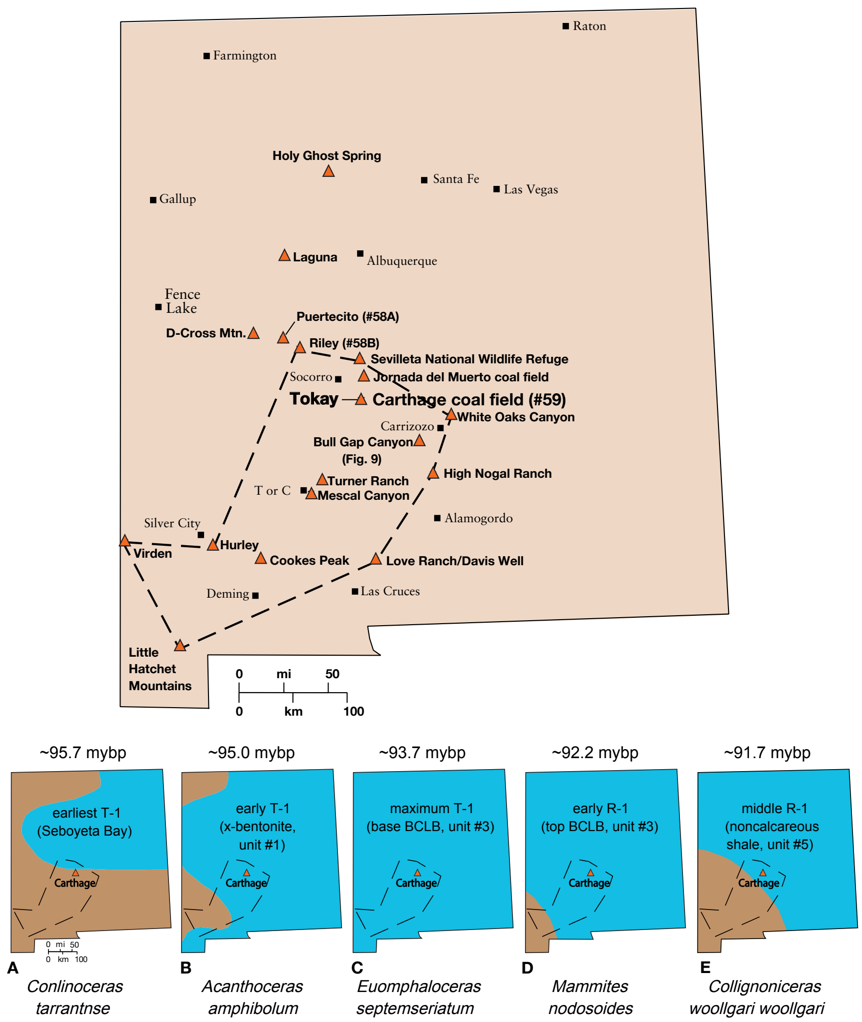


Figure 1—Map of New Mexico showing key Upper Cretaceous outcrop localities in New Mexico. The dashed polygon encloses the area within which the Tokay Tongue of the Mancos Shale has been recognized. Thumbnail maps of New Mexico (A–E) show paleogeographic reconstructions of the positions of land (brown) and sea (blue) during T-1, the initial transgression (A–C), and R-1, the initial regression (D–E), of the western shoreline of the Late Cretaceous Seaway from ~95.7 mybp to ~91.7 mybp. The R-1 shoreline continued to regress northeastward beyond Carthage for about another one million years.

Introduction

Overview

The Upper Cretaceous Tokay Tongue of the Mancos Shale (new name) is a relatively thick, member-rank, stratigraphic unit that occurs at or near the base of Upper Cretaceous strata over much of central and southern New Mexico, often at isolated exposures (Fig. 1). The sediments that became the Tokay Tongue were deposited in the Late Cretaceous Seaway during the initial transgressive/regressive cycle (T-1/R-1) of the seaway's western shoreline across New Mexico. The Tokay Tongue, which lies between the undifferentiated or main body of the Dakota Sandstone and the overlying Tres Hermanos Formation is composed primarily of shale, but contains subordinate amounts of sandstone, siltstone, and limestone. However, none of the previously described members or tongues of Dakota Sandstone that interfinger with temporal equivalents of the Tokay Tongue elsewhere in New Mexico can be differentiated and mapped within this tongue. Its type locality is in the western portion of the Carthage coal field, Socorro County, New Mexico (Fig. 1), about 2 mi (3.2 km) north of the former coal-mining town of Tokay, from which it takes its name. There, the Tokay Tongue is well exposed even though it consists primarily of easily eroded and covered shale. At its type section the Tokay

Tongue is 575 ft (175 m) thick, is composed of five bed-rank units, and contains a marine fauna that ranges in age from late middle Cenomanian to earliest middle Turonian, spanning approximately four million years. As defined, the Tokay Tongue of the Mancos Shale can be recognized in isolated outcrops over an area of New Mexico of approximately 14,650 sq. mi (37,944 sq. km) (Fig. 1). This area is bounded by known outcrops of the Tokay Tongue: 1) on the north at Riley and the southern end of the Sevilletta National Wildlife Refuge; 2) on the east at White Oaks Canyon and High Nogal Ranch; 3) on the southeast by Love Ranch/Davis Well; 4) on the south by a truncated exposure in the Little Hatchet Mountains; and on the west at 5) Virden and 6) Hurley. The polygon with these outcrops as vertices includes portions of Socorro, Lincoln, Otero, Doña Ana, Sierra, Luna, Hidalgo, and Grant Counties.

North and northwest of this area, especially in the southeastern margin of the San Juan Basin, the temporal equivalents of the Tokay Tongue are included in formally named, member-rank units of the intertongued Dakota Sandstone and Mancos Shale (Landis et al. 1973). This intertongued sequence includes—in ascending order—the Oak Canyon Member of the Dakota Sandstone, the Cubero Tongue of the Dakota Sandstone, the Clay Mesa Tongue of the Mancos Shale, the Paguate Tongue of the Dakota Sandstone, the Whitewater Arroyo Tongue of the Mancos Shale, the Twowells Tongue of the Dakota Sandstone, and Rio Salado Tongue of the Mancos Shale. Recognition of the lower two tongues of Mancos Shale requires the presence of the bounding tongues of Dakota Sandstone. The Rio Salado Tongue, the uppermost of the Mancos Shale tongues in this sequence, is bounded by the Twowells Tongue of the Dakota Sandstone below and the Tres Hermanos Formation (or equivalent) above.

Although the Tokay Tongue at its type section contains the temporal equivalents of all but the Oak Canyon Member and lower two-thirds of the Cubero Tongue of the Dakota Sandstone, none of the overlying tongues of Dakota Sandstone can be differentiated lithologically within the Tokay Tongue throughout its outcrop in the Carthage coal field and in its outcrop area in southern and central New Mexico (Fig. 1). Therefore, none of the existing Dakota Sandstone and Mancos Shale terminology from this intertongued sequence can be applied.

Historical background

The two decades from 1970 and to 1990 were an unprecedented time of research and discovery in the stratigraphy and biostratigraphy of the Upper Cretaceous of New Mexico. Among notable accomplishments, Landis et al. (1973) worked out the intertonguing relationships between the Dakota Sandstone and Mancos Shale in the middle and upper Cenomanian part of the section; Hook et al. (1983) demonstrated that the Turonian wedge of marine and nonmarine rocks that splits the Mancos Shale into two major tongues in central and southern New Mexico was the Tres Hermanos Formation and not a Gallup Sandstone; Molenaar (1983) showed the complex intertonguing relationships among the upper Turonian and Coniacian Gallup Sandstone, Mancos Shale, and Crevasse Canyon Formation; and Cobban et al. (1989) illustrated the late Cenomanian/early Turonian ammonite fauna of southwest New Mexico. The late Cenomanian portion of this ammonite fauna consists of at least 63 species distributed among 31 genera, making it the most diverse late Cenomanian ammonite fauna in the world. This new understanding of the Upper Cretaceous was used to map large areas of the southern Acoma Basin (Chapin et al. 1979) and the southern Zuni Basin (e.g., Anderson 1987).

Much, but certainly not all, of this progress in understanding the Upper Cretaceous of New Mexico can be attributed to a series of collaborative projects between the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) and the U.S. Geological Survey (USGS) during the late 1970s and early 1980s. The driving force behind these advances was the detailed biostratigraphy that Cobban had developed for use in the Western Interior of the United States, often with specific application to west-central New Mexico (e.g., Cobban 1977 and 1984a, and Cobban and Hook 1989). In addition, Owens's work on the Dakota Sandstone (e.g., Owen 1966 and 1982), which was not supported financially by the NMBMMR or the USGS, was instrumental in determining the depositional environments and correlation for both the Dakota Sandstone and immediately underlying Jurassic units.

Between July 1976 and March 1981 more than 800 Upper Cretaceous fossil invertebrate localities in New Mexico were added to the USGS Denver Mesozoic Invertebrate Locality database as a result of this collaboration. Most of these collections were in central and southern New Mexico; many were tied to detailed measured sections that were important in working out stratigraphic and map relationships.

Unfinished project

One of the authors' unfinished projects from that unprecedented time is the designation of a formal stratigraphic name for the thick tongue of Mancos Shale in southern and central New Mexico that lies between the main body of the Dakota Sandstone and the Tres Hermanos Formation. Hook et al. (1983, chart 1, section 59) used the informal designation lower part of the Mancos Shale for this member-rank unit at Carthage, but also used the same informal designation for the thinner tongue of Mancos between the main body of the Dakota Sandstone and the Twowells Tongue of the Dakota Sandstone at Puertecito (Fig. 1, section #58A; Fig. 2), which contains the type section of the Rio Salado Tongue of the Mancos Shale and the type area of the Tres Hermanos Formation (Hook et al. 1983). As shown on Figure 2, the informal, lower tongue (or part) of the Mancos Shale in west-central New Mexico is composed of rocks of different thickness and time-equivalency depending on whether its upper boundary is at the base of the Twowells Tongue or at the base of the Tres Hermanos Formation (Fig. 2). Hook et al. (1983, p. 24–27) named the tongue of shale between the Twowells and Tres Hermanos, the Rio Salado Tongue of the Mancos Shale. Anticipating that later workers might have difficulty in applying the member-rank Rio Salado Tongue correctly, Hook et al. (1983, p. 27) state:

> East of Puertecito, the Twowells Tongue of the Dakota Sandstone pinches out into Mancos Shale. Although both time and lithologic equivalents of the Rio Salado Tongue can be recognized from Riley to Carthage to Truth or Consequences, the Rio Salado Tongue cannot be differentiated out of this larger body of shale that extends from the top of the main body of the Dakota Sandstone to the base of the Tres Hermanos Formation. In those areas, strata equivalent to the Rio Salado are included within the undifferentiated Mancos Shale. However, individual limestones within the Bridge Creek Limestone Beds of the Rio Salado Tongue can be traced in continuous outcrop from Puertecito to Riley and correlated with equivalent beds at Carthage and Truth or Consequences.

Nonetheless, the absence of a formal name for this thicker shale tongue has resulted in 1) the misapplication of the name "Rio Salado Tongue of the Mancos Shale" to this larger shale body at Carthage, in the Caballo Mountains, and at Love Ranch/Davis Well, and 2) a misunderstanding of the larger tongue's age and physical relationships. By naming this unit formally as the Tokay Tongue of the Mancos Shale, establishing a type section, and describing its lithology and fauna in detail, the authors hope to eliminate these problems for future stratigraphers and geologic mappers.

Previous work

The Carthage coal field (Fig. 1), Socorro County, is a key Upper Cretaceous stratigraphic and biostratigraphic control point in central New Mexico because it 1) provides the lithologic and paleontologic links from the better known, more or less continuous

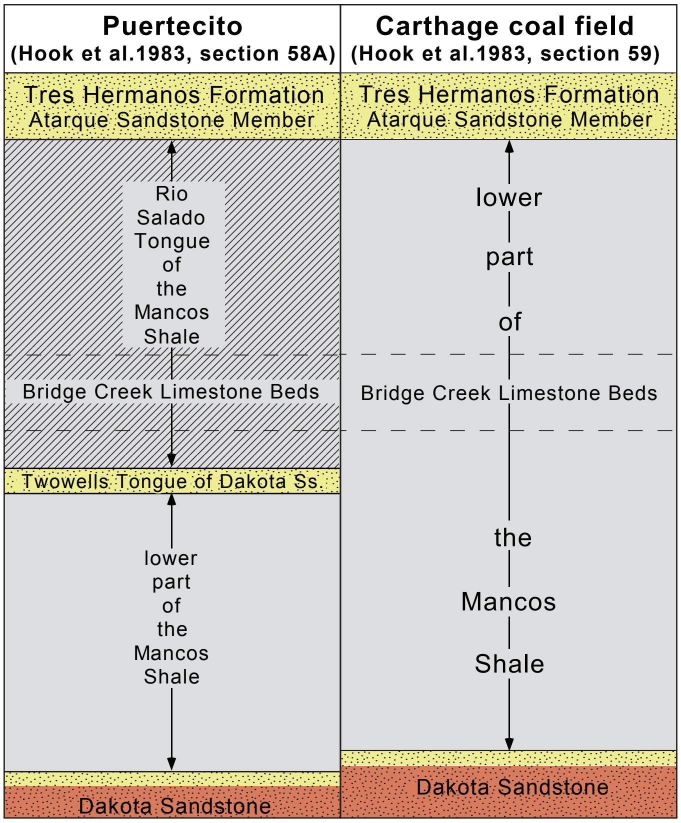


Figure 2—Diagram showing that the informal stratigraphic term "lower part of the Mancos Shale" has been used to described rocks of different thicknesses, boundaries, and age-equivalencies in Socorro County, New Mexico.

exposures in the San Juan Basin to lesser known, isolated outcrops in central and southern New Mexico and 2) contains type or reference sections for the Tokay Tongue of the Mancos Shale (this paper) and the Tres Hermanos Formation and two of its members: the Carthage and Fite Ranch Sandstone Members (Hook et al. 1983). Hook (2009, p. 25) reported that the lower tongue (=Tokay Tongue) of Mancos Shale at Carthage contained more discrete ash beds of middle to late Cenomanian age than any other published section in the Western Interior, thus providing a potential means for detailed correlation between widespread sections. In addition, the lower tongue contains the Cenomanian/Turonian boundary limestone, which can be correlated to its global boundary stratotype at Pueblo, Colorado.

The geologic literature on the Carthage coal field extends back to at least 1868, when Le Conte (1868, p. 136) mentioned coal from the mine eight miles east of San Antonio and the Rio Grande. Interest in the area has continued over the intervening 147 years not only because of the economic importance of coal to New Mexico, but also because of good exposures, abundant fossils, and well exposed structures of Laramide and Rio Grande Rift ages in the coal field. Carthage has become a natural geologic laboratory for generations of students studying at the New Mexico Institute of Mining and Technology, which was established in Socorro in 1889. The earliest fossil collections from Carthage date back to at least 1905 when Willis T. Lee, U.S. Geological Survey, collected fossils from the base of the Fite Ranch Sandstone Member of the Tres Hermanos Formation (Kauffman, 1965, p. 76, localities 63 and 64).

Reports dealing specifically with the lowest portion of the Mancos Shale at Carthage span more than 100 years. Gardner (1910), in his report on the Carthage coal field, published the first measured section at Carthage. He subdivides the Upper Cretaceous into three units: Dakota(?) Sandstone, Colorado Group, and Montana Group. The basal unit of his 895-ft-thick Colorado Group is the shale herein named the Tokay Tongue; he describes it as 500 feet of drab shale, but lists no fossils from it (Fig. 3).

Lee (1916, p. 41), in his study of the relationship between the Cretaceous formations of Colorado and New Mexico to the Rocky Mountains, recognizes that Carthage is the southernmost locality in the Rocky Mountain region with a "satisfactory" Upper Cretaceous section. He repeats Gardner's (1910) measured section, but correlates the 895 ft of marine deposits with the Mancos Shale of the San Juan Basin (Fig. 3).

Darton (1928, p. 74–75), in his monumental discussion of the geology of New Mexico, repeats Gardner's (1910) section, but suggests that the fossiliferous sandstone beds above the 500 ft of drab shale are "… the Greenhorn limestone underlain by the Graneros shale, and the upper fossiliferous bed with concretions is closely similar to the Carlile shale in the northern part of the State."

Rankin (1944), in his stratigraphy of the Colorado Group in New Mexico, presents the first new measured section at Carthage and extends the Great Plains terminology of Graneros Shale, Greenhorn Limestone, and Carlile Shale into the drab shale of the Carthage area (Fig. 3). Rankin's (1944, p. 21–22) section at Carthage was "…[m]easured near Tokay, T. 14 [sic] N., R. 2 E., Socorro County, New Mexico, by C. E. Needham; supplemented by details added by the author." Thus, Rankin's measured section near the town of Tokay is in the same general area (major fault block) as the type section of the Tokay Tongue. Rankin shows the lower Mancos to be considerably thinner at 297 ft than both Gardner's section and the one presented in this paper; his section may have been measured across unrecognized faults. He subdivides the lower Mancos into three units: 1) a lower black fissile shale, 157 ft thick that is very sandy near the base (the Graneros shale); 2) a middle black, calcareous shale, 30 ft thick, with thin calcareous sandstones at the top and four-to eight-inch thick limestones near the base (the Greenhorn limestone); and 3) an upper silty to sandy shale, 110 ft thick, with numerous limestone concretions (basal part of the Carlile shale). Rankin (1944, p. 25) recognizes the great stratigraphic utility of the "… Greenhorn limestone [that was] deposited so uniformly over such a wide area." On page 9 he notes that "[w]herever the Greenhorn has been studied in northern New Mexico, the characteristic fossil, *Inoceramus labiatus* Schlotheim has been found. *Baculites asper* Norton is also common." He finds the uniformity of faunal types over such a wide area to be "most unusual." (Note: *Inoceramus labiatus* was a general form that today would include *Mytiloides mytiloides*, M. *puebloensis*, and *M. hattini* from the upper part of the Bridge Creek; and *Baculites asper* is a misidentification of *Sciponoceras gracile* (Shumard), the only baculite to occur in the Bridge Creek Limestone Beds, from the basal part.)

Pike (1947, p. 87), in his classic paper on the intertonguing Upper Cretaceous of the southwest, uses Gardner's (1910) measured section at Carthage (his section "P"). He uses the informal "lower Mancos Shale" for the 500 feet of drab, marine shale between the "Dakota" Sandstone and the lower part of the Gallup Member of the Mesaverde (= Tres Hermanos Formation). Although Pike (1947, p. 88) refers to Rankin's (1944) work, he does not use his measured section or fossils. The extreme thickness of the "Dakota" at Carthage suggests to Pike (1947, p. 87) that the "Dakota" represented both the Dakota (?) and Tres Hermanos Sandstones of earlier workers and that the top of the "Dakota" was of Graneros age. Pike (1947, p. 88) qualifies his correlations by saying they "…have been made entirely upon lithologic evidence, sequence of beds, and interval and are not supported by such meager paleontological evidence as is available." However, in his correlation chart from Mesa Verde, Colorado, to Atarque, New Mexico, Pike (1947, pl. 11) uses the Zones of *Inoceramus labiatus* (= *Mytiloides mytiloides*) and *Gryphaea* (= *Pycnodonte*) *newberryi* to help correlate the lower part of the Mancos Shale. A lower [portion of the] Mancos Shale and the higher Pescado Tongue are indicated at Carthage on his three-dimensional correlation diagram (Pike 1947, pl. 12). On page 87 Pike refers to the lower Mancos simply as "… drab marine shale."

Wilpolt and Wanek (1951), on their geologic map of the area from Carthage to Chupadera Mesa, Socorro County, New

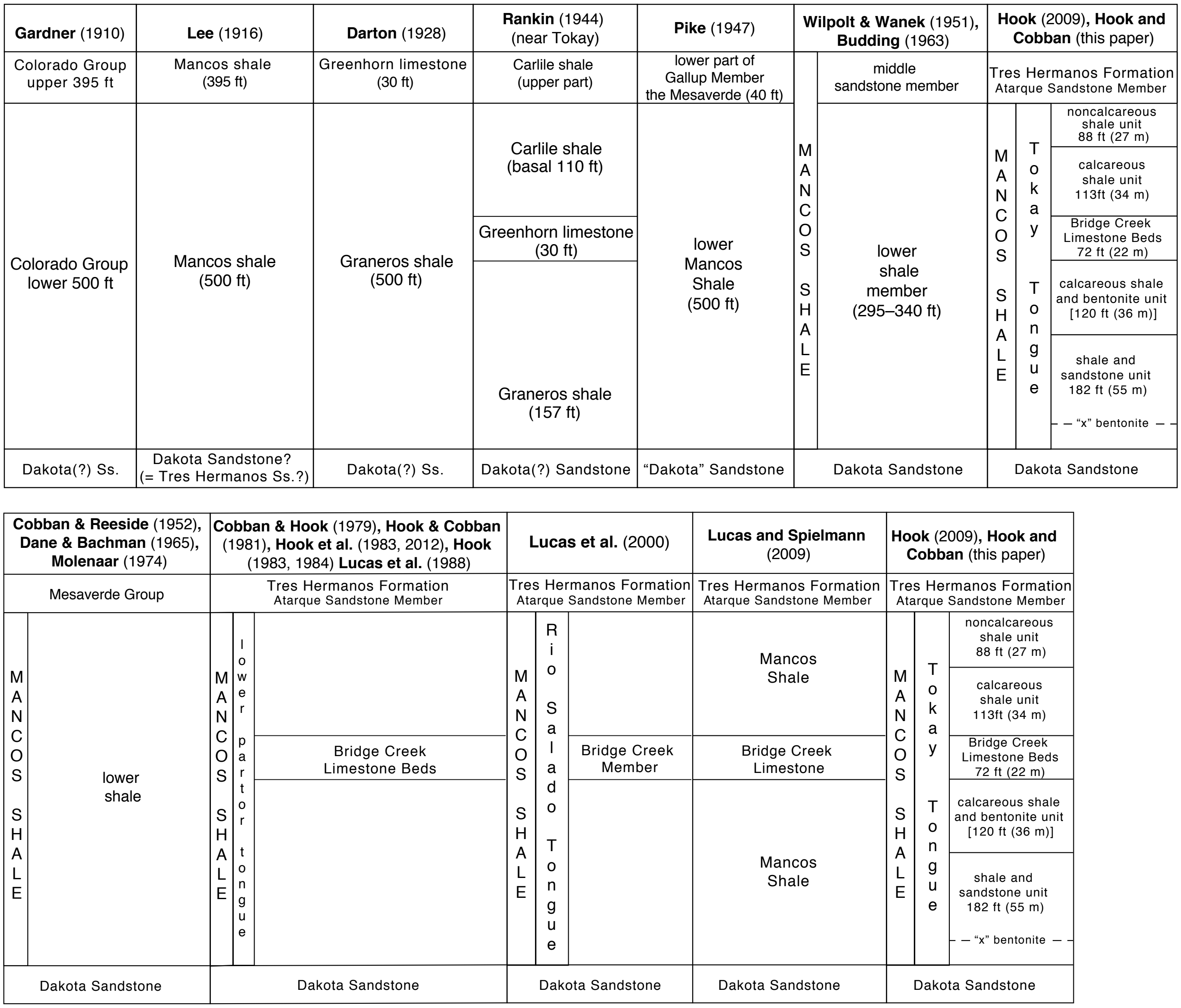


Figure 3—Evolution of stratigraphic nomenclature used to describe the lower tongue of the Mancos Shale in the Carthage coal field from 1910 to 2015.

Mexico, differentiate the Mancos Shale at Carthage into three informal members; a lower shale (= Tokay Tongue), a middle sandstone (= Tres Hermanos Formation); and an upper shale (= D-Cross Tongue). They describe the lower member as " dark-gray to dove-gray, friable, calcareous shale with several beds of flaggy limestone just above the middle," 295–340 ft thick. Their flaggy limestone is identifiable as today's Bridge Creek Limestone Beds. Budding (1963) used the same scheme in a field trip guide to the Carthage coal field.

Cobban and Reeside (1952), Dane and Bachman (1965), and Molenaar (1974) call the lower shale at Carthage the Mancos Shale. Cobban and Reeside (1952), in their correlation of Western Interior Cretaceous Formations, indicate that there is a "thin limestone member" near the base; Dane and Bachman (1965) generalize Cretaceous units for use on the geologic map of New Mexico; and Molenaar (1974), whose emphasis was on the stratigraphically higher Gallup Sandstone, shows only a portion of the shale that he called "lower Mancos Shale."

Cobban and Hook (1979, fig. 3), in a graphic section at Carthage in their study of a middle Turonian ammonite fauna from the Western Interior, present a newly measured section at Carthage that shows the lower tongue of Mancos Shale to be about 440 ft thick with a 60 ft limestone unit (= Greenhorn Limestone of Rankin 1944), 200 ft above the base. Their section contains a considerable amount of cover in the lower half of the unit; it was measured about 0.5 mi east of the type section of the Tokay Tongue, in the next major fault block to the east (Anderson and Osburn 1983). However, they are the first to date the shale section from top to bottom paleontologically. They show four fossils collections in the lower shale tongue: a middle Cenomanian *Inoceramus arvanus* collection near the base; an upper Cenomanian *Sciponoceras gracile* collection at the base of the limestone; an early Turonian *Mammites nodosoides* collection at the top of the limestone; and a middle Turonian *Collignoniceras woollgari woollgari* collection at the top of the shale.

Hook and Cobban (1981, p. 6), in a paper on Greenhorn-age discontinuity surfaces in southwest New Mexico, demonstrated that the limestone unit in the middle of the lower tongue of Mancos Shale was equivalent to only the lower part of the uppermost member of the Greenhorn Limestone, the Bridge Creek Member, at its principal reference section near Pueblo, Colorado (see Fig. 5). They, therefore, designated this limestone unit as the Bridge Creek Limestone Member of the Colorado Formation for use in southwest New Mexico.

Hook et al. (1983, pp. 24–27 and chart 1, control point 59), in their paper on Cretaceous stratigraphy in west-central New Mexico, reduce the stratigraphic rank of the Bridge Creek from member to bed for use in the lower tongue of the Mancos Shale at Carthage. This puts the units at Carthage in compliance with the North American Code of Stratigraphic Nomenclature. Their detailed graphic section shows the lower part of the Mancos Shale to be 440 ft thick, with sandy/silty beds at the base; a 57-ft-thick limestone and shale unit, the Bridge Creek Limestone Beds, that is 210 ft above the Dakota Sandstone; and a 170-ft-thick shale that lies between the Bridge Creek Beds and the Tres Hermanos Formation. They show nine numbered, USGS Mesozoic fossil collections ranging in age from middle Cenomanian at the base of the shale to middle Turonian at the top. A thick bentonite (the x-bentonite of present usage) is shown about 30 ft above the Dakota, as are two thick bentonites just below the base of the Bridge Creek. Up to the present paper, this is the best-documented (paleontologically and lithologically) section in the literature on the lower shale tongue at Carthage. The same stratigraphic nomenclature is used in Hook (1983 and 1984).

Lucas et al. (1988, fig. 14, col. 6) in a diagram showing the correlation of the Upper Cretaceous in the Cookes Range with rocks elsewhere in New Mexico, show the shale tongue that lies between the Dakota Sandstone and Tres Hermanos Formation at Carthage as the "lower part of the Mancos Shale." They (Lucas et al. 1988, fig. 14, col. 6) mis-assign member-rank status to the Bridge Creek Limestone, which is within a member-rank unit, the lower part of the Mancos Shale.

Lucas et al. (2000, p. fig. 7) correlate the lower part of the Mancos at Carthage with the (less inclusive, thinner) Rio Salado Tongue. Compounding the miscorrelation error, they show a formally named limestone unit, the Bridge Creek [Limestone] Member, in the middle part of their Rio Salado Tongue, which is itself a member–rank stratigraphic unit.

Lucas and Spielmann (2009, p. 311 and fig. 1), in their paper on a selachian assemblage at Carthage, split the Mancos Shale below the Tres Hermanos Formation into two parts with a limestone unit. Both parts are labeled Mancos Shale (formational rank) on their figure 1. The limestone is called the Greenhorn Limestone (formational rank) in the title, but labeled Bridge Creek Limestone (formational rank) on their figure 1.

In this paper the 575 ft (175 m-)-thick Tokay Tongue is subdivided into five lithologically defined bed-rank units. In ascending order they are 1) a shale and sandstone unit, 182 ft (55 m) thick; 2) a calcareous shale and bentonite unit, 120 ft (36 m) thick, containing 40 individual bentonites; 3) the Bridge Creek Limestone Beds, 72 ft (22 m) thick; 4) a calcareous shale unit, 112 ft (34 m) thick; and 5) a noncalcareous shale unit, 88 ft (27 m) thick. Only the middle unit (3) is named formally; the other four units are designated informally. This is essentially the same bed-rank scheme used in Hook (2009), although he applied the informal name, lower tongue of the Mancos Shale, to this member-rank unit.

Figure 3 reveals that there has been a considerable difference of opinion about the names and stratigraphic ranks applied to subdivisions within the lower tongue of shale at Carthage. Part of this difference is just the natural evolution of understanding of the stratigraphic section and how it fits into the regional picture; part is due to miscorrelation; part is due to other causes.

Generalized stratigraphy and biostratigraphy

Stratigraphy

At its type section in the Carthage coal field, the Tokay Tongue (Fig. 4) is 575 ft (175 m) thick and ranges in age from middle Cenomanian to middle Turonian. It consists, in ascending order, of the following five, bed-rank, lithologic units: 1) a shale and sandstone unit, 182 ft (55 m) thick; 2) a shale and bentonite unit, 120 ft (36 m) thick, containing 40 individual bentonites; 3) the Bridge Creek Limestone Beds, 72 ft (22 m) thick; 4) a calcareous shale unit, 112 ft (34 m) thick; and 5) a noncalcareous shale unit, 88 ft (27 m) thick. The name of the lowest bed-rank unit (#1) is changed slightly from that given in Hook (2009) from sandstone and shale to shale and sandstone to reflect the greater amount of shale than sandstone in the unit. Initially, the offshore muds that became the lower part of the shale and sandstone unit consisted of noncalcareous clays, reflecting the proximity of the western shoreline to Carthage (Fig. 1A, B). As the shoreline transgressed farther to the southwest during T-1, these offshore muds became more and more calcareous, eventually resulting in the limestones at the base of the Bridge Creek Limestone Beds, deposited at the time of maximum transgression of the seaway (Fig. 1C). As the shoreline retreated (regressed) during R-1, these calcareous muds were replaced by noncalcareous muds and eventually coarser grained clastics, now called the Atarque Sandstone Member of the Tres Hermanos Formation. The broad pattern of shale units within the Tokay Tongue consists, from bottom to top, of noncalcareous shale that gradually becomes more calcareous until limestones appear near the middle of the tongue, followed by calcareous shale that becomes less and less calcareous. Thus, noncalcareous and calcareous shale units are arranged symmetrically on either side of the limestone beds. **Appendix 1** repository contains the detailed measured section for the Tokay Tongue at its type section.

The lower contact of the Tokay Tongue is conformable with the Dakota Sandstone; the upper few inches of the Dakota are burrowed above a chert-pebble conglomerate, which could indicate an intraformational unconformity within the Dakota or simply a transgressive lag associated with the initial transgression. The upper contact of the Tokay Tongue is fairly abrupt into the overlying Atarque Sandstone Member of the Tres Hermanos Formation. Both upper and lower contacts are diachronous throughout the tongue's geographic extent in New Mexico (Fig. 1). The basal contact at Carthage is in the middle Cenomanian *Acanthoceras bellense* Zone; at Mescal Canyon, it is one zone higher in the *A. amphibolum* Zone. The upper contact at Mescal Canyon is in the lower Turonian *Mammites nodosoides* Zone; at Carthage it is one zone higher in the middle Turonian *Collignoniceras woollgari* Zone (Hook et al. 2012).

At Carthage the upper few inches of the Dakota Sandstone (Fig. 4, unit 1) through the basal part of the Bridge Creek Limestone Beds (Fig. 4, unit 181) represent deposition during the initial transgression (early T-1) of the Late Cretaceous Seaway into New Mexico that began in the middle Cenomanian. As the southern shoreline of Seboyeta Bay (Fig. 1A) transgressed south and southwestward across New Mexico (Fig. 1B), the distance from the shoreline and water depth at Carthage increased. Nearshore coarser grained sands and silts at the base of the section were succeeded by more offshore noncalcareous clays, then calcareous clays, and eventually, at maximum transgression (Fig. 1C), almost pure carbonates that became the base of the Bridge Creek Limestone Beds. The upper part of the Bridge Creek through the remainder of the Tokay Tongue into the basal part of the Tres Hermanos Formation (Fig. 4, units 192–234) were deposited during the initial regression (R-1) of the seaway. As the western shoreline of the seaway retreated northeasterly across New Mexico (Fig. 1D), the distance from the shoreline and water depth at Carthage decreased. The offshore carbonates of the upper Bridge Creek were succeeded by nearer-shore, calcareous clays, then noncalcareous clays, and eventually, the nearshore, coarser clastics of the Atarque Sandstone Member of the Tres Hermanos Formation. The overlying Carthage Member is nonmarine, reflecting deposition as the shoreline retreated to the northeast beyond Carthage and reached maximum regression during this initial depositional cycle.

The lower, transgressive contact of the Tokay Tongue with the Dakota Sandstone rises to the south and west (landward) of Socorro County from the earliest middle Cenomanian at Riley, New Mexico, to late middle Cenomanian in the Caballo Mountains, near Truth or Consequences, to earliest late Cenomanian in the Deming/Silver City area. Its upper, regressive contact rises to the north and east (seaward) from latest early Turonian near Truth or Consequences to early middle Turonian at Sevilleta National Wildlife Refuge (Hook and Cobban 2007; Hook et al. 2012).

Ash beds (bentonites) are extremely abundant in the Tokay Tongue at Carthage. There are at least 77 discrete bentonites

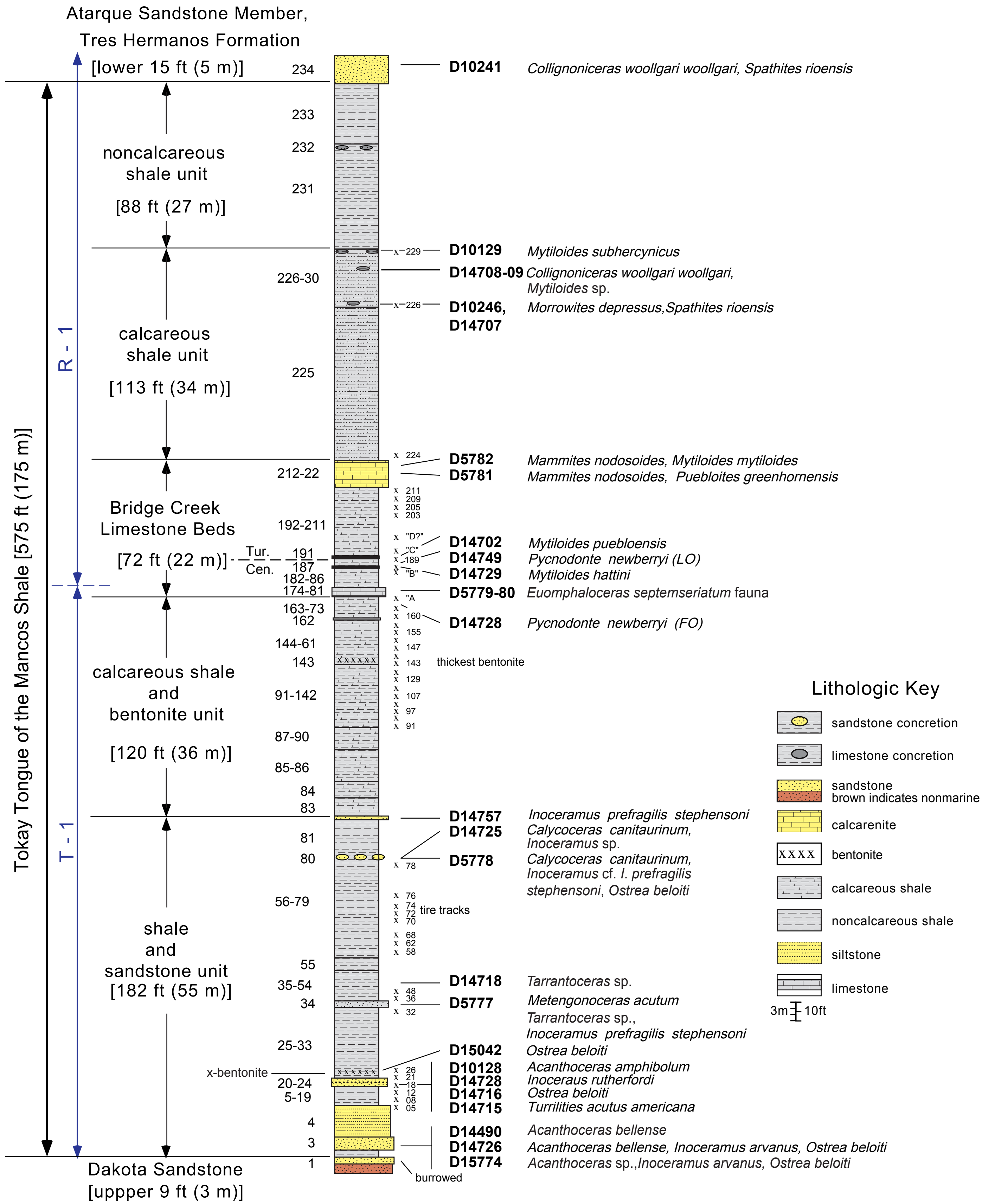


Figure 4—Detailed, measured section of the Tokay Tongue of the Mancos Shale at its type section in the Carthage coal field, Socorro County, New Mexico. The tongue is divided into five bed-rank units, only one of which is formally named. Numbers to the left of the lithologic column are measured section units; more information on each unit can be found in **Appendix 1**. (NOTE: Appendix 1 in blue links to data repository 20150001 throughout this article). A small x to the right of the column indicates the position of a bentonite; numbers preceded by the letter D are USGS Denver Mesozoic Invertebrate collecting localities.

Unit	Name	Thickness -ft(m)	% thickness of total Tongue	Start (mybp)	End (mybp)	Duration (ky)	% duration of total Tongue	Rate-in/ky (cm/ky)
#5	noncalcareous shale	88 (27)	15.30%	91.53	91.37	160	4.23%	6.6 (16.8)
#4	calcareous shale	113 (34)	19.65%	91.70	91.53	170	4.50%	8.0 (20.3)
#3	Bridge Creek Limestone Beds	72 (22)	12.52%	93.68	91.70	1,980	52.38%	0.4 (1.1)
#2	calcareous shale and bentonite	120 (36)	20.87%	94.47	93.68	790	20.90%	1.8 (4.6)
#1	shale and sandstone	182 (55)	31.65%	95.15	94.47	680	17.99%	3.2 (8.2)
	Tokay Tongue	**575 (175)**	**100.00%**	**95.15**	**91.37**	**3,780**	**100.00%**	**1.8 (4.6)**

Table 1—Compacted sedimentation rates in the Tokay Tongue of the Mancos Shale.

distributed throughout the lower 486 ft (148 m) of the tongue; in addition there are five ferruginous beds that may represent altered bentonites. The upper 89 ft (27 m) of the tongue, which has no observed bentonites, underlies the ridge-forming Atarque Sandstone and is generally covered with sandstone debris. The measured bentonites range from 0.25 to 14 inches (0.6 to 35.6 cm) in thickness; most are white, but weather orange. On the basis of thickness, stratigraphic position, and underlying fauna, unit 26, a 12-inch- (30.5 cm-) thick bentonite, 40 ft (12.2 m) above the Dakota Sandstone is correlated with the widespread x-bentonite, which is found throughout the Western Interior. Four bentonites above or just below the base of the Bridge Creek Limestone Beds have been used by Elder (1989) to make high precision correlations between Carthage and sections elsewhere in the Western Interior. The bentonites in the Tokay Tongue will be discussed in more detail in a later section.

Biostratigraphy

Fossils collected from the Tokay Tongue of the Mancos Shale in its type area in the Carthage coal field, Socorro County, New Mexico, range in age from late middle Cenomanian to early middle Turonian, spanning approximately 3.78 my from 95.15 mybp to 91.37 mybp (Fig. 5). The lowest collections from 4 to 8 ft (1.2–2.4 m) above the base of the shale and sandstone unit includen *Acanthoceras belllense*, *Inoceramus arvanu*s, and *Ostrea beloiti*, all indicative of the middle Cenomanian *A. bellense* Zone (Fig. 4, D5774, D14726, and D14450). The highest collection, at the contact between the calcareous and noncalcareous shale units, consists of *Mytiloides subhercynicus*, indicative of the middle Turonian *Collignoniceras woollgari woollgari* Subzone (Fig. 4, D10129). In addition, *C. woollgari woollgari* occurs below this collection in the calcareous shale unit (Fig. 4, D14708-09) and above it at the base of the Atarque Sandstone Member of the Tres Hermanos Formation (Fig. 4, D10241).

Index fossils indicative of seven of the first 19 standard Upper Cretaceous ammonite zones for New Mexico have been collected from the Tokay Tongue at Carthage (Fig. 5): three ammonites and three inoceramids from the shale and sandstone unit (#1); zero from the calcareous shale and bentonite unit (#2), four inoceramids and two ammonites from the Bridge Creek Limestone Beds (#3); one ammonite and one inoceramid from the calcareous shale unit (#4); and zero from the noncalcareous shale unit (#5). The two units without index ammonites or inoceramids are unfossiliferous, at least at the macrofossil level.

Two assumptions apply to the ages shown for the ammonite zones on Figure 5. First, all dated bentonites are assumed to be from the base of the ammonite zone from which it was collected. Second, if there is more than one ammonite zone between two dated bentonites, each zone is assumed to be of equal duration. The first assumption is generally not true. For example, a sample of the marker bentonite (= x-bentonite) from Niobrara County, Wyoming, provides the age date for the middle Cenomanian *Acanthoceras amphibolum* Zone (Obradovich and Cobban 1975, table III). In the Pueblo, Colorado, area the x-bentonite lies just above the middle of the known stratigraphic range of *A. amphibolum* (Cobban and Scott 1972). The second assumption concerning the durations of ammonite zones is untestable, but probably also not true. However, these assumptions provide a means to make gross estimates for compacted sedimentation rates and frequency of events within the Tokay Tongue, especially for the lower three units, where there is more detailed faunal data. The red age dates shown on Figure 5 are based on dated bentonites in the fossil zone somewhere in the Western Interior (Cobban et al. 2006); black age dates are interpolated between calculated ages by applying the two assumptions discussed above.

In addition, the faunal duration of each bed-rank unit of the Tokay Tongue is simplified by assuming that: unit #1 lasted from the beginning of the *Acanthoceras bellense* Zone to the end of the *Calycoceras canitaurinum* Zone; unit #2 lasted from the beginning of the *Dunveganoceras* spp. Zone to the end of the *Vascoceras diartianum* Zone; Unit #3, the Bridge Creek Limestone Beds, lasted from the beginning of the *Euomphaloceras septemseriatum* Zone to the end of the *Mammites nodosoides* Zone; and units #4 and #5, and the Atarque Sandstone Member of the Tres Hermanos Formation split the *Collignoniceras woollgari woollgari* Subzone evenly.

Using the age dates from Figure 5, Table 1 indicates that the entire Tokay Tongue was deposited over ~3.78 my beginning about 95.15 mybp and ending about 91.37 mybp; it has a compacted sedimentation rate of 1.8 inches/ky (4.6 cm/ky). Unit # 1 was deposited over ~680 ky, representing about 18% of the total time, with a compacted sedimentation rate of 3.2 inches/ky (8.2 cm/ky); unit #2, ~790 ky, 21%, with 1.8 inches/ ky (4.6 cm/ky); unit #3, the Bridge Creek Limestone Beds, ~1, 980 ky, 52%, with 0.4 inches/ky 1.1 cm/ky); units #4,~170 ky, 5%, 8.0 inches/ky (20.3 cm/ky); and #5, ~160 ky, 4%, with 6.6 inches/ky (16.8 cm/ky). These quantitative estimates are compatible with the qualitative assessments based on shoreline movement. As the T-1 shoreline moved southwestward across the area, the sedimentation rate would be relatively high as sands and silts were deposited (basal part of unit #1). As the shoreline transgressed farther

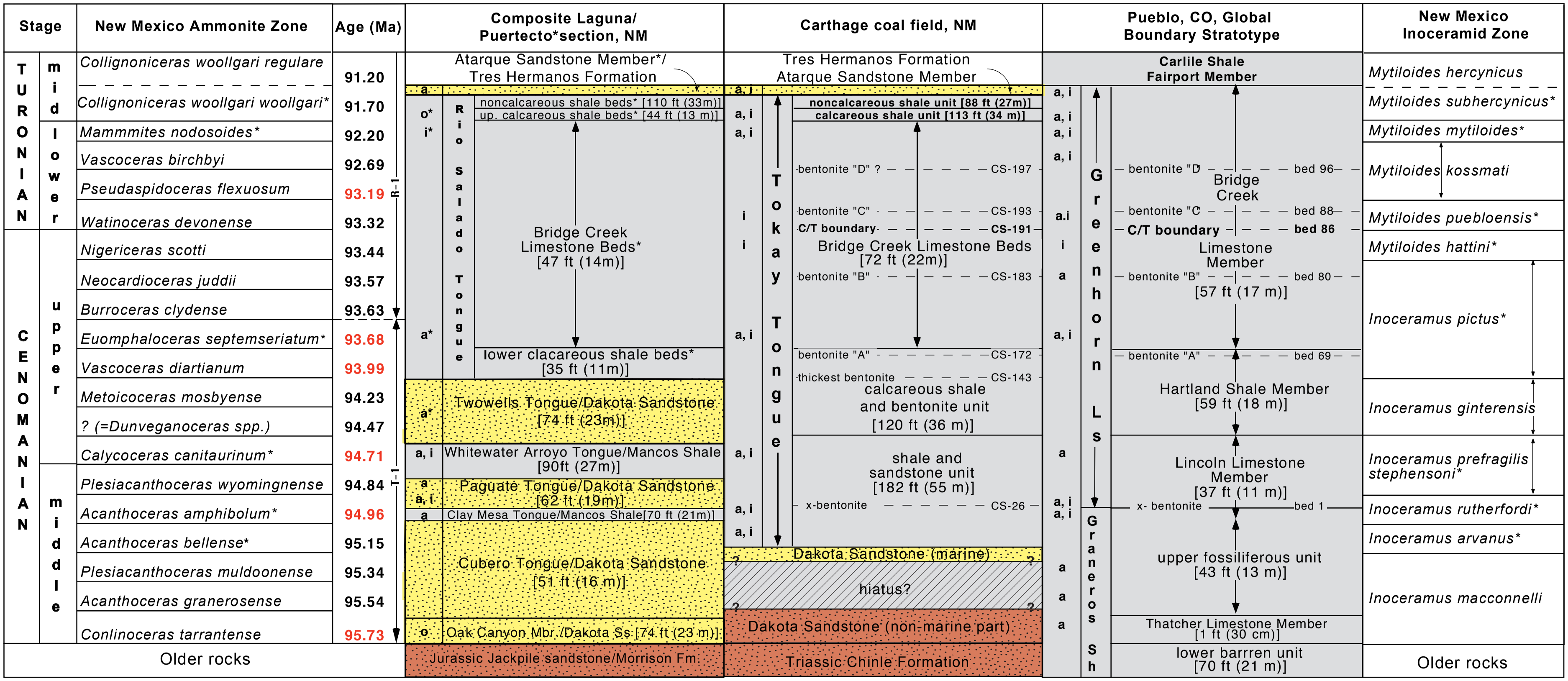


Figure 5—Correlation of the Tokay Tongue of the Mancos Shale at its type section in the Carthage coal field, New Mexico, with 1) the intertongued Dakota Sandstone and Mancos Shale in west-central New Mexico and 2) the reference sections of the Graneros Shale and Greenhorn Limestone near Pueblo, Colorado. Standard ammonite and inoceramid zones of New Mexico (=southern Western Interior) are shown to the left and right side of the diagram. Symbols used: "a" indicates that the zonal index ammonite occurs in the section; "i", that the index inoceramid occurs in the section; "o", that some other molluscan fossil confined to that zone occurs in the section; a number preceded by "CS" is the bed number in the Carthage measured section (see Fig. 4 and **Appendix 1**); T-1=transgression 1; and R-1 = regression 1. Red age dates are calculated from bentonites collected within the zone somewhere in the Western Interior; black age dates are interpolated. An asterisk following a fossil name in the zonal column indicates that index species has been collected from the Tokay Tongue at its type section. Color code: yellow = marine sandstone; gray = marine shale; brown = nonmarine sandstone. The Laguna section (Oak Canyon Member through Twowells Tongue) is from Landis et al. (1973, pp. J4-J8); the Puertecito section (Rio Salado Tongue) is from Hook et al. (1983, p. 25); the Pueblo section (Rock Canyon Anticline) is from Cobban and Scott (1972). Only fossils collected from these measured sections are indicated in the left-hand portion of the stratigraphic columns.

Unit	Name	Unit T-ft(m)	Duration (ky)	# bentonites	# >= 4 in (10 cm)	max T-in (cm)	total T- in (cm)	% of unit	frequency (ky/fall)	T/fall [in(cm)]
#5	noncalcareous shale	88 (27)	160	0	0	---	0 (0)	0.00%	---	0.0
#4	calcareous shale	113 (34)	170	3	1 (33%)	7 (17.8)	11 (28)	0.82%	57	3.7 (9.3)
#3	Bridge Creek Limestone Beds	72 (22)	1,980	10	2 (20%)	6 (15.2)	24.5 (62.2)	2.83%	198	2.5 (6.4)
#2	calcareous shale & bentonite	120 (36)	790	40	6 (15%)	14 (35.6)	79.8 (202.7)	5.54%	20	2.0 (5.1)
#1	shale and sand-stone	182 (55)	680	24	5 (21%)	12 (30.5)	60.0 (152.4)	2.77%	28	2.5 (6.4)
	Tokay Tongue	**575 (175)**	**3,780**	**77**	**14 (18%)**	**14 (35.6)**	**175.3 (445.2)**	**2.54%**	**49**	**2.3 (5.8)**

Table 2—Volcanic activity recorded in the Tokay Tongue of the Mancos Shale.

southwestward, the sedimentation rate would decrease as offshore clays were deposited (unit #2) and would reach a minimum at maximum transgression when the finest grained carbonates were deposited at the base of the Bridge Creek Limestone (basal part of unit #3). Ideally, these rates would increase in a similar fashion as the R-1 shoreline regressed toward Carthage and the distance from shore decreased. Unfortunately, the data are not detailed enough to show more than a marked increase in sedimentation rate for units #4 and #5.

Bentonites

Ash beds (=bentonites) are so abundant in the well-exposed shales of the Tokay Tongue at its type section that the normally medium to dark gray shales appear light gray in satellite images. The 77 discrete bentonites within the Tokay Tongue comprise an aggregate thickness of 14.6 ft (4.5 m) and represent the greatest number of ash falls recorded in a published section of comparable age anywhere in the Western Interior. Hook (2009, p. 25) compares portions of the Tokay Tongue at Carthage, which he called the lower tongue of the Mancos, to age-comparable, detailed measured sections at Pueblo and Mesaverde, Colorado. In each comparison, the Tokay Tongue contained considerably more bentonite beds and had a greater aggregate thickness of ash. Sixty-eight of the 77 bentonites occur below the Cenomanian/Turonian boundary limestone (Fig. 4, unit 191), making the middle and late Cenomanian a time of relatively intense volcanic activity, at least in the southern portion of the Western Interior. Elder (1988) studied the distribution and thickness of four ash beds just above and below the Cenomanian/Turonian boundary in the southern Western Interior; he designated these beds informally with the letters A-D, with A as the oldest. One of his studied sections was at Carthage. He concluded that three of these ash beds had source areas far to the west near the convergence of present-day California, Nevada, and Arizona. The fourth, bed " B", had a source near the Canadian border.

The 77 measured ash beds are distributed unevenly through the lower four bed-rank units in the tongue (Table 2). There are 24 in the shale and sandstone (unit #1); 40 in the calcareous shale and bentonite (unit #2); 10 in the Bridge Creek (unit #3); and 3 in the calcareous shale (unit #4). Aggregate bentonite thickness represents 2.5% of the entire tongue. However, ash percentage increases from 2.8% of unit #1 to 5.5% of unit #2; then decreases to 2.8% of the Bridge Creek (#3), and to less than 1.0% of unit #4. Volcanic activity measured in terms of numbers of ash beds and aggregate thickness reached a peak during the early late Cenomanian within the calcareous shale and bentonite unit (#2).

In terms of frequency of eruptions, the Tokay Tongue as a whole records one ash fall approximately every 49 ky (Table 2). The lower two bed rank units (#1 and #2) have frequencies of 28 and 20 ky/ash indicating that the middle and earliest late Cenomanian was a time of intense volcanic activity in the southern Western Interior. The average frequency of eruptions decreases in the overlying Bridge Creek Limestone Beds (#3) and calcareous shale unit (#4) to one eruption every 198 ky and 57 ky, respectively.

The bar graph (Fig. 6) summarizes much of the descriptive information from Table 2 as well as showing the thickness distribution of the bentonites within the tongue. The waxing and waning of the intensity of volcanic activity, which may reflect the proximity of active volcanoes, are shown in terms of thickness of individual bentonites that are arranged chronologically, but not to time scale, with the oldest bed on the left and youngest bed on the right. Bentonite numbers on the horizontal axis correspond to the numbered bentonites in the measured section (**Appendix 1**).

Using an arbitrary cutoff thickness of 4 inches (10 cm) to separate thick bentonites from thin, there are 14 of these high intensity events recorded within the entire Tokay Tongue, representing 18% of the measured bentonites. Their distribution is uneven with 11 of them below the Bridge Creek Limestone, two within the unit, and one above. This pattern of waxing and waning bentonite thicknesses may also reflect factors other than intensity of volcanic activity, such as wind speed and direction, currents, waves, and storms. Several of the bentonites in Figure 6 are given descriptive names and will be discussed in chronological order below.

A thick bentonite bed (CS-26, #7), 40 ft (12.2 m) above the Dakota Sandstone in the basal shale and sandstone unit is the appropriate age and thickness to be the widespread middle Cenomanian x-bentonite that has been traced/correlated from Montana to northern New Mexico. Bed CS-26 is as much as 12 inches (30 cm) thick and probably lies within the *Acanthoceras amphibolum* Zone, although no fossils that are confined to *A. amphibolum* Zone have been found above the bentonite (Figs. 4). CS-26 produces a wide outcrop band at Carthage because it occurs on or just above a resistant, tan-weathering siltstone ledge (CS-24) that forms a major dipslope. The soft bentonite tends to smear along this resistant dipslope, creating a white outcrop belt that is several times wider than the bentonite is thick.

In the major fault block that comprises the type area of the Tokay Tongue, the x-bentonite varies in thickness between 10 and 12 inches (25–30 cm). It can sit directly on the underlying siltstone ledge (CS-24) or be separated from the ledge by an inch or so of shale (CS-25). These differences over such a small area are probably the effects of local currents.

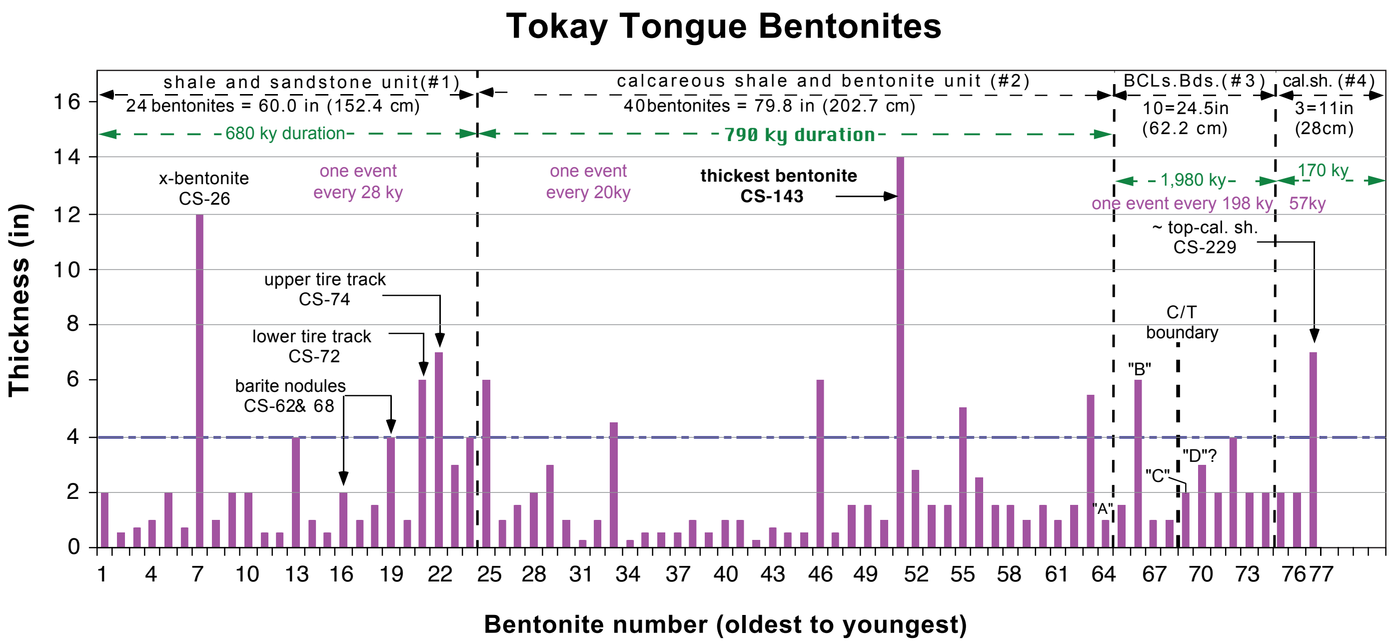


Figure 6—Bar graph showing thickness of measured ash beds within the bed-rank units of the Tokay Tongue at its type section arranged chronologically from oldest (1) to youngest (77). Blue, horizontal dashed line is at an arbitrary thickness of 4 inches (10 cm), separating thick from thin bentonites. Key or unusual bentonites are labeled with names and bed numbers (see Fig. 4 and **Appendix 1**).

The x-bentonite is an important middle Cenomanian marker bed in the Western Interior. In the Pueblo, Colorado, area, for example, Cobban and Scott (1972) use it as the boundary between the Graneros Shale (below) and the Lincoln Member of the Greenhorn Limestone (above). It provides the age date of 94.96 Ma for the middle Cenomanian *Acanthoceras amphibolum* Zone used throughout the Western Interior (Cobban et al. 2006). The x-bentonite lies approximately in the middle of the range of *A. amphibolum* at Pueblo.

Grayish-brown barite nodules, most irregularly shaped spherical masses, up to 3 inches (7.6 cm) in diameter with a radial internal structure, litter the ground below bentonites #16 and #19 (CS-62 and CS-68). These two bentonites are 2 and 4 inches (5 and 10 cm) thick, respectively, and occur 115 and 120 ft (35 and 37 m) above the top of the Dakota in the shale and sandstone unit. The barite nodules are probably alteration products related to the ash.

Two of the thickest bentonites in the shale and sandstone unit, #21 (CS-72), which is 6 inches (15.2 cm) thick, and #22 (CS-74), which is 7 inches (17.8 cm) thick, are separated from each other by 1.5 ft (46 cm) of calcareous shale. Their distinctive outcrop pattern on a near-horizontal surface near the top of unit looks like white tire tracks or the tracks from a narrow gauge railroad.

The thickest ash bed in the Tokay Tongue is # 51 (CS-143), a 14 inch- (36 cm-) thick, white-weathering bentonite that is in the upper third of the shale and bentonite unit, 36 ft (11 m) below the base of the Bridge Creek Limestone Beds. This bed shows up well on satellite images of the fault block as a white band offset by minor north-south trending, normal faults. If the compacted sedimentation rate for the entire shale and bentonite unit (1.6 inches/ky (4.1 cm/ky)) applied to this bentonite, it would have taken 8.8 ky to form! Obviously, the overall sedimentation rate does not apply to this (or any other) bentonite. This rate over-estimates the settling time of bentonites by at least three orders of magnitude (base 10).

The four lettered bentonites, A (# 64), B (# 66), C (#69), and D (# 70) [CS- 172, 183, 193, and 197] were used by Elder (1988) in his study on Upper Cretaceous bentonite beds in the southern Western Interior. From their isopachs he determined that the volcanic source areas were both northwest and southwest of the central Western Interior basin.

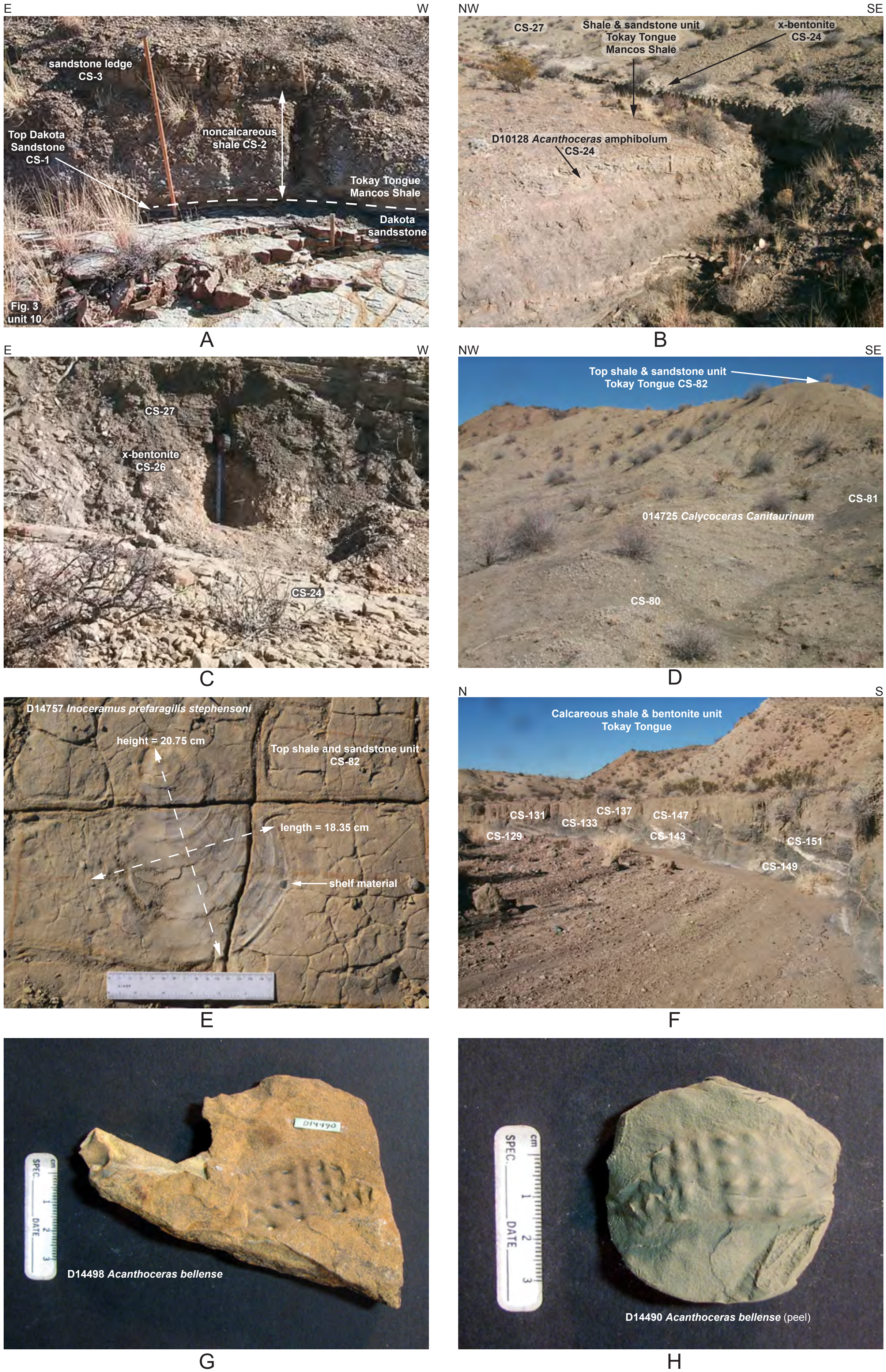
The last labeled bentonite on Fig. 6 is #77 (CS-229) is a 7 inch- (26.5 cm-) thick, white-weathering bentonite that can be used to establish the boundary between the calcareous and noncalcareous shale units. The 2 inch- (5 cm-) thick limestone (CS-230) that forms the boundary in the type area is not well-developed elsewhere in the coal field, but the bentonite is always present.

Detailed stratigraphy and biostratigraphy

In this section the stratigraphy and fauna of each of the five bed-rank units that comprise the 575 ft (175 m) thick Tokay Tongue of the Mancos Shale at its type locality in the Carthage coal field are discussed in detail. From bottom to top, these are: #1) the shale and sandstone unit (informal name); #2) calcareous shale and bentonite unit (informal name); #3) the Bridge Creek Limestone Beds (formal name); #4) calcareous shale unit (informal name); and #5) noncalcareous shale unit (informal name). Each of these bed-rank units is compared to (1) the principal reference sections for the Graneros Shale and Greenhorn Limestone near Pueblo, Colorado, and (2) the intertongued Dakota Sandstone/Mancos Shale sequence in west-central New Mexico.

Shale and sandstone unit (#1)

Stratigraphy—Unit #1, the shale and sandstone unit, is the thickest of the subdivisions of the Tokay Tongue (Table 1). Its 182 ft (55 m) thickness represents 32% of the total thickness of the tongue, even though its duration represents only 18% of that of the entire tongue. Its compacted sedimentation rate is 1.8 times greater than that of the tongue as a whole, primarily because its early sedimentation occurred in relatively nearshore environments as the T-1 shoreline transgressed over the area (Fig. 1 A, B). Unit #1 is composed primarily of medium to dark gray shale (94%), which includes ash beds, with a subsidiary amount (6%) of either fine-grained, tan weathering, thin bedded sandstone or siltstone. Both its lower and upper contacts are conformable. Its basal contact with the Dakota Sandstone is drawn at the base of 2.1 ft- (64 cm-) thick, dark gray, noncalcareous shale (CS-2) that lies on the Dakota dipslope (Figs. 4 and 7A). Its upper contact is placed at the last ridge-forming bed below the basal limestone in the Bridge Creek Limestone Beds, which forms the next ridge in the sequence. This resistant bed (CS-82) is a 3 inch- (8 cm-) thick, tan-weathering siltstone that creates an impressive plane of a dipslope that is completely clear



E
W
sandstone ledge
CS-3
Top Dakota
Sandstone
CS-1
noncalcareous
shale CS-2
Tokay Tongue
Mancos Shale
Dakota
sandsstone
Fig. 3
unit 10
A
NW
SE
CS-27
Shale & sandstone unit
Tokay Tongue
Mancos Shale
x-bentonite
CS-24
D10128 *Acanthoceras* amphibolum
CS-24
B
E
W
CS-27
x-bentonite
CS-26
CS-24
C
NW
SE
Top shale & sandstone unit
Tokay Tongue CS-82
CS-81
014725 *Calycoceras Canitaurinum*
CS-80
D
D14757 *Inoceramus prefaragills stephensoni*
height = 20.75 cm
Top shale and sandstone unit
CS-82
length = 18.35 cm
shelf material
E
N
S
Calcareous shale & bentonite unit
Tokay Tongue
CS-131
CS-133
CS-137
CS-147
CS-129
CS-143
CS-151
CS-149
F
D14498 *Acanthoceras bellense*
G
D14490 *Acanthoceras bellense* (peel)
H

Figure 7—Previous page. Outcrop photographs of the type section of the Tokay Tongue in the Carthage coal field, New Mexico, part 1. **A)** Contact of the Tokay Tongue of the Mancos with the Dakota Sandstone. **B)** Lower portion of the shale and sandstone unit (#1). The x-bentonite (CS-26) weathers to a wide, white ribbon. **C)** Close-up view of the x-bentonite. **D)** Upper part of the shale and sandstone unit (#1) showing the *Calycoceras canitaurinum* concretions (CS-80) and ridge formed below the uppermost hard bed in the unit (CS-82). **E)** Uppermost bed of unit #1 preserves a single fossil—an impression of a giant *Inoceramus prefragilis stephensoni*. **F)** The middle portion of the calcareous shale and bentonite unit (#2) lives up to its name in this arroyo where at least eight white bentonites crop out below an angular unconformity. **G)** and **H)** Impression and peel of *Acanthoceras bellense* Adkins (USNM # 616437) from 4 ft (1.2 m) above the base of the Tokay Tongue of the Mancos Shale at USGS Mesozoic Invertebrate Locality D14490.

of weathered debris from the overlying shales (Figs. 4 and 7D, E).

Shale beds in the lowest part of the unit are noncalcareous, but become progressively more calcareous up section (Fig. 4). Shales in the upper half of the unit cannot be differentiated visually from those in the overlying calcareous shale and bentonite unit. Presumably, the noncalcareous shales reflect the proximity of the shoreline with its influence of fresh water. By the time the x-bentonite was deposited, the shoreline was south of Truth or Consequences, at least 80 mi (128 km) southwest of Carthage (Fig. 1B). The shales above the x-bentonite are slightly calcareous; those stratigraphically higher become progressively more calcareous, although not every shale bed was tested (Fig. 4, **Appendix 1**).

There are at least 24 discrete bentonite beds in the shale and sandstone unit, including the foot-thick x-bentonite (Figs. 4, 7B,C) that lies 40 ft (12.2 m) above the base of the Tokay. Dividing the number of discrete ash beds by the calculated duration of the unit yields an average frequency of one volcanic eruption every 28 ky (Table 2). Five (21%) of the bentonites are at least 4 inches (10 cm) thick. The x-bentonite provides the age date of 94.96 Ma for the *Acanthoceras amphibolum* Zone (Fig. 5) that is used throughout the Western Interior (Cobban et al. 2006); the base of the x-bentonite (also called the marker bentonite) is used as the boundary between the Graneros Shale (below) and the Lincoln Member of the Greenhorn Limestone (above) in the Pueblo, Colorado, area, (Cobban and Scott, 1972).

The aggregate compacted thickness of the bentonites is 60 inches (152 cm) or ~2.8% of the unit. Average compacted thickness per fall is 2.5 inches (6.4 cm), slightly more than the average for the tongue. In addition, there are two ferruginous beds and one unusual limestone that may represent altered ash beds (**Appendix 1**). The limestone (CS-30) is gray, 2 inches (5 cm) thick, and crystalline. Its upper surface appears to be covered with thin, flattened tubes a few millimeters in diameter. The authors' first impression was that this surface consisted of coral branches. Closer inspection revealed that the tubes had no surface markings, were a centimeter or so long and arranged haphazardly on the surface. They were interpreted in the field as inorganic in origin. When dug out, one outcrop had a thin, powdery clay at the base of the limestone that may have been the remnants of a bentonite.

Fauna and age—The shale and sandstone unit is poorly fossiliferous in terms of megafaunal body fossils. Collected fossils consist of seven species of ammonites, three species of clams, and one species of oysters collected from only 10 of the 82 rock subunits in the shale and sandstone unit. With one exception these low diversity faunas are found in sandstones and siltstones. The lone exception is from sandy, limestone concretions near the top (Fig. 4, D14725 and D5778) that contains the lowermost upper Cenomanian zonal index ammonite *Calycoceras canitaurinum*. However, the ammonite *Metengonoceras acutum*?, collected from CS-34 just below the middle of the unit, is known from only three other localities in the Western Interior: Colorado, Iowa, and Minnesota (Cobban 1987, p.C3).

The lowest fossils (D14726, D14490, and D5774) from the unit come from CS-3, a 7 ft-(2.1 m-) thick, thin-bedded, fine- grained sandstone that is 2.1 ft (64 cm) above the base of the tongue (Figs. 4 and 7A). Fossils collected from this ledge-forming unit include the ammonite *Acanthoceras bellense* (Fig. 7G, H), the clam *Inoceramus arvanus*, and the oyster *Ostrea beloiti*. Together, these fossils represent the upper middle Cenomanian *A. bellense* Zone (Fig. 5). Although the fauna is of low diversity, the clam and especially the oyster occur in great abundance, often as fragments on bedding planes. The ammonite, of which there are three specimens, occurs as impressions (bounce marks?) on bedding surfaces (Fig. 7G). *Acanthoceras bellense* is an uncommon ammonite in New Mexico, but is known from the Dakota Sandstone on the nearby Sevilleta National Wildlife Refuge (Hook and Cobban 2007, p. 94; Fig. 1). *Acanthoceras bellense* gave rise to the morphologically similar *A. amphibolum*, which occurs stratigraphically higher in the type section of the Tokay Tongue. The two species differ "… most obviously in the much earlier loss of differentiated inner and outer ventrolateral tubercles in *A. amphibolum*, where a massive horn develops, and the equally early loss of the siphonal tubercles (Kennedy and Cobban 1990, p. 104)."

The next level of fossils occurs in the siltstone ledges (CS-20 through CS-24) just beneath the x-bentonite (Figs. 4 and 7B,C), about 37 ft (11 m) above the Dakota. Collected fossils include the ammonites *Acanthoceras amphibolum* (D10128) and *Turrilites acutus americanus* (D14715), the clam *Inoceramus rutherfordi* (D14728), and the oyster *Ostrea beloiti* (D14716). These fossils represent the next higher middle Cenomanian zone of *A. amphibolum*. Preservation is the same as the previous zone. This assemblage is common in the Paguate Sandstone Tongue of the Dakota Sandstone in the San Juan Basin to the northwest (Cobban 1977, table 1).

The 40 ft (12 m) of slightly calcareous shale with interbedded thin sandstones above the x-bentonite is almost barren of megafauna. A thin sandstone about 5 ft (1.5 m) above the x-bentonite yielded a complete right valve of a large *Ostrea beloiti* (D15042) that has a height of 4.0 cm and a length of 2. 4 cm. *Metengonoceras acutum*? (D5777) occurs as an internal mold in CS-34, a 3 inch- (8cm-) thick sandstone 81 ft (25 m) above the Dakota. Other fossils occurring with the *Metengonoceras* are *Tarrantoceras* sp. and *Inoceramus prefragilis stephensoni*. *Tarrantoceras* sp. (D14718) occurs as an impression in CS-50, a 7 inch- (18 cm-) thick, fine grained sandstone, 14 ft (4.3 m) higher in the section (Fig. 4).

Tarrantoceras is a common ammonite in west-central New Mexico often associated with *Acanthoceras amphibolum* (Cobban 1977, table 1). Cobban et al. (1989, p. 28) note that *T. sellardsi* can range as high as the *Calycoceras canitaurinum* Zone. The presence of *Inoceramus prefragilis stephensoni* in these collections indicates they are more likely to be from the *Calycoceras canitaurinum* Zone.

Calycoceras canitaurinum (D5778 and D14725), the name-bearer for the lowest upper Cenomanian ammonite zone occurs as poorly preserved internal molds in sandy limestone concretions (CS-80) about 20 ft (6.1 m) below the top of the unit (Figs. 4 and 7D). Occasional fragments of *Inoceramus* sp. occur in the concretions as well.

The uppermost bed (CS-82) of the shale and sandstone unit has produced only one fossil, but with a height of 20.75 cm and an estimated length of 18.25 cm it turns out to be the largest inoceramid collected in the Carthage area (Fig. 7E). This giant *Inoceramus prefragilis stephensoni* (Fig. 4, D14757) was collected as a peel.

Assuming that the giant *Inoceramus prefragilis stephensoni* (D14757) at the top of the unit #1 (CS-82) represents the top of the basal upper Cenomanian *Calycoceras canitaurinum* Zone and that the base of this unit (CS-2) represents the base of the middle Cenomanian *Acanthoceras bellense* Zone, then the shale and sandstone unit was deposited over ~680 ky (Table 1).

In terms of the principal reference section of the Graneros Shale and Greenhorn Limestone at Pueblo, Colorado, (Cobban and Scott 1972), the 182 ft- (55 m-) thick shale and sandstone unit (#1) is the temporal equivalent of the upper part of the Graneros Shale and the entire Lincoln Limestone Member of the Greenhorn Limestone (Fig. 5), which together are approximately 50 ft (15 m) thick. It is also the temporal equivalent of the upper two thirds of the Cubero Tongue through the lower part of the Twowells

Tongue of the Dakota Sandstone (Fig. 5). Included, then, are the entire Clay Mesa, Paguate, and Whitewater Arroyo Tongues at the Laguna measured section (Landis et al. 1973, pp. J4-J8). Together, the correlative portions of these tongues are approximately 250 ft (76 m) thick.

Calcareous shale and bentonite unit (#2)

Stratigraphy—Unit #2, the calcareous shale and bentonite unit, is the second thickest of the subdivisions of the Tokay Tongue (Table 1). Its 120 ft (36 m) thickness represents 21% of the total thickness of the tongue; its duration also represents 21% of that of the entire tongue. Its compacted sedimentation rate of 1.8 inches (4.6 cm/ky) is identical to that of the tongue as a whole. Sedimentation occurred entirely in offshore environments as the T-1 shoreline had transgressed to the point that New Mexico was completely covered by marine water (Fig. 1 C), although the T-1 shoreline had not yet reached maximum transgression. Unit #2 is composed almost entirely of medium to dark gray, calcareous shale (94%) and white bentonite beds (6%). Both its lower and upper contacts are conformable. The calcareous shale and bentonite unit is one of the easiest to differentiate in the Carthage coal field—it is the soft, slope-forming, partially to almost completely covered, shale between the highest ridge of the shale and sandstone unit (CS-82) and the lowest ridge of the Bridge Creek Limestone Beds (CS-174).

There are more discrete bentonite beds in the calcareous shale and bentonite unit than in any other unit in the Tokay Tongue (Table 2; Fig. 7F). These 40 ash beds contain an aggregate compacted thickness of 79.8 inches (202.7 cm) and account for almost 6% of the unit's thickness. Six (15%) of these 40 bentonites are at least 4 inches (10 cm) thick, including the thickest bentonite in the tongue, CS-143, which is 14 inches (35.6 cm) thick. The average frequency of one volcanic eruption every 20 ky (Table 2), is the shortest for any of the bed rank units. Figure 7F shows a portion of the angular unconformity between the Quaternary alluvium and the Tokay Tongue at Carthage. There are 12 white bentonite beds exposed in the 20 ft (6 m) of the calcareous shale and bentonite exposed beneath the unconformity.

Average compacted thickness per ash fall is 1.8 inches (4.6 cm), the average for the entire tongue. In addition, there are three ferruginous beds that may represent altered ash beds (**Appendix 1**). Elder's (1988) "A" bentonite (CS-172) occurs just below the top of the unit, 11 inches (28 cm) below the base of the first Bridge Creek Limestone. The "A" bentonite has a source area to the west in the Sierra Nevada batholith according to Elder (1988, p. 837).

Fauna and age—Fossils have been collected from only one interval in the calcareous shale and bentonite unit: D14728 from a thin shale (CS-171) 1 ft (30 cm) below the top of the unit contains original shells of the oyster *Pycnodonte newberryi*. This first occurrence (FO) of *P. newberryi* is probably from the top of the *Vascoceras diartianum* Zone. Otherwise, the unit is unfossiliferous in terms of megafaunal body fossils. Therefore, it has to be dated indirectly using the highest datable fossil in the underlying unit (*Inoceramus prefragilis stephensoni*) and the lowest datable fossil in the overlying unit (*Euomphaloceras septemseriatum*) to bracket its age (Figs. 4 and 5). This bracket places the calcareous shale and bentonite unit entirely in the upper Cenomanian between the basal upper Cenomanian *Calycoceras canitaurinum* Zone and the middle upper Cenomanian *Euomphaloceras septemseriatum* Zone. Assuming that the inoceramid at the top of the lower unit represents the top of the *C. canitaurinum* Zone and that E. *septemseriatum* at the base of the Bridge Creek represents the base of the zone, then the calcareous shale and bentonite unit was deposited over ~790 ky (Table 1).

The lack of megafossils in unit #2 is directly attributable to its complete lack of hard beds (e.g., limestones and limy concretions) to preserve the fossils once they are exposed at the surface. Study of the Candy Lane core (USGS CL-1) from Montrose County, Colorado (Ball et al. 2009), indicates that Upper Cretaceous shales can preserve flattened fossils, but they are of delicate, original shell preservation. These fossils as well as the enclosing shale deteriorate rapidly once they are exposed at the surface. However, the Candy Lane well was not drilled deeply enough to penetrate rocks that are the temporal equivalent of the calcareous shale and bentonite unit.

Hook et al. (2012, p. 131) suggest that the lack of fossils in this unit could have been a result of the extensive volcanic activity that fouled the water with ash, thus inhibiting bottom-dwelling, filter-feeding organisms, such as clams and oysters. The 20 ky, on average, between recorded bentonites (Table 2) suggest that this hypothesis is not tenable over the entire unit. Unfortunately, the Candy Lane well is not deep enough to have penetrated this portion of the section. Therefore, a direct comparison of bentonites and fossils is not possible. Nektonic organisms, especially ones that could have floated for some time after death like the ammonites, would not have been affected by the ash in the water. The lack of concretions and/or hard beds may be a better explanation for the absence of megafossils. A few, thin, resistant beds (lenses?) of very fine-grained calcarenite are present near the top of the unit. Theses beds are composed almost entirely of the tests of globigerinid foraminifera.

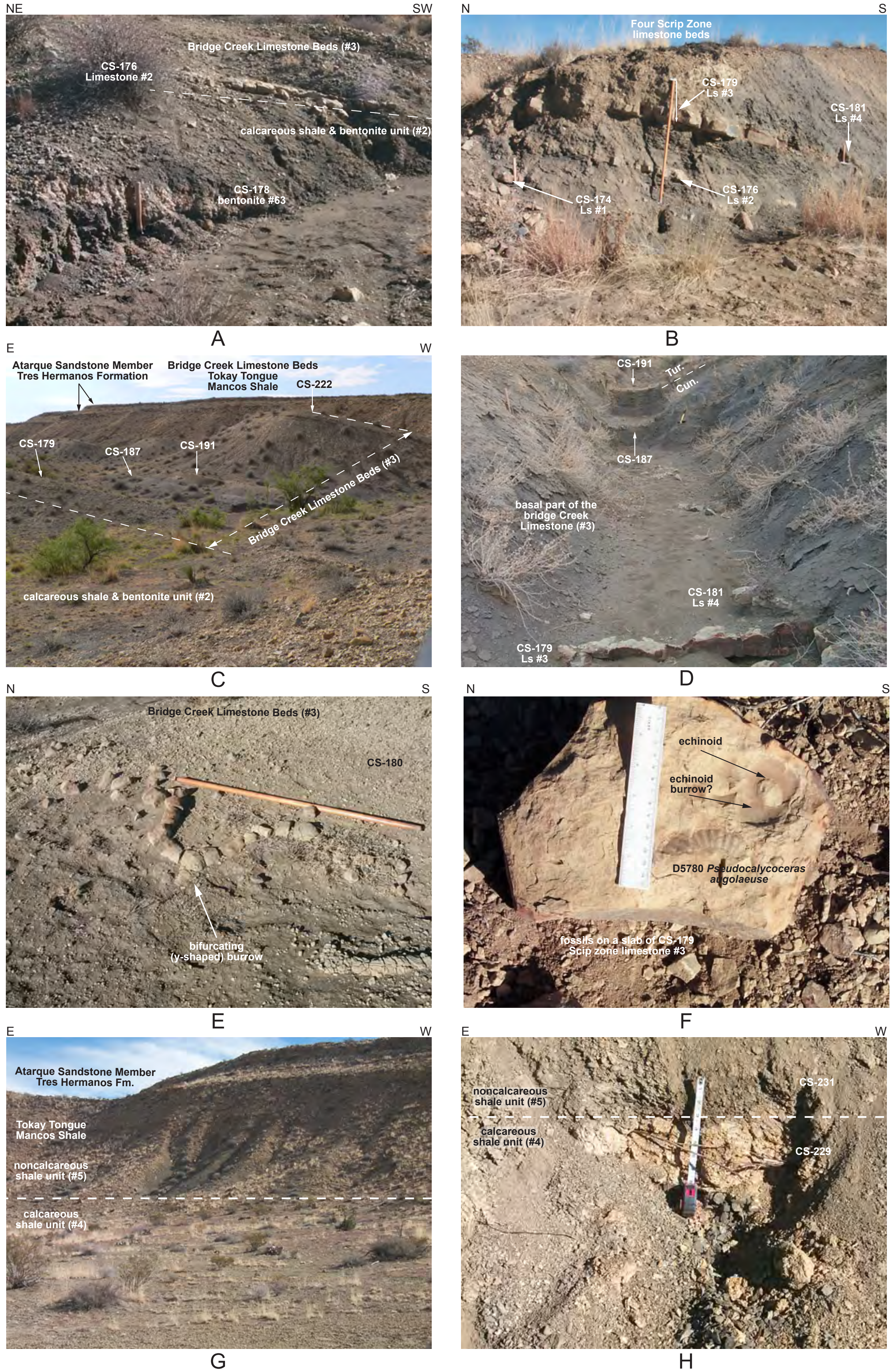
Cobban and Scott (1972, p. 31) note the lack of fossils in this portion of the section at Pueblo, Colorado: "[t]he poor preservation of fossils in both the Lincoln and Hartland Members may be due to the activity of *Ptychodus*, the shell-crushing [shark]. The few fossils that are described were found by splitting the shale and the thinly layered calcarenite beds." At Carthage, there are few calcarenite beds in the calcareous shale and bentonite unit (**Appendix 1)**, but no *Ptychodus* teeth have been found on its outcrop.

The 120 ft- (36 m-) thick calcareous shale and bentonite unit of the Tokay Tongue is the exact temporal equivalent of the 59 ft (18 m-) thick Hartland Shale Member of the Greenhorn Limestone (Fig. 5). It is also the temporal equivalent of the upper 85% (63 ft (19 m) of the Twowells Tongue of the Dakota Sandstone and the entire 35 ft- (11 m-) thick lower calcareous shale beds of the Rio Salado Tongue of the Mancos Shale (Fig. 5). Together these units are approximately 98 ft (30 m) thick.

The temporal equivalent of the Twowells Tongue is generally well exposed everywhere in the Carthage coal field near the middle of the Tokay Tongue beneath the base of the Bridge Creek Limestone Beds; this interval consists almost entirely of calcareous shale (**Appendix 1**). Intermittently along the outcrop, a 6 inch- (15 cm-) thick, highly calcareous, very fine-grained sandstone to siltstone crops out approximately 10 ft (3 m) below the base of the Bridge Creek Limestone Beds and 7.5 ft (2.3 m) below the first occurrence of the oyster *Pycnodonte newberryi*.

The stratigraphic position of this thin bed is approximately where the top of the Twowells Tongue should lie based on regional geology of Socorro County. Fifty-two miles (84 km) to the northwest of Carthage, the Twowells pinches out to the east between Puertecito and Riley into the laterally continuous Tokay Tongue (Fig. 1). At Puertecito (Hook et al. 1983, chart 1, #58A), the Twowells is 49 ft (15 m) thick and lies 15 ft (4.6 m) below the base of the Bridge Creek Limestone Beds of the Rio Salado Tongue of the Mancos Shale. The only ammonite, and one of the few fossils, collected from the Twowells in the Puertecito area is *Metoicoceras mosbyense* (Hook et al. 1983, sheet 1, section 58A, D10267).

Twenty–four miles (39 km) the north of Carthage (Fig. 1), the Twowells is 90 ft (27 m) thick in the central portion of the Sevilleta National Wildlife Refuge (SNWR), but is not present in (pinches out into?) an isolated exposure of the Tokay Tongue approximately 4 mi (6.4 km) to the south (Hook and Cobban 2007 and unpublished measured sections). Although the basal nodular limestones of the Bridge Creek Limestone Beds are not developed on SNWR, the top of the Twowells lies 5 ft (1.5 m) below the first occurrence (FO) of *Pycnodonte newberryi*. The only fossil collected from the Twowells on SNWR is the ammonite *Metoicoceras mosbyense* (Hook 1983, fig. 3, D10979; Hook et al. 2012, fig. 6). The Twowells is not present in the Jornada del Muerto coal field, which is 10 mi (16 km) south of SNWR, between SNWR and Carthage (Fig. 1).



NE
SW
Bridge Creek Limestone Beds (#3)
CS-176
Limestone #2
calcareous shale & bentonite unit (#2)
CS-178
bentonite #63
A
N
S
Four Scrip Zone
limestone beds
CS-179
Ls #3
CS-181
Ls #4
CS-174
Ls #1
CS-176
Ls #2
B
E
W
Atarque Sandstone Member
Tres Hermanos Formation
Bridge Creek Limestone Beds
Tokay Tongue
Mancos Shale
CS-222
CS-179
CS-187
CS-191
Bridge Creek Limestone Beds (#3)
calcareous shale & bentonite unit (#2)
C
CS-191
Tur.
Cun.
CS-187
basal part of the
bridge Creek
Limestone (#3)
CS-181
Ls #4
CS-179
Ls #3
D
N
S
Bridge Creek Limestone Beds (#3)
CS-180
bifurcating
(y-shaped) burrow
E
N
S
echinoid
echinoid
burrow?
D5780 Pseudocalycoceras
angolaeuse
fossils on a slab of CS-179
Scip zone limestone #3
F
E
W
Atarque Sandstone Member
Tres Hermanos Fm.
Tokay Tongue
Mancos Shale
noncalcareous
shale unit (#5)
calcareous
shale unit (#4)
G
E
W
noncalcareous
shale unit (#5)
CS-231
calcareous
shale unit (#4)
CS-229
H

Figure 8—Left on page 40. Outcrop photographs of the type section of the Tokay Tongue in the Carthage coal field, New Mexico, part 2. **A)** Contact of the Bridge Creek Limestone Beds (#3) with the underlying calcareous shale and bentonite unit (#2); CS-170 is the thickest bentonite in the Tokay Tongue at its type section. **B)** All four Scip zone limestones at the base of the Bridge Creek Limestone Beds are developed and exposed in this arroyo. **C)** Ridges held up by limestones or calcarenites in the Bridge Creek Limestone Beds (#3) are well developed in the type area of the Tokay Tongue of the Mancos Shale. **D)** Limestones in the basal part of the Bridge Creek Limestone Beds (#3) are well exposed in this arroyo from the pinching and swelling Scip zone limestone #3 (CS-179) to the Cenomanian/Turonian boundary limestone (CS-191). **E)** Large Y-shaped sedimentary structure developed in the shale between Scip zone limestones #3 and #4. Jacob staff is 5 ft (1.5 m) long. **F)** Slab of Scip zone limestone #3 (USNM #616438) containing an internal mold of the ammonite *Pseudocalycoceras angolaense* and an internal mold of the echinoid *Mecaster batnensis* in a depression interpreted as its burrow. The echinoid has a width of 2.5 cm; the burrow has a diameter of 6.4 cm. From the Scip zone limestone #3 at the base of the Bridge Creek Limestone Beds of the Tokay Tongue of the Mancos Shale, USGS Mesozoic Invertebrate Locality D5780. **G)** The flat, almost horizontal outcrop pattern of the calcareous shale unit (#4) changes abruptly to the steep slope of the noncalcareous shale unit (#5), which is supported by the highly resistant Atarque Sandstone Member of the Tres Hermanos Formation. In rivulets in the steep slope, the noncalcareous shale has 100% exposure. **H)** The stratigraphically highest bentonite in the Tokay Tongue (#77, CS-229), a 7 inch- (18 cm-) thick ash bed, occurs at or just below the boundary between calcareous shale (unit #4) below and noncalcareous shale (unit #5) above.

In summary, the Twowells Tongue of the Dakota Sandstone in Socorro County lies within the upper Cenomanian *Metoicoceras mosbyense* Zone, can be as thick as 90 ft (27 m), and its top lies 15 ft (4.6 m) to 5 ft (1.5 m) below the first occurrence of the abundant oyster *Pycnodonte newberryi*. The Twowells Tongue is not present in the Carthage coal field.

Pike (1947, p. 87) noted explicitly at Carthage that there "…is no large sandstone near the base of marine shale (unit 2) [=Tokay Tongue] which might be correlated with the Tres Hermanos [=Twowells Tongue]." The absence of a mappable (> 5 ft (1.5m) thick), continuous quartzose sandstone at Carthage and elsewhere in the hypothetical outcrop belt of the Tokay Tongue (Fig. 1) precludes use of not only the Twowells Tongue, but also the (overlying) Rio Salado and (underlying) Whitewater Arroyo Tongues of the Mancos Shale as stratigraphic names in the area.

Bridge Creek Limestone Beds (#3)

Stratigraphy—Unit #3, the Bridge Creek Limestone Beds, is the thinnest of the subdivisions of the Tokay Tongue (Table 1). Its 72 ft (22 m) thickness represents 13% of the total thickness of the tongue, whereas its duration of ~1,980 ky represents 52% of that of the entire tongue. Its compacted sedimentation rate of 0.4 inches (1.1 cm)/ky is only 22% of that of the tongue as a whole, primarily because sedimentation occurred in relatively deep, offshore environments as the T-1 shoreline reached maximum transgression (Fig. 1 C). Unit #3 is composed primarily of medium gray, blocky to chippy weathering, highly calcareous shale (77%) with subsidiary amounts of calcarenite (16%), limestone (5%), and bentonite (3%). Using a twofold lithologic division, it is 79% shale and 21% limestone. However, the resistant limestones, which are concentrated at the top and bottom of the unit, form persistent ridges in the shale valley between the hogback formed by the Dakota Sandstone and the high ridge formed by the Atarque Sandstone Member of the Tres Hermanos Formation (Fig. 8B). Both its lower and upper contacts are conformable. Both contacts are resistant limestone against nonresistant shale and are easily picked in the field (Fig. 8A, B, C).

The four thin—generally less than 7 inches (18 cm) thick—bedded to concretionary to nodular limestones in the basal 5 ft (1.5 m) of the Bridge Creek Limestone Beds are distinctive because of their nodular appearance, resistance to weathering, and their golden-brown weathering color. In addition, they contain the most diverse fauna in the tongue with six species of ammonites, two oysters, one clam, one echinoid, one brachiopod, and several gastropods. The straight ammonite *Sciponoceras gracile* is so common in the these basal limestones that they are referred to (informally) as the Scip zone limestones and numbered from #1 at the bottom to #4 at the top (Fig. 8A, B, D). Limestone #1 (CS-174) is concretionary and crops out intermittently in the section; limestone #2 (CS-176) is bedded and persistent; limestone #3 (CS-179) is a dense, black, almost lithographic limestone that pinches and swells (Fig. 8D) and is as much as 13 inches (33 cm) thick; and limestone #4 (CS-181) is concretionary, but generally present. These four limestones contain the prolific *Euomphaloceras septemseriatum* fauna.

Occasional in situ internal molds of the ammonite *Metoicoceras geslinianum* (e.g., D14855 from Scip zone limestone #1) are corroded on the side that is stratigraphically up, but well preserved on the downside. In addition, the corroded side is encrusted by oysters, suggesting that the internal mold represents a hiatus concretion, in which encrustation occurred after the hardened mold was eroded out of the sediment on the seafloor. Hook and Cobban (1981, p. 13) interpret similar oyster-encrusted molds elsewhere in New Mexico as evidence for discontinuity surfaces. The scenario they envision involves burial of the sediment-filled ammonite shell; dissolution of the aragonitic shell resulting in prefossilization of the sediment filling (internal mold); erosion of the sediment surrounding the hardened internal mold; colonization by oysters of the discontinuous hardground provided by the internal mold(s), which would form a lag deposit on the seafloor. However, all four Scip zone limestones contain the *Euomphaloceras septemseriatum fauna*, which indicates that any hiatus, if present, is minor. Hence, no hiatus is shown on Figure 5. A similar situation appears to exist in the Mancos Shale as far north as Mesa Verde National Park, Colorado, where a worn internal mold of *M. geslinianum* is encrusted by oysters (Leckie et al. 1997, fig. 31A).

An eight inch- (20 cm-) thick, white-weathering limestone bed (CS-191) that is 20.5 ft (6.3 m) above the base of the Bridge Creek Limestone Beds (Fig. 8D) contains *Mytiloides puebloensis* (D14702), the inoceramid that is used to define the base of the Turonian in the Western Interior (Fig. 4). This bed is correlated with an 11inch (28 cm-) thick limestone bed at Pueblo, Colorado, which is approximately 300 mi (480 km) northeast of Carthage. The Pueblo limestone, bed 86, also contains the first occurrence of the ammonite *Watinoceras devonense*, the name-bearer for the basal zone of the Turonian Stage (Fig. 5). Bed 86 is the Global Boundary Stratotype Point for the base of the Turonian Stage of the Cretaceous System worldwide (Kennedy et al. 2000, 2005). The occurrence of *M. puebloensis* at Carthage was noted initially in Hook (2009) and marked the first time in New Mexico that the boundary between the Cenomanian and Turonian Stages had been tied to the Global Boundary Stratotype Section and Point for the base of the Turonian Stage. Since then, *M. puebloensis* has been found in New Mexico in the Bridge Creek Limestone Beds of the Tokay Tongue at Bull Gap Canyon, Lincoln County (Hook and Cobban 2013, fig. 2) and in the Jornada del Muerto coal field, Socorro County (unpublished). Figure 1 shows the locations of these two outcrops within the polygon showing the hypothetical area where the Tokay Tongue can be recognized.

Mytiloides hattini (D14729), the oldest Cenomanian inoceramid (Fig. 4) occurs in a 10 inch- (25 cm-) thick limestone, CS-187, 5 ft (1.5 m) below the bed containing *M. puebloensis* (Fig. 8D). A six–inch thick bentonite bed (CS-183) that is 4 ft (1.2 m) below the *M. hattini* bed appears to be bentonite "B" (bed 80) from the Pueblo section (Fig. 5). A two-inch thick bentonite (CS-193) that is 7 inches above the *M. puebloensis* limestone correlates to bentonite "C" (bed 88).

The brown-weathering, thin-bedded, ridge-capping calcarenites at the top of the Bridge Creek Limestone Beds (C-217 and 219) are composed of the comminuted remains of the inoceramid bivalve *Mytiloides mytiloides* (D5782) and contain occasional internal molds of the lower Turonian ammonites *Mammites nodosoides* and *Puebloites greenhornensis* (D5781).

There are 10 discrete bentonite beds in the Bridge Creek Limestone Beds. These 10 ash beds contain an aggregate compacted thickness of 24.5 inches (62.2 cm) and account for almost

3% of the unit's thickness. Two (20%) of the bentonites are at least 4 inches (10 cm) thick, the thickest CS-183, is 6 inches (15 cm) thick. The average frequency of one volcanic eruption every 198 ky (Table 2) is the longest for any of the bed rank units with at least 10 bentonites. Average compacted thickness per ash fall is 2.5 inches (6.4 cm), slightly more than the average for the tongue, but greater than that of the calcareous shale and bentonite unit. Elder's (1988) "B, C, and D" bentonites (CS-183, 193, and 197) occur in the lower half of the unit. According to Elder (1988, p. 837), bentonite B has a source area to the north near the U.S.-Canadian border and C and D have a source area to the west in the Sierra Nevada Batholith.

Fauna and age—The Bridge Creek Limestone Beds are the most fossiliferous portion of the Tokay Tongue. A high diversity molluscan fauna from the four Scip zone limestones dates the base of the unit as late Cenomanian and places it in the *Euomphaloceras septemseriatum* Zone; a low diversity molluscan fauna from the uppermost calcarenites dates the top of the unit as latest early Turonian and places it in the *Mammites nodosoides* Zone. A *Mytiloides hattini* collection (D14729) from a limestone 15.3 ft (4.7 m) above the base is from the latest Cenomanian in the *Nigericeras scotti* Zone; a *Mytiloides puebloensis* collection (D14702) from a limestone 20.4 ft (6.2 m) above the base is earliest Turonian from the *Watinoceras devonense* Zone and establishes the position of the Cenomanian/Turonian boundary at the base of CS-191 (Fig. 4).

Ammonites collected from the four Scip zone limestones at Carthage are:

- *Pseudocalycoceras angolaense* (Spath),
- *Euomphaloceras septemseriatum* (Cragin)
- *Metoicoceras geslinianum* (d'Orbigny),
- *Allocrioceras annulatum* (Shumard),
- *Sciponoceras gracile* (Shumard), and
- *Worthoceras vermiculus* (Shumard).

Other fossils include: the oysters *Pycnodonte newberryi* (Stanton) and *Rhynchostreon levis* (Stephenson); the bivalves *Inoceramus pictus* Sowerby and *Plesiopinna* sp., the echinoid *Mecaster batnensis* (Coquand); the brachiopod *Discinisca* sp., and a few mostly unidentified gastropods that include *Turritella* sp.

Figure 9 shows an unusually dense occurrence of key fossils from Scip zone limestone #3 (D5780) collected from CS-179 at the type section (Fig. 4). The hand specimen is 4.2 inches (10.7 cm) long, 2.9 inches (7.4 cm) wide, and 1.3 inches (3.4 cm) deep. It contains two specimens of the index ammonite *Euomphaloceras septemseriatum*, the larger with a diameter of 4.0 cm; two specimens of *Sciponoceras gracile*, the larger running the entire length of the hand specimen; one specimen of *Allocrioceras annulatum*; and a fragment of the index inoceramid *Inoceramus pictus*.

Burrows are common in the Scip zone limestones. Limestone #2, in particular, is highly burrowed with burrow fillings of many different orientations and sizes. Burrows that are vertical or oblique to bedding are up to 0.5 inches (1.3 cm) in diameter; those that are parallel to bedding can be up to 1.0 inch (2.5 cm) in diameter. All burrows are filled with matrix, but tend to weather a reddish brown.

The most enigmatic sedimentary structures in the basal portion of the Bridge Creek at Carthage are long, cylindrical, often y-shaped limestone "tubes." Figure 8E shows one of the best preserved examples: a 3 inch (8 cm) diameter, y-shaped, cylindrical limestone structure that is developed on, but not in, limestone #3 (CS-179). These tubes are common at the base of the Bridge Creek Limestone Beds at Carthage, but are not developed elsewhere in the outcrop belt of the Tokay Tongue (Fig. 1). They can be several feet long, are orientated parallel to bedding, and bifurcate. They are composed of hard, dense micrite and break into conical segments that litter the ground, often covering the outcrop. Similar structures occur in the shale between the first two Scip zone limestones.

If these cylindrical, y-shaped micrite tubes represent burrows— for example, large *Ophiomorpha* burrows— they would have to have been made by a fairly large animal, perhaps a crab or other crustacean. No crustacean fossils have been found in the basal Bridge Creek Beds at Carthage even though several days were spent looking expressly for crustacean fossils, or fossils of other animals that could have made such large burrows. Based on the absence of crustacean fossils or fossils of other burrowing animals large enough to make a 3 inch-diameter burrow, and the presence of these limestone tubes in the shale above, but not in the limestone, the authors originally concluded that these large, y-shaped, cylindrical tubes were of inorganic origin.

However, the discovery of an echinoid internal mold within what appears to be its burrow (Fig. 8F) in a slab of limestone #3 (C-179) suggests that the these y-shaped limestone structures could be the burrows of the irregular echinoid *Mecaster batnensis*, which is abundant in the Scip zone limestones at Carthage. The interpreted burrow (Fig. 8F) has a diameter that is 2.5 times the width of the echinoid. The largest echinoid collected from the Scip zone limestones at Carthage has a length of 4.16 cm and a width of 4.12 cm. If this ratio of burrow diameter to echinoid width (fig. 8F) holds, then it is possible that the large "tubes" shown in Figure 8E were made by burrowing echinoids. Kier (1987, fig. 18.81) shows three still pictures taken sequentially of a modern spatangoid burrowing into soft sediment on the Caribbean sea floor. *Mecaster*, a member of the Order Spatangoida, was a detritus-feeding animal that lived buried deeply in the sediment and used its long tube feet to maintain its burrow (see Kier, 1987, fig. 18.77). The presence of abundant specimens of *M. batnensis* at Carthage at this stratigraphic level attests to the soft nature of the seafloor at Carthage during deposition of the basal Bridge Creek. The major problem with this burrow interpretation is that an echinoid's burrow would be primarily vertical, rather than horizontal. However, Bernadi et al. (2010, Fig. 4) report echinoid burrows from the Oligocene of Italy that extend for "metric distances" with traces that are"…parallel to the stratification." There is also little reason to think that an echinoid's burrow would bifurcate. In addition, echinoid fossils in the basal part of the Bridge Creek are confined to the four Scip zone limestones; none have been found in the intervening shales.

The uppermost, ridge-forming beds of the Bridge Creek Limestone (CS – 212-222) are composed primarily of thin bedded, yellowish brown-weathering calcarenites and calcilutites composed of the comminuted remains of inoceramid debris (inoceramites). Shell debris and internal molds of *Mytiloides mytiloides* crowd the upper surface of CS-219, a 10 inch- (25 cm-) thick calcarenite that is the major ridge-forming bed. Occasional impressions and fragments of internal molds of *Mammites nodosoides* are also present. These calcarenites are similar lithologically to those from the much younger Juana Lopez Beds of the D-Cross Tongue of the Mancos Shale at SNWR, the Jornada del Muerto coal field, and Lincoln County (Hook et al. 2012 and Hook and Cobban, 2013).

Murphy et al. (2007) document a selachian assemblage dominated by teeth of the shell-crushing shark *Ptychodus* from the top of the Bridge Creek Limestone Beds at Carthage from the type area of the Tokay Tongue. However, Murphy et al.'s (2007, p. 63) assertions that the "… sandy limestone/calcarenite at the top of the Bridge Creek Member [near the town of Carthage] yields numerous shells of the bivalves *Ostrea beloiti* and *Mytiloides mytiloides*" and that "this assemblage falls within the *Sciponoceras gracile* ammonite zone" are incorrect. The oyster *Ostrea beloiti* is known only from rocks of middle and late Cenomanian age, ranging from the *Conlinoceras tarrantense* Zone through the *Dunveganoceras pondi* (=*Calycoceras canitaurinum* on Fig. 5) Zone (Cobban and Hook 1980, p. 170). The clam *Mytiloides mytiloides* occurs in early Turonian rocks in the *Mammites nodosoides* Zone (Cobban 1984b, p. 35). In the type section of the Tokay Tongue (Fig. 4) the last occurrence of *O. beloiti* is in sandy limestone concretions (CS-80) near the top of the shale and sandstone unit, 160 ft (49 m) above the top of the Dakota Sandstone; the first occurrence of *M. mytiloides* is in a calcarenite (CS-219) near the top of the Bridge Creek Limestone Beds, 371 ft (113 m) above the top of

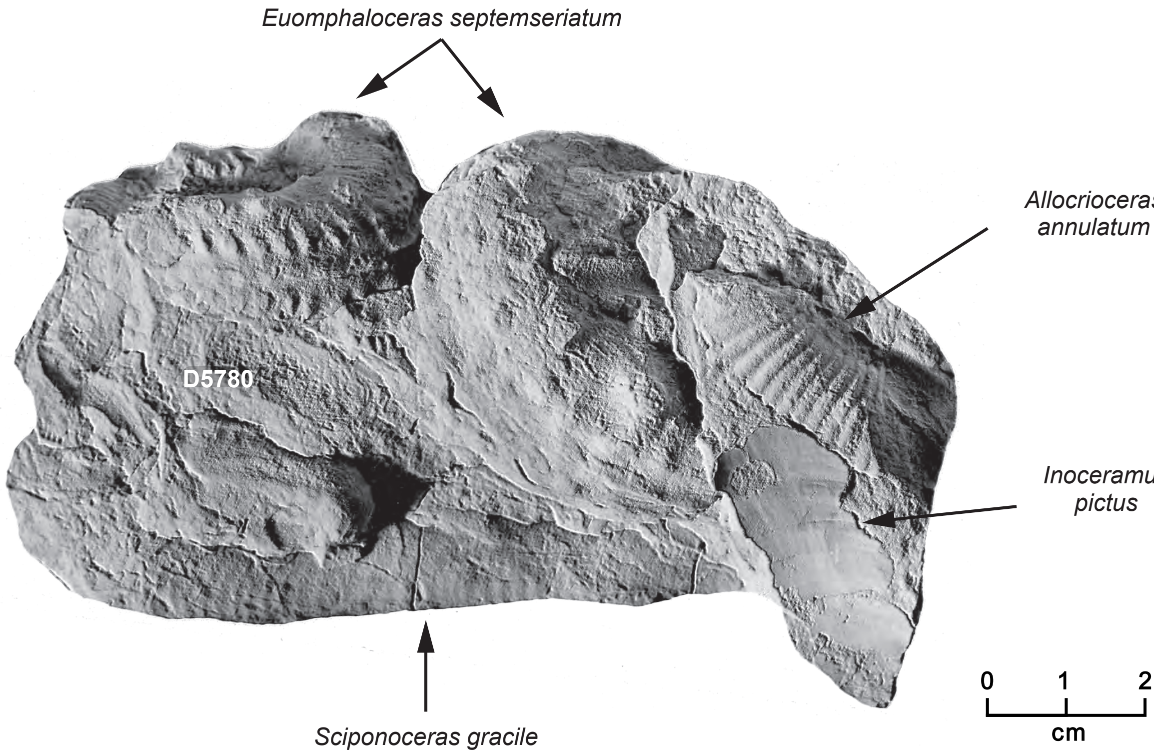


Figure 9—Hand specimen from the basal part of the Bridge Creek Limestone Beds at the type section (USNM #616439). The upper surface of this fragment of CS-179 (Fig. 4) reveals two specimens of the index ammonite *Euomphaloceras septemseriatum*, the larger with a diameter of 4.0 cm; two specimens of *Sciponoceras gracile*, the larger runs the entire length of the hand specimen; one specimen of *Allocrioceras annulatum*; and a fragment of the index inoceramid *Inoceramus pictus*. This dense occurrence of key fossils is from Scip zone limestone #3 near the base of the Bridge Creek Limestone Beds of the Tokay Tongue of the Mancos Shale, USGS Mesozoic Invertebrate Locality D5780. Three specimens of *S. gracile* from this locality are illustrated by Cobban (1990, fig. 1 A-C, L-M, and Q-R).

the Dakota Sandstone. *Sciponoceras gracile* is a late Cenomanian ammonite that does not range into the Turonian (Cobban et al. 1989, pp. 62-64) and, therefore, could not occur with either *M. mytiloides* or *O. beloiti*.

Fossils from the Scip zone limestones place the base of the Bridge Creek Limestone Beds in the upper Cenomanian *Euomphaloceras septemseriatum* Zone; those from the top, in the lower Turonian *Mammites nodosoides* Zone. Therefore, the Bridge Creek Limestone Beds at Carthage were deposited over a span of ~1.98 my, the longest duration of any of the bed-rank units in the Tokay Tongue, and 52% of the entire duration of the tongue. (Table 1).

In terms of the Pueblo reference section (Fig. 5), the 72 ft- (22 m-) thick Bridge Creek Limestone Beds of the Tokay Tongue are the temporal equivalent of approximately the lower 35 ft (11 m) of the 57 ft- (17 m-) thick Bridge Creek Limestone Member of the Greenhorn Limestone. They are also the exact temporal equivalent of the entire 47 ft- (14 m-) thick Bridge Creek Limestone Beds of the Rio Salado Tongue of the Mancos Shale at the Puertecito measure section (Fig. 5).

Calcareous shale unit (#4)

Stratigraphy—Unit #4, the calcareous shale, is in the middle of the five subdivisions of the Tokay Tongue in terms of thickness (Table 1). Its 113 ft (34 m) thickness represents 20% of the total thickness of the tongue, whereas its duration of 170 ky represents less than 5% of that of the entire tongue. Its compacted sedimentation rate of 8.0 inches (20.3 cm)/ky is 4.4 times of that of the tongue as a whole, primarily because sedimentation occurred in relatively shallow, offshore environments as the R-1 shoreline retreated to the northwest across southwest New Mexico (Fig. 1 D). Unit #4 is composed almost entirely of medium gray, blocky to chippy weathering, calcareous shale (99%) that becomes progressively less calcareous upsection. There are also insignificant amounts of bentonite and limestone (in the form of concretions). However, the concretions contain all the fossils. For practical purposes the top of the upper (CS-229) of the two bentonites in the unit marks the top of the unit, with noncalcareous shale above and slightly calcareous shale below (Fig. 8H). Both its lower and upper contacts are conformable. The lower contact is above a resistant calcarenite and is easily picked in the field. The upper contact (Fig. 8C, D) is often covered because it involves two easily eroded units against each other. Occasionally, the upper contact will be visible as a white band in the steep slope under the Tres Hermanos ridge. The lower 70% of the unit is usually at least partially covered and forms an almost flat surface from the calcarenites at the top of the Bridge Creek Limestone Beds to the break in slope beneath the Tres Hermanos ridge (Fig. 8G).

Fauna and age—The calcareous shale unit is sparsely fossiliferous; only the upper 31 ft (9.4 m) contains megafossils. These fossil occurrences are confined to either limestone concretions developed on top of bentonites (CS-227 and CS-230) or to flattened or gypsiferous concretions developed in CS-228, a slightly calcareous shale just below the top of the unit. All five collections (D10129, D10246, and D14707-09) reveal that the upper part of the unit lies in the lower part of the lower Turonian *Collignoniceras woollgari* Zone. The fossils are few in number and low in diversity. They consist of the ammonites *Morrowites depressus* and *C. woollgari woollgari*, and the bivalves *Mytiloides subhercynicus* and *M.* sp. In terms of the Pueblo reference section (Fig. 5), the calcareous shale unit is the temporal equivalent to the upper part, but not the uppermost part, of the Bridge Creek Limestone Member of the Greenhorn Formation.

The calcareous shale unit along with the overlying noncalcareous shale unit and the Atarque Sandstone Member of the Tres Hermanos Formation together are the approximate temporal equivalent of the upper 22 ft (7 m) of the Bridge Creek Limestone Member of Greenhorn Limestone at the Pueblo measured section (Fig. 5). It is approximately the temporal equivalent of the upper calcareous shale unit of the Rio Salado Tongue of the Mancos

Shale at the Puertecito measured section (Fig. 5).

Noncalcareous shale unit (#5)

Stratigraphy—Unit #5, the noncalcareous shale, is 88 ft (27 m) thick, the second thinnest unit in the Tokay Tongue. It is composed almost entirely of medium gray, chippy to blocky weathering, noncalcareous shale (Fig. 8G). It represents 4% of the total thickness of the tongue, whereas its duration of ~160 ky represents less than 5% of that of the entire tongue (Table 1). Its compacted sedimentation rate of 6.6 inches (16.8 cm)/ky is 3.7 times that of the tongue as a whole, primarily because sedimentation occurred in shallowing offshore environments as the R-1 shoreline retreated to the northwest across southwest New Mexico (Fig. 1 D). Unit #5 forms the steep, debris-covered slope beneath the Atarque Sandstone ridge (Fig. 8G). Exposures of shale can be pieced together from rivulets in the slope. The only lithologic deviation from noncalcareous shale in unit 5 is a 3 inch- (7.5 cm-) thick bed of irregularly shaped, unfossiliferous, white limestone concretions (CS-232), 56 ft (17 m) above the base of the unit. No bentonites were observed in unit #5, which was measured with less detail than any of the other four units because of lack of fossils and bentonites. Both its lower and upper contacts are conformable. As a matter of convenience, the lower contact is drawn at CS-229, the 7 inch- (18 cm-) thick bentonite (Fig. 8H) just below the top of the calcareous shale unit. The upper contact is sharp to slightly gradational with the overlying Atarque Sandstone Member of the Tres Hermanos Formation (Fig. 8G).

Fauna and age—No fossils have been collected from the noncalcareous shale unit in the Carthage coal field. Therefore, unit #5 has to be dated indirectly using fossils from the underlying and overlying units. Both the top of the underlying calcareous shale unit (Fig. 4, D10129) and the base of the overlying Atarque Sandstone Member of the Tres Hermanos Formation (Fig. 4, D10241) lie in the basal middle Turonian *Collignoniceras woollgari woollgari* Subzone.

The change from calcareous shale below to noncalcareous shale above is interpreted to represent a change in the chemistry of the seawater caused by the influx of more fresh water into the depositional system because of the encroaching (regressing) shoreline (Fig. 1E). This contact, which is diachronous, has been verified at outcrops of the Rio Salado Tongue at Puertecito, and at outcrops of the Tokay Tongue at the Jornada del Muerto coal field, the Carthage coal field, and Mescal Canyon east of Truth or Consequences.

In terms of the principal reference section of the Graneros Shale and Greenhorn Limestone at Pueblo, Colorado (Fig. 5), the noncalcareous shale unit (#5) of the Tokay Tongue is the temporal equivalent of the upper, but not uppermost part of the Bridge Creek Limestone Member of the Greenhorn Limestone, which extends through the *Collignoniceras woollgari woollgari* Subzone. It is approximately the temporal equivalent of the noncalcareous shale unit of the Rio Salado Tongue of the Mancos Shale at the Puertecito measured section (Fig. 5).

The noncalcareous shale unit along with the underlying calcareous shale unit and the overlying Atarque Sandstone Member of the Tres Hermanos Formation together are the approximate temporal equivalent of the upper 22 ft (7 m) of the Bridge Creek Limestone Member of Greenhorn Limestone at the Pueblo measured section (Fig. 5).]

Conclusions

After more than 100 years of geologic investigation into the stratigraphy and paleontology of the lowermost marine shale in the Carthage coal field, the following conclusions can be drawn (with the original citation in parentheses):

1) The lower shale unit is at least 500 ft thick (Gardner 1910);
2) The lower shale is part of the Mancos Shale (Lee 1916);
3) The lower shale contains fossils that are Graneros and Greenhorn equivalents (Darton 1928);
4) The lower shale contains temporal and physical equivalents of the Graneros Shale and Greenhorn Limestone of Great Plains usage (Rankin 1944);
5) The limestone beds near the middle of the lower shale are equivalent to only a portion of the upper member of the Greenhorn Formation, not the entire formation (Hook et al. 1983); and
6) The lower shale ranges in age from late middle Cenomanian to early middle Turonian (Cobban and Hook 1979).

For many years this shale body between the Dakota Sandstone and Tres Hermanos Formation at Carthage and elsewhere in southern New Mexico was known informally as the lower tongue (or part) of the Mancos Shale. However, this same informal designation was used for a thinner tongue of Mancos, temporally equivalent to only the lower part of the Tokay Tongue (Fig. 2), between the main body of the Dakota Sandstone and the Twowells Tongue of the Dakota Sandstone in northwest Socorro County (Hook et al. 1983, chart 1). This informal usage for rocks of differing thicknesses, differing boundaries, and differing temporal equivalencies led to confusion and to the misapplication of the name "Rio Salado Tongue of the Mancos Shale" to the entire lower shale at Carthage. The lower tongue of the Mancos Shale at Carthage is herein named the Tokay Tongue of the Mancos Shale. The detailed description of type section of the Tokay Tongue at Carthage, presented above, should eliminate this confusion, while at the same time presenting geographic, paleogeographic, paleontologic, lithostratigraphic, and biostratigraphic limits on its usage.

In addition this detailed analysis: 1) locates the lithostratigraphic and biostratigraphic position of the Cenomanian and Turonian stage boundary within the Tokay Tongue and ties it to the global boundary stratotype and point at Pueblo, Colorado; 2) identifies with biostratigraphic precision the "x" bentonite, which is widespread in the Western Interior; 3) shows that the Tokay Tongue at any locality ranges in age from middle to late Cenomanian at its base and from latest early Turonian to early middle Turonian at its top; 4) shows that over its lateral extent both the base and top of the Tokay Tongue are diachronous, with the age of the base of the section rising to the southwest (landward) and the age of the top rising to the northeast (seaward); and 5) shows that the late Cenomanian was a time of extensive volcanic activity in the southern portion of the Western Interior.

Acknowledgments

We thank the U.S. Geological Survey for use of facilities and access to fossil collections stored at their repository in Denver, Colorado. We continue to owe a special debt of gratitude to K. C. McKinney, U. S. Geological Survey, Denver, for his friendship and expertise, without which this paper would not have been possible. He took the photograph of the hand specimen used as Figure 9. He also sponsored Hook as an adjunct at the U.S. Geological Survey working on the Upper Cretaceous stratigraphy and paleontology of New Mexico.

We thank Don and Lila Swearinger and Dewy and Linda Brown, San Antonio, New Mexico, for access to their private land. Primary field support for this study was provided by Atarque Geologic Consulting, LLC. Early field support (prior to 2002) was provided by the New Mexico Bureau of Mines and Mineral Resources under the direction of Dr. Frank Kottlowski. Fossil collections have been assigned U.S. Geological Survey Mesozoic locality numbers; they begin with the prefix "D" for Denver and are housed at the Federal Center in Denver, Colorado. Illustrated specimens have been assigned USNM numbers and are reposited in the U.S. National Museum in Washington, D.C.

Bruce A. Black (Black Oil) and Greg Mack (New Mexico State University) reviewed the manuscript and made many helpful suggestions, which we appreciate greatly.

References

Anderson, O. J., 1987, Geology and coal resources of Atarque Lake 1:50,00 quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 61.

Anderson, O. J., and Osburn, J. C., 1983, Geologic map and cross section of Cretaceous rocks along and south of U.S. 380 in the vicinity of Carthage, New Mexico; in Chapin, C. E., and Callender, J. F., (eds.), Socorro region II: New Mexico Geological Society, Guidebook 34, fig. I-60.55, p. 24.

Ball, B. A., Cobban, W. A., Merewether, E. I. A., Grauch, R. I., McKinney, K. C., and Livo, K. E., 2009, Fossils, lithologies, and geophysical logs of the Mancos Shale from core hole USGS CL-1 in Montrose County, Colorado: U.S. Geological Survey, Open-File Report 2009-1294, 38 pp.

Bernadi, M., Boschele, S., Ferretti, P. , and Avanzini, M., 2010, Echinoid burrow *Bichordites monastiriensis* from the Oligocene of NE Italy: Acta Palaeontologica Polonica, v. 55, no. 3, pp. 479–486.

Budding, A. J., 1963, Field trip 7, Carthage area: New Mexico Geological Society, Guidebook 14, pp. 74–77.

Chapin, C. E.; Osburn, G. R.; Hook, S. C.; Massingill, G. L.; Frost, S. J., 1979, Final report; Coal, uranium, oil and gas potential of the Riley-Puertecito Area, Socorro County, New Mexico, New Mexico Bureau Mines Mineral Resources, Open-file Report, v. 0103, pp. 1–33.

Cobban, W. A., 1977, Characteristic marine molluscan fossils from the Dakota Sandstone and intertongued Mancos shale, west-central New Mexico: U.S. Geological Survey, Professional Paper 1009, 30 pp.

Cobban, W. A., 1984a, Mid-Cretaceous ammonite zones Western Interior, United States: Geologic Society of Denmark, Bulletin 33, pp. 71–89.

Cobban, W. A., 1984b, The Upper Cretaceous guide fossil, *Mytiloides mytiloides* (Mantell), in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Annual Report, July 1, 1982 to June 30, 1983, pp. 35–36.

Cobban, W. A., 1987, The Upper Cretaceous (Cenomanian) ammonites *Metengonoceras dumbli* (Cragin) and M. acutum Hyatt: U.S. Geological Survey, Bulletin 1690-C, 16 pp.

Cobban, W. A., 1990, *Sciponocerus gracile* (Shumard) Common Upper Cretaceous guide fossil in New Mexico: New Mexico Geology, v. 12, no. 4, pp. 90–91.

Cobban, W. A., and Hook, S. C., 1979, *Collignoniceras woollgari woollgari* (Mantell) ammonite fauna from Upper Cretaceous of Western Interior, United States: New Mexico Bureau of Mines and Mineral Resources, Memoir 37, 51 pp.

Cobban, W. A., and Hook, S. C., 1980, Occurrence of *Ostrea beloiti* Logan in Cenomanian rocks of Trans-Pecos Texas; in Dickerson, P. W., Hoffer, J. M., and Callender, J. F. (eds.), Trans-Pecos region (west Texas): New Mexico Geological Society, Guidebook 31, pp. 169–172.

Cobban, W. A. and Hook, S. C., 1989, Mid-Cretaceous molluscan record from west-central New Mexico: New Mexico Geological Society, Guidebook 40, pp. 247–264.

Cobban, W. A., and Reeside, J. B., Jr., 1952, Correlation of the Cretaceous formations of the Western Interior of the United States: Geological Society of America, v. 63, no. 10, pp. 1011–1043.

Cobban, W. A., and Scott, G. R., 1972 [1973], Stratigraphy and ammonite fauna of the Graneros Shale and Greenhorn Limestone near Pueblo, Colorado: U.S. Geological Survey, Professional Paper 645, 108 pp.

Cobban, W. A., Hook, S. C., and Kennedy, W. J., 1989, Upper Cretaceous rocks and ammonite faunas of southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 45, 137 pp.

Cobban, W. A., Walaszczyk, I., Obradovich, J. D., and McKinney, K. C., 2006, A USGS zonal table for the Upper Cretaceous middle Cenomanian-Maastrichtian of the Western Interior of the United States based on ammonites, inoceramids, and radiometric ages: U.S. Geological Survey Open-File Report 2006-1250, 46 pp.

Dane, C. H. and Bachman, G. O., 1965, Geologic map of New Mexico: scale 1:500,000.

Darton, N. H., 1928, “Red beds” and associated formations in New Mexico: U.S. Geological Survey, Bulletin 794, 356 pp.

Elder, W. P., 1988, Geometry of Upper Cretaceous bentonite beds: Implications about volcanic source area and paleowind patterns, western interior, United States: Geology, v. 16, pp. 835–838.

Elder, W. P., 1989, Molluscan extinction patterns across the Cenomanian-Turonian Stage boundary in the Western Interior of the United States: Paleobiology, v. 15, pp. 299–320.

Gardner, J. H., 1910, The Carthage coal field, New Mexico: U.S. Geological Survey, Bulletin 381, pp. 452–460.

Hook, S. C., 1983, Stratigraphy, paleontology, depositional framework, and nomenclature of marine Upper Cretaceous rocks, Socorro County, New Mexico, in Chapin, C. E., and Callender, J.F., (eds.), Socorro region II: New Mexico Geological Society, Guidebook, 34, p. 165–172.

Hook, S. C., 1984, Evolution of stratigraphic nomenclature of the Upper Cretaceous of Socorro County, New Mexico: New Mexico Geology, v. 6, pp. 28–33.

Hook, S. C., 2009, Bentonites and boundaries in the lower tongue of the Mancos Shale, Carthage coal field, Socorro County, New Mexico; in Lueth, V. W., Lucas, S. G., and Chamberlin, R. M., (eds.), Geology of the Chupadera Mesa: New Mexico Geological Society, Guidebook 60, p. 23–26.

Hook, S. C., and Cobban, W. A., 1981, Late Greenhorn (mid-Cretaceous) discontinuity surfaces, southwest New Mexico; in Hook, S. C. (comp.), Contributions to mid-Cretaceous paleontology and stratigraphy of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 180, pp. 5-21.

Hook, S. C., and Cobban, W. A., 2007, A condensed middle Cenomanian succession in the Dakota Sandstone (Upper Cretaceous), Sevilletta National Wildlife Refuge, Socorro County, New Mexico: New Mexico Geology, v. 29, n. 3, pp. 75–96.

Hook, S. C., and Cobban, W. A., 2013, Middle Turonian (Late Cretaceous)rudistids from the lower tongue of the Mancos Shale, Lincoln County, New Mexico: New Mexico Geology, v. 35, n. 1, pp. 13–20.

Hook, S. C., Mack, G. H., and Cobban, W. A., 2012, Upper Cretaceous stratigraphy and biostratigraphy of south-central New Mexico; in Lucas, S. G., McLemore, V. T., Lueth, V. W., Spielmann, J. A., and Kraimer, K. (eds.), Geology of Warm Springs region: New Mexico Geological Society, Guidebook 63, pp. 121–137.

Hook, S. C., Molenaar, C. M., and Cobban, W. A., 1983, Stratigraphy and revision of nomenclature of upper Cenomanian to Turonian (Upper Cretaceous) rocks of west-central New Mexico; *in* Hook, S. C. (comp.), Contributions to mid-Cretaceous paleontology and stratigraphy of New Mexico—part II: New Mexico Bureau of Mines and Mineral Resources Circular 185, pp. 7–28.

Kauffman, E. G., 1965, Middle and late Turonian oysters of the *Lopha lugubris* group: Smithsonian Miscellaneous Collections, v. 148, no. 6, 92 pp.

Kennedy, W. J. and Cobban, W. A., 1990, Cenomanian ammonite faunas from the Woodbine Formation and lower part of the Eagle Ford Group, Texas: Palaeontology, v. 33, pt. 1, pp. 75–144.

Kennedy, W. J., Walaszczyk, I., and Cobban, W. A., 2000, Pueblo, Colorado, USA, candidate Global Boundary Stratotype Section and Point for the base of the Turonian Stage of the Cretaceous, and for the base of the Middle Turonian Substage, with a revision of the Inoceramidae (Bivalvia): Acta Geologica Polonica, v. 50, no. 3, p. 295–334.

Kennedy, W. J., Walaszczyk, I., and Cobban, W. A., 2005, The Global Boundary Stratotype Section and Point for the base of the Turonian Stage of the Cretaceous, Pueblo, Colorado, U.S.A: Episodes, v. 28, no. 2, p. 93–104.

Kier, P. M., 1987, Class Echinoidea; in Boardman, R. S., Cheetham, A. H., and Rowell, A. J. (eds.), Fossil Invertebrates: Blackwell Scientific Publications, Palo Alto, CA, pp. 596–611.

Landis, E. R., Dane, C. H., and Cobban, W. A., 1973, Stratigraphic terminology of the Dakota Sandstone and Mancos Shale, west-central New Mexico: U.S. Geological Survey, Bulletin 1372-J, 44 pp.

Leckie, R. M., Kirkland, J. I., and Elder, W. P., 1997, Stratigraphic framework and correlation of a principal reference section of the Mancos Shale (Upper Cretaceous), Mesa Verde, Colorado: New Mexico Geological Society Guidebook, 48, Mesozoic Geology and Paleontology of the Four Corners Region, pp. 163–216.

Le Conte, J. L., 1868, Cretaceous coals in New Mexico: American Journal of Science, 2d series, v. 45, pp. 136.

Lee, W. T., 1916, Relation of the Cretaceous Formations to the Rocky Mountains in Colorado and New Mexico: U.S. Geological Survey, Professional Paper 95-C, pp. 27–58.

Lucas, S. G. and Spielmann, J. A., 2009, Low diversity Selachian assemblage from the Upper Cretaceous Greenhorn Limestone, Socorro County, New Mexico; in Lueth, V. W., Lucas, S. G., and Chamberlin, R. M., (eds.), Geology of the Chupadera Mesa: New Mexico Geological Society, Guidebook 60, pp. 311–314.

Lucas, S. G., Estep, J. W., Boucher, L. D., and Anderson, B. G., 2000, Cretaceous stratigraphy, biostratigraphy and depositional environments near Virden, Hildago County, New Mexico, in Lucas S. G. (ed.), New Mexico's fossil record 2: New Mexico Museum of Natural History and Science Bulletin 16, pp. 107–119.

Lucas, S. G., Kues, B. S., Hayden, S. N., Allen, B. D., Kietzke, K. K.,

Williamson, T. E., Sealy, P., and Pence, R., 1988, Cretaceous stratigraphy and biostratigraphy, Cooke's Range, Luna County, New Mexico: New Mexico Geological Society, Guidebook 39, pp. 143–167.
Molenaar, C. M., 1974, Correlation of the Gallup Sandstone and associated formations, Upper Cretaceous, eastern San Juan and Acoma Basins, New Mexico: New Mexico Geological Society, Guidebook 25, pp. 251–258.
Molenaar, C. M., 1983, Major depositional cycles and regional correlations of Upper Cretaceous rocks, southern Colorado Plateau and adjacent areas, in Reynolds, M. W., and Dolly, E. D. (eds.); Mesozoic paleogeography of west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, pp. 201–224.
Murphy, J. W., Lucas, S. G., and Spielmann, J. A., 2007, Upper Cenomanian selachian assemblage from the Bridge Creek Member of the Mancos Shale, Socorro County, New Mexico: New Mexico Geology, v. 29, no. 2, p. 63 (abs.)
Obradovich, J. D. and Cobban, W. A., 1975, A time-scale for the Late Cretaceous of the Western Interior of North America: The Geological Association of Canada, Special Paper 13, pp. 31–54.
Owen, D. E., 1966, Nomenclature of Dakota Sandstone (Cretaceous) in San Juan Basin, New Mexico and Colorado: American Association of Petroleum Geologists Bulletin, v. 50, pp. 1023–1028.
Owen, D. E., 1982, Correlation and paleoenvironments of the Jackpile sandstone (Upper Jurassic) and intertongued Dakota Sandstone-lower Mancos Shale (Upper Cretaceous) in west-central New Mexico: New Mexico Geological Society, Guidebook 33, pp. 267–270.
Pike, W. S., 1947, Intertonguing marine and nonmarine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: Geological Society of America, Memoir 24, 103 pp.
Rankin, C. H., 1944, Stratigraphy of the Colorado Group, Upper Cretaceous, in northern New Mexico: New Mexico School of Mines, Bureau of Mines and Mineral Resources, Bulletin 20, 30 pp.
Wilpolt, R. H., and Wanek, G., 1951, Geology of the region from Socorro and San Antonio east to Chupadera Mesa, Socorro County, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Map 121.