Cretaceous stratigraphy and paleontology in the Dry Cimarron Valley, New Mexico, Colorado, and Oklahoma

Barry S. Kues and Spencer G. Lucas

1987, pp. 167-198. https://doi.org/10.56577/FFC-38.167

in:

Northeastern New Mexico, Lucas, S. G.; Hunt, A. P.; [eds.], New Mexico Geological Society 38 th Annual Fall Field Conference Guidebook, 354 p. https://doi.org/10.56577/FFC-38

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

CRETACEOUS STRATIGRAPHY AND PALEONTOLOGY IN THE DRY CIMARRON VALLEY, NEW MEXICO, COLORADO AND OKLAHOMA

BARRY S. KUES and SPENCER G. LUCAS
Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131

Abstract—Cretaceous strata exposed in the Dry Cimarron Valley of Union County, New Mexico, Baca County, Colorado and Cimarron County, Oklahoma pertain to the following units (in ascending order): Lytle Sandstone, Glencairn Formation, Dakota Group (Mesa Rica Sandstone, Pajarito Formation and Romeroville Sandstone), Graneros Shale and Greenhorn Formation. The Lytle Sandstone is as much as 20 m of crossbedded sandstone, siltstone and conglomeratic sandstone of middle-late Albian age that disconformably overlies the Jurassic Morrison Formation. The Glencairn Formation consists of up to 22 m of predominantly marine, generally fossiliferous sandstone, shale, mudstone and siltstone that overlies the Lytle with erosional disconformity. A distinctive, massive, thin, bioturbated sandstone at the base of the Glencairn is here named the Long Canyon Sandstone Bed. The upper part of the Glencairn is a regressive sequence of nonmarine siltstone and sandstone locally containing plant fossils. The term Mesa Rica Sandstone is extended from east-central New Mexico for the basal, cliff-forming, crossbedded sandstone unit of the Dakota Group that overlies the Glencairn with erosional disconformity. The Mesa Rica attains a maximum thickness of 33 m, contains conglomeratic lenses locally and forms most of the caprock of the canyons carved by the Dry Cimarron and its tributaries. The overlying Pajarito Formation (a term also extended from east-central New Mexico) consists of as much as 20 m of interbedded sandstone, siltstone and shale, with concentrations of plant debris and lignite locally, and sparse dinosaur tracks. Its age appears to be latest Albian. The Romeroville Sandstone (new name) represents the upper unit of the Dakota Group, conformably overlies the Pajarito in most areas and reaches a maximum thickness of 8 m. The Romeroville is a transgressive, gray to orange quartzarenite that conformably underlies the Cenomanian marine Graneros Shale. The uppermost Cretaceous unit in the Dry Cimarron area is the Greenhorn Formation, of Cenomanian-Turonian age.

The late Albian Glencairn Formation in the Dry Cimarron area contains a moderately diverse (about 50 reported species), bivalve-dominated marine invertebrate fauna that shares 66 to 71% of its taxa with contemporaneous faunas in the Kiowa Formation of south-central Kansas and the Tucumcari Shale of east-central New Mexico. The bivalve *Texigryphaea* dominates this fauna, representing probably more than 90% of the biomass of shelled invertebrates that existed in the Glencairn sea. *Texigryphaea tucumcarii*, the common Late Albian species in the Tucumcari Shale, is by far the most abundant form in the Dry Cimarron Glencairn, but small numbers of texigryphaeas assigned to *T.* aff. *T. pitcheri* and *T.* cf. *T. washitaensis* are also present. These taxa rested upon substrates of different firmness and exhibited morphologic variability. The presence of the ammonoid *Eopachydiscus marcianus* indicates general correlation of the Glencairn with the Duck Creek Formation of Texas and part of the Kiowa Formation of Kansas, as suggested by previous workers.

The Glencairn through Pajarito formations were deposited during transgressive and regressive phases of the Kiowa-Skull Creek eustatic cycle; the Romeroville Sandstone marks the onset of the transgressive phase of the Greenhorn cycle. The Glencairn fauna lived in shoreface to offshore marine environments. A partial barrier, in the form of an eastward extending shoal or peninsula possibly associated with a rejuvenated Bravo Dome, separated marine Glencairn faunas from those of the Tucumcari basin to the south, but did not significantly hinder faunal interchange between the two areas. Regionally, faunal diversity declines abruptly a short distance north of the Dry Cimarron area, probably mainly because of lowered salinity in the seaway; only a few taxa are known from Glencairn-equivalent units in central and northern Colorado.

INTRODUCTION

The valley of the Dry Cimarron River is a canyon that extends 120 km from just east of Folsom, Union County, New Mexico, to north of Boise City, Cimarron County, Oklahoma. Along this canyon are exposed Triassic, Jurassic and Cretaceous strata normally not available for study in this region due to the covered surfaces of the High Plains north and south of the Dry Cimarron.

The Cretaceous strata exposed in the Dry Cimarron Valley (Fig. 1) were first examined by Lee (1902), and have been studied subsequently by several workers. Despite these studies, many lithostratigraphic and biostratigraphic problems have plagued these strata. Our goal here is to resolve most of these problems by reviewing in detail the lithostratigraphy, biostratigraphy and paleontology of the Cretaceous strata exposed along the Dry Cimarron. Throughout this paper, UNM refers to the Department of Geology, University of New Mexico.

STRATIGRAPHY

Introduction

Seven Cretaceous rock-stratigraphic units of formational rank are exposed in the Dry Cimarron Valley. They are: Lytle Sandstone (oldest), Glencairn Formation, Mesa Rica Sandstone, Pajarito Formation, Romeroville Sandstone (the last three make up the Dakota Group), Gra-

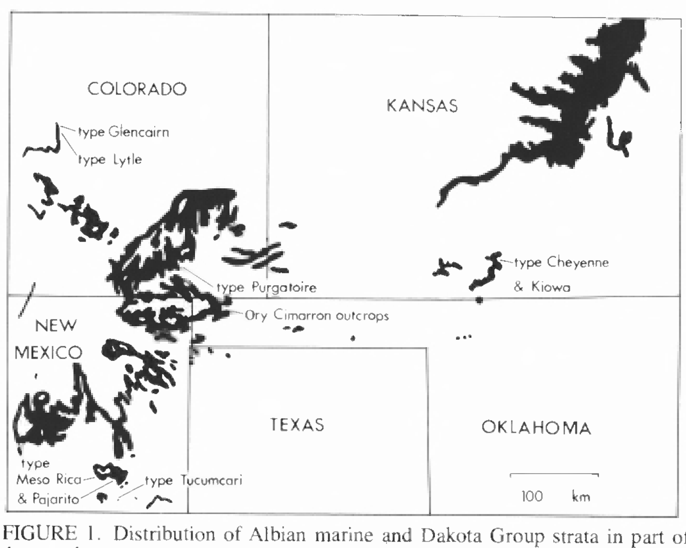


FIGURE 1. Distribution of Albian marine and Dakota Group strata in part of the Southern High Plains of the southwestern United States (after King and Beikman, 1974). The Dry Cimarron outcrops are indicated, as are the type areas of the Cheyenne Sandstone, Lytle Sandstone, Glencairn Shale, Kiowa Shale, Mesa Rica Sandstone, Pajarito Shale and Purgatoire Formation.

neros Shale and Greenhorn Formation. Here we summarize previous studies of these units and review their lithostratigraphy. This review is based on eight stratigraphic sections measured by us and on 37 sections measured by previous workers (Fig. 2).

Previous studies

Lee (1902) presented the first detailed observations on Cretaceous strata in the Dry Cimarron Valley in his effort to document the extent of the Morrison Formation in southeastern Colorado and northeastern New Mexico (also see Lee, 1901). In stratigraphic sections from near Long Canyon to near the old site of Exter, Lee (1902, figs. 3, 5) identified the Dakota Sandstone above a thick, "shale"-dominated sequence that he assigned to the Morrison Formation (Fig. 3). Lee's (1902) Morrison Formation in the Dry Cimarron Valley clearly included all the strata between the Dakota and Triassic red beds except at those locales where Lee's (1902) Exeter Sandstone was present between the Morrison and the Triassic. Lee's (1902) belief that what he termed Morrison Formation in the Dry Cimarron Valley is Cretaceous was bolstered by his discovery (Lee, 1903, 1904) of characteristic Lower Cretaceous fossils (*Gryphaea corrugata,* according to Stanton, 1905) in the "Morrison" near Garrett, Cimarron County, Oklahoma. However, it is clear from Lee's (1902, figs. 3, 5) stratigraphic sections that he included strata now termed Glencairn (and Lytle), which have a Cretaceous marine invertebrate fauna dominated by gryphaeids, in the Morrison.

Indeed, Stanton (1905) resolved the correlation problem created by Lee's work. Thus, Stanton (1905, p. 664) documented an Early Cretaceous invertebrate fauna near Garrett in 50 to 60 ft of "dark shales with layers of brown flaggy sandstone and bands of somewhat calcareous yellow sandstone" below the Dakota Sandstone. Stanton noted that he could trace these strata on strike westward up the Dry Cimarron Valley to Folsom and referred to them as "Comanche," emphasizing that "the Comanche throughout this paper is used as a general term of correlation—not as a formation" (Stanton, 1905, p. 667). Stanton (1905, p. 664) further recognized 50 to 60 ft of "coarse sandstone" below the "Comanche" of the Dry Cimarron, and assigned the "variegated shales, gray sandstones and bands of siliceous limestone" below the sandstone to the Morrison (Fig. 3).

Whereas Lee (1902) had inappropriately extended upward the usage of the Morrison Formation, usually considered Upper Jurassic, the next stratigraphic examination of the Cretaceous in the Dry Cimarron Valley, by Rothrock (1925), inappropriately extended downward the use of Purgatoire Formation (of Stose, 1912), a Lower Cretaceous stratigraphic unit. Below the Dakota Sandstone in Cimarron County, Oklahoma, Rothrock (1925) assigned all the exposed bedrock to the Purgatoire Formation except the lowest exposed strata, variegated "shales" he identified as Morrison Formation (Fig. 3).

DeFord (1927), however, soon pointed out Rothrock's error. He outlined a Cretaceous section in Cimarron County, Oklahoma consisting of three stratigraphic units—Benton shales and limestones, Dakota Sandstone and Purgatoire Formation (upper "black fossiliferous shales about 30 feet thick" and lower "white sandstone 15 to 50 feet thick")—disconformably overlying the Morrison Formation (Fig. 3).

Bullard (1928) in Oklahoma and Darton (1928) in New Mexico essentially followed DeFord's (1927) stratigraphy although neither examined the Upper Cretaceous strata DeFord termed Benton (Fig. 3).

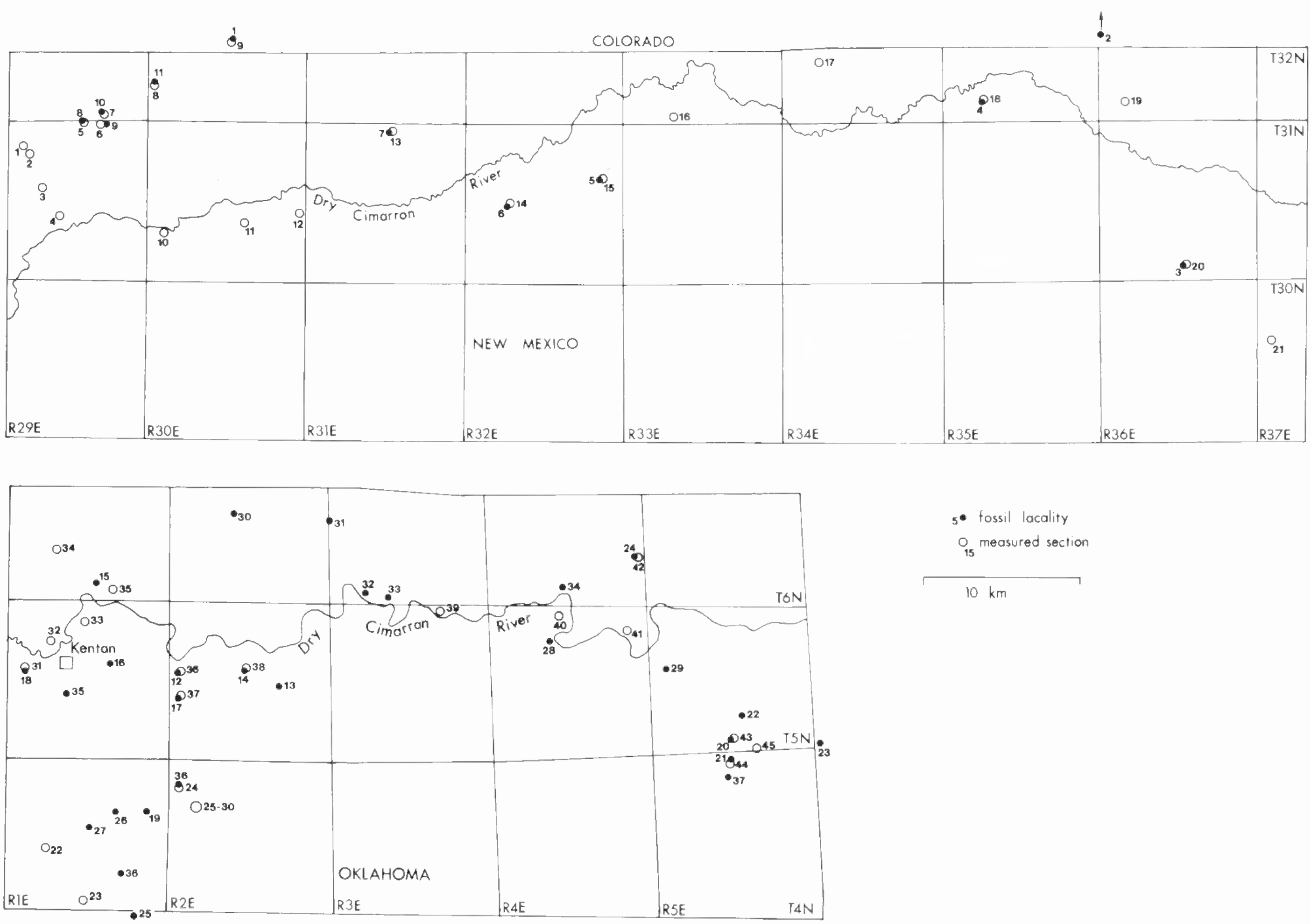


FIGURE 2. Control points (fossil localities and measured stratigraphic sections) in Cretaceous strata exposed in the Dry Cimarron Valley. See Appendices 1 and 2 for precise locations of control points.

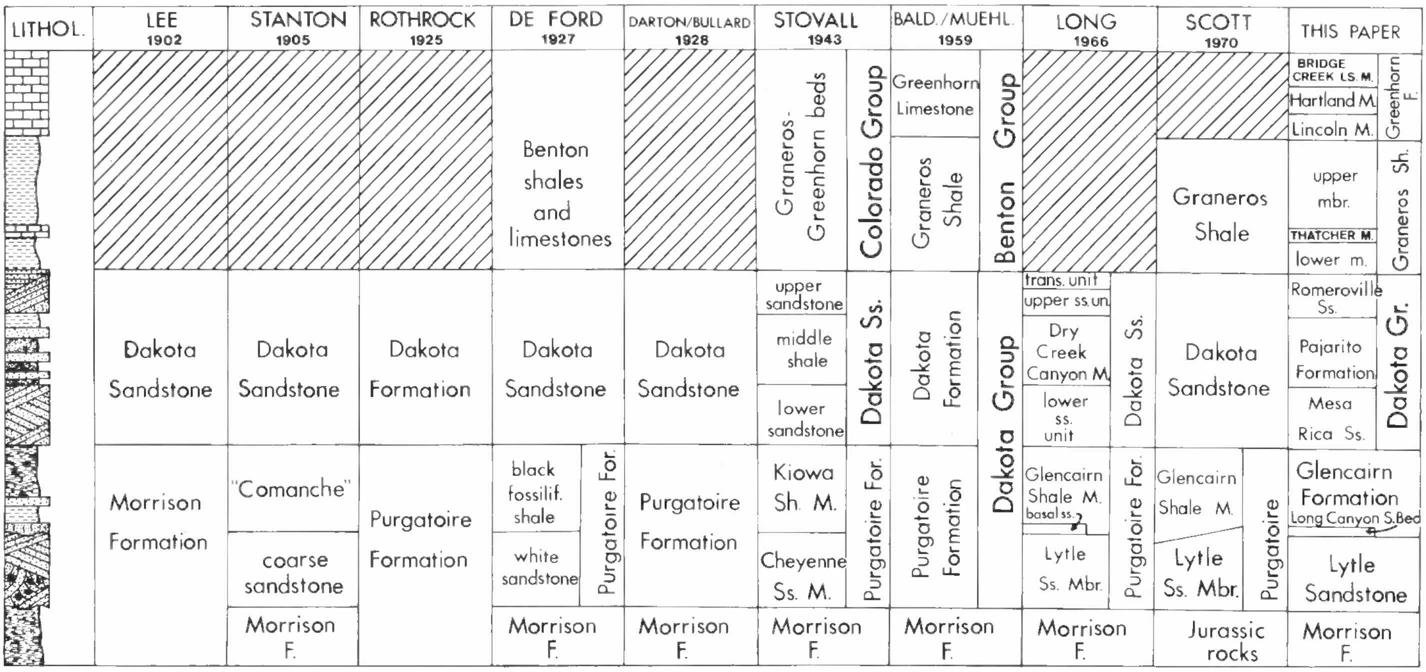


FIGURE 3. Stratigraphic nomenclature of Cretaceous rocks in the Dry Cimarron Valley used by previous workers compared with the nomenclature advocated in this paper.

However, it is worth noting that Darton (1928) made a mistake similar to that made by Rothrock (1925). In the structurally complex area around Wedding Cake Butte, Darton (1928) mistook the variegated, Upper Triassic strata beneath the Entrada Sandstone (= Exeter Sandstone of Lee, 1902: Lucas et al., 1985) for the Morrison Formation, much as Rothrock (1925) mistook the same strata in Oklahoma. (These strata are Upper Triassic Sloan Canyon Formation: Parker, 1933; Stovall and Savage, 1939).

None of the early workers who applied the term Purgatoire to Cretaceous strata in the Dry Cimarron Valley attempted formal subdivision of the Purgatoire, even though Finlay (1916) had already proposed the terms Lytle and Glencairn in Colorado. Formal subdivision of the Purgatoire and a more refined stratigraphy of the Cretaceous in the Dry Cimarron Valley were first presented by Stovall (1943). Earlier, Stovall (1938, p. 587) used Cragin's (1889, 1894a) terms Kiowa and Cheyenne for upper and lower divisions, respectively, of the Purgatoire Formation in Cimarron County, Oklahoma. Stovall (1943) continued this usage (Fig. 3), and quoted a letter by S. L. Schoff regarding this nomenclature:

> The Committee [U.S. Geological Survey Committee on Geologic Names] pointed out that "Purgatoire" has been recognized as a formation for Colorado and Cimarron County, Oklahoma, and perhaps some other places, but has not been extended to Kansas; and that the Kiowa and Cheyenne are *formation* names in Kansas, and have not been extended to Cimarron County, Oklahoma. In view of the forthcoming Cimarron County report [Oklahoma Geological Survey, Bulletin 64], the Committee agreed to extend the Kiowa and Cheyenne into Cimarron County, Oklahoma, as members of the Purgatoire formation—but not into Colorado or New Mexico . . . (Stovall, 1943, p. 74).

Above the Purgatoire, Stovall (1943) recognized a tripartite Dakota Sandstone consisting of lower and upper sandstones divided by a "middle shale" (Fig. 3). The youngest Cretaceous strata were assigned by Stovall (1943) to the Colorado Group and also referred to as the "Graneros-Greenhorn Beds" (Fig. 3).

Baldwin and Muehlberger (1959), working in Union County, New Mexico, presented a somewhat less refined nomenclature of Cretaceous strata in the Dry Cimarron Valley than did Stovall (Fig. 3). However, although Baldwin and Muehlberger (1959) did not subdivide either their Purgatoire or Dakota formations, it is clear from their stratigraphic sections and text that they were aware of essentially the same stratigraphic subdivisions of these units that Stovall (1943) delineated. Unlike Stovall (1943), Baldwin and Muehlberger (1959) distinguished the Graneros Shale from the Greenhorn Limestone (Fig. 3).

Long's (1966) study of the basal Cretaceous strata of southeastern Colorado encompassed two stratigraphic sections in southeasternmost Colorado tributaries of the Dry Cimarron Valley. Long (1966, pp. 14–15) pointed out that there are four alternative nomenclatures for these strata:

> (1) the first named Dakota Sandstone, Kiowa Shale, Cheyenne Sandstone terminology of southern Kansas; (2) the later, locally named Dakota Sandstone and Purgatoire Formations, with the Glencairn and Lytle Members; (3) the combined usage of Dakota Sandstone, Purgatoire Formation with the Kansas terms, Kiowa and Cheyenne as members; and (4) Waagé's [1955, 1961] Dakota Group, containing the South Platte and Lytle Formations.

Long (1966) opted for the second alternative (Fig. 3), although with reservations, particularly about subsuming the Lytle and Glencairn in the Purgatoire Formation.

Scott (1970b) also recognized the Glencairn and Lytle as members of the Purgatoire Formation in the Dry Cimarron Valley (Fig. 3). Noting lithologic differences between the Kansas Kiowa and the Colorado Glencairn, as well as the lack of physical continuity of the Kansas Cheyenne and Colorado Lytle, Scott (1970b, p. 1232) recommended that "'Kiowa' and 'Cheyenne' be abandoned as member names of the Purgatoire Formation in Colorado, New Mexico, and the Oklahoma Panhandle, and that the Glencairn and Lytle be extended from the Front Range." Above the Glencairn, Scott recognized an undivided Dakota Sandstone (or Formation) overlain by the Graneros Shale in the Dry Cimarron Valley (Fig. 3).

The stratigraphic nomenclature we advocate for Cretaceous rocks in the Dry Cimarron Valley (Fig. 3) differs somewhat from that used by previous workers. In the following discussion, we justify this nomenclature.

Lithostratigraphy

Lytle Sandstone

Finlay's (1916, pp. 7–8) name Lytle Sandstone is applied by us to the oldest Cretaceous strata exposed in the Dry Cimarron Valley, a usage essentially identical to that of Long (1966) and Scott (1970b). A reference section of the Lytle Sandstone in the Dry Cimarron Valley

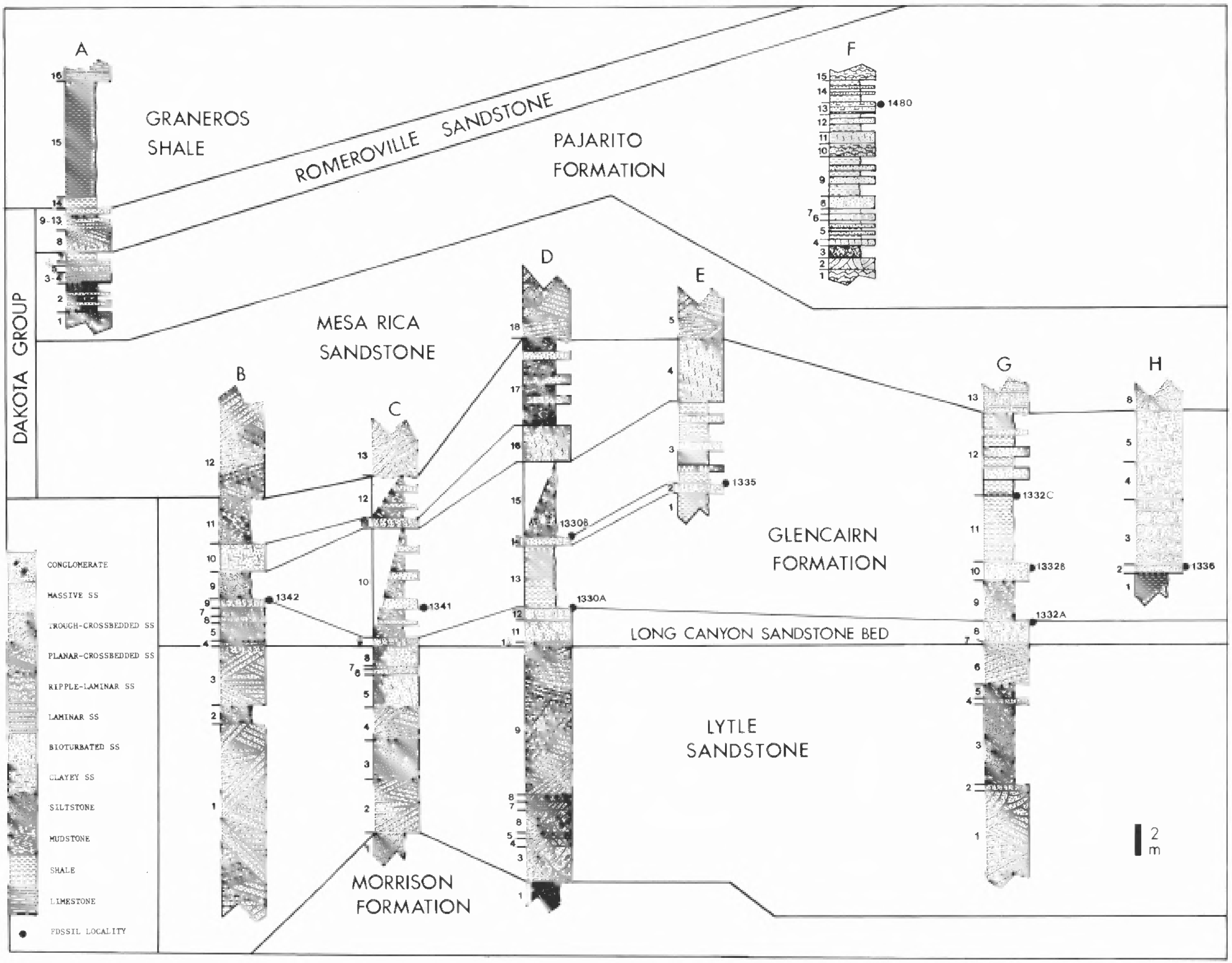


FIGURE 4. Measured stratigraphic sections of Cretaceous rocks in the Dry Cimarron Valley from Tollgate Canyon, New Mexico (section A) to north of Boise City, Oklahoma (section H). See Figure 2 and Appendix 3 for locations and descriptions of lithologies in measured sections.

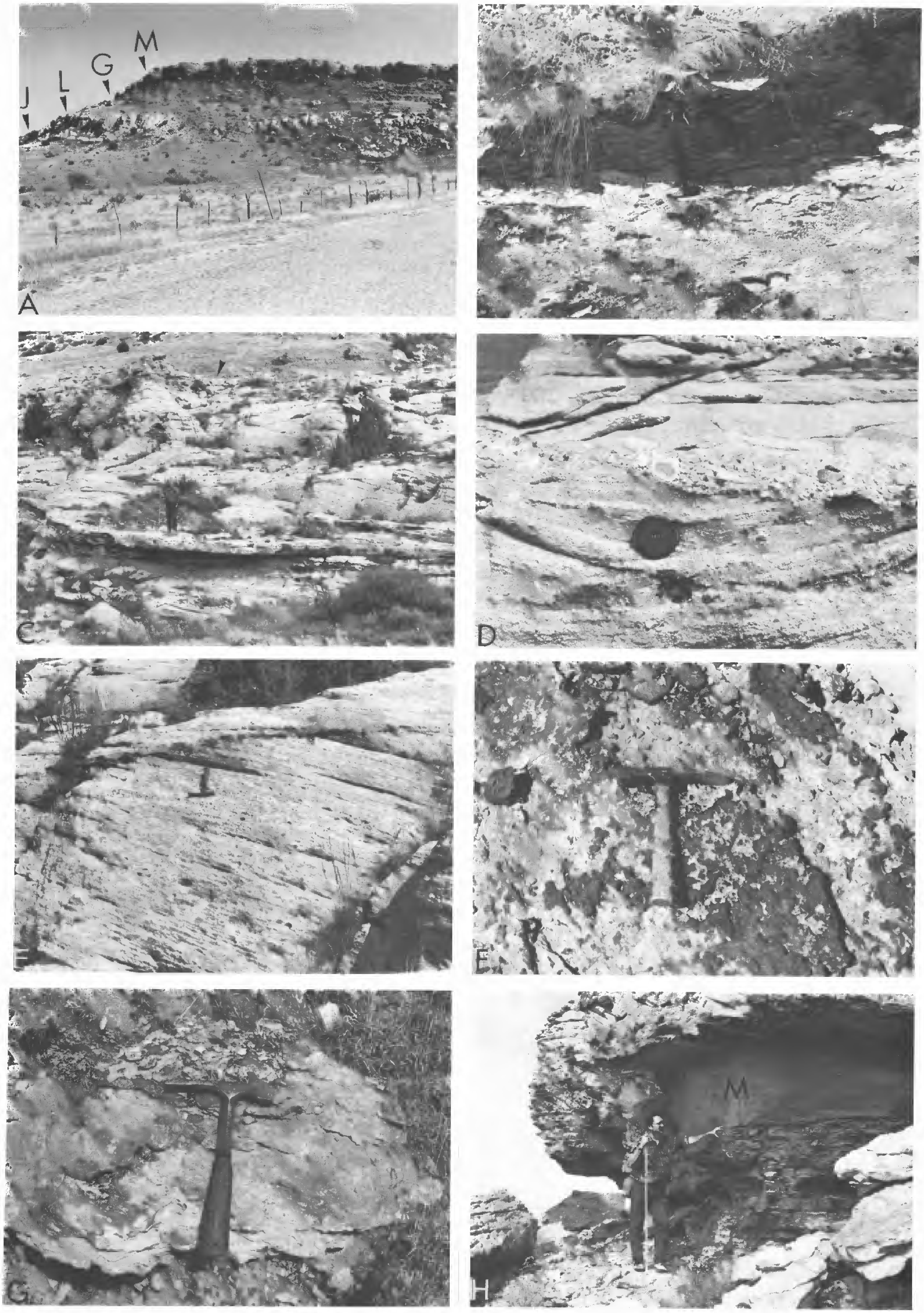
(units 3–9 of our section D: Figs. 4, 5A, C–E) is also designated by us.

The Lytle Sandstone is a prominent unit throughout the Dry Cimarron Valley and is almost continuously exposed from Folsom, New Mexico to north of Boise City, Oklahoma (Stovall, 1943, pl. 2; Baldwin and Muehlberger, 1959, pls. 1a–b). The Lytle in this area generally forms a prominent, white sandstone bench or cliff beneath a Glencairn shale slope and above a Morrison siltstone/claystone slope (e.g., Fig. 5A).

The Lytle Sandstone in the Dry Cimarron is as much as 20 m of sandstone, siltstone and conglomeratic sandstone. Dominant colors of the sandstone and conglomerate are pale orange, yellowish orange and yellowish gray; the siltstones are variegated grayish pink, pale red and pale olive. The sandstones are quartzose, generally fine-grained (although medium- and coarse-grained beds are present), and display abundant planar, and less common trough crossbeds. Sand grains usually are clear or white quartz; some black grains of chert and pink quartz grains also are present. Lytle conglomerates in the Dry Cimarron Valley are dominantly trough-crossbedded and clast supported. Clasts are mostly chert pebbles up to 4 cm in diameter (e.g., Fig. 5D) with lesser amounts of quartzite and quartz. Lytle siltstones are sandy and noncalcareous.

Throughout the Dry Cimarron Valley, the Lytle Sandstone overlies the Morrison Formation. Given the middle-late Albian (Cretaceous) age of the Lytle and the Tithonian (Jurassic) age of the uppermost Morrison (see later discussion), the Lytle-Morrison contact is a disconformity that represents about 30 m.y. (cf. Kent and Gradstein, 1985). Despite this hiatus, no significant stratigraphic evidence of a profound disconformity exists at the Morrison-Lytle contact. Indeed, placement of this contact seemed so arbitrary to Baldwin and Muehlberger (1959, pl. 2) that they identified the Lytle as "Purgatoire or Morrison Formation?" and devoted nearly three printed pages (pp. 54–56) to the "Purgatoire-

FIGURE 5. Photographs of the reference section of the Lytle Sandstone and Glencairn Formation in the Dry Cimarron Valley (section D in Figure 4). A, Overview of the reference section. B, Uppermost siltstone of the Morrison Formation (Fig. 4, unit 1 of section D). C, Overview of crossbedded Lytle sandstones and Lytle-Glencairn contact (arrow). D, Conglomeratic sandstone of Lytle with chert-pebble clasts (Fig. 4, unit 5 of section D). E, Typical crossbedded Lytle Sandstone (Fig. 4, unit 9 of section D). F, Top surface of the Long Canyon Sandstone Bed (Fig. 4, unit 12 of section D). G, *Texigryphaea* shells in sandstone, UNM locality 1330B (Fig. 4, unit 14 of section D). H, Glencairn-Mesa Rica contact (Fig. 4, units 17 and 18 of section D). Abbreviations are: G = Glencairn Formation, J = Morrison Formation, L = Lytle Sandstone and M = Mesa Rica Sandstone.


M
G
L
J
A
C
D
F
E
G
M
H

Morrison contact." We picked the Morrison-Lytle contact at the base of quartzose sandstone above variegated red and green siltstones and claystones we assign to the Morrison Formation. This placement of the Morrison-Lytle boundary in the Dry Cimarron Valley is in agreement with the boundary placed in stratigraphic sections and in mapping by Stovall (1943), Cooley (1955, who called the Lytle "Cheyenne") and Baldwin and Muehlberger (1959), if their unit "Purgatoire or Morrison Formation?" is recognized as Lytle.

A different placement of the Morrison-Lytle contact in the Dry Cimarron Valley is advocated by Mateer (1987). Mateer correctly noted that where an uppermost Morrison sandstone is directly overlain by the Lytle, placement of the formational boundary may be difficult (also see Baldwin and Muehlberger, 1959 and Long, 1966). However, Mateer (1987) claimed that in such situations the base of the Lytle should be placed at the first conglomerate encountered in the sandstone section. Near Travesser Park (SW¼, sec. 12, T31N, R32E), Mateer (1987, fig. 5A) illustrated such a conglomerate, identifying it as a laterally persistent bed that should be used to mark the base of the Lytle. However, Mateer's own illustration demonstrates the pinchout of this conglomerate within a meter or two of its occurrence. Indeed, our measured section C (Fig. 4), measured very near the point of Mateer's (1987, fig. 5A) illustration, identifies no Lytle conglomerate. Furthermore, as our stratigraphic sections (Fig. 4) and those of earlier workers (Stovall, 1943; Cooley, 1955; Baldwin and Muehlberger, 1959) demonstrate, there are no persistent conglomeratic sandstones in, or near the base of, the Lytle Sandstone in the Dry Cimarron Valley. Therefore, Mateer's (1987) criterion for drawing the Morrison-Lytle contact can be rejected.

The upper contact of the Lytle Sandstone with the overlying Glencairn Formation is a sharp, erosional disconformity. Here, generally fine-grained, quartzose, bioturbated, fossiliferous sandstone that weathers orange to yellowish brown (Long Canyon Sandstone Bed of the Glencairn Formation; see below) rests with a sharp contract (e.g., Fig. 6A–B) on typical sandstone of the Lytle.

Although the maximum reported thickness of the Lytle in the Dry Cimarron is 20 m (Baldwin and Muehlberger, 1959, pl. 2, section 9), its thickness typically is around 10 m. No consistent thickness trend is apparent in the Lytle from west to east, down the Dry Cimarron Valley (Fig. 10), nor do there appear to be any consistent trends in lithologic features (e.g., mineralogic composition, grain size). Thus, in Tollgate Canyon near the western end of the Dry Cimarron Valley (Fig. 8A), the Lytle is dominantly white (N9) to very light gray (N8), quartzose, medium-grained, moderately well-sorted, subrounded, noncalcareous sandstone. Other than minor differences in coloration, it does not differ in any particular way from Lytle exposures in Oklahoma.

Glencairn Formation

The term Glencairn Formation, based on Finlay's (1916) Glencairn Shale Member of the Purgatoire Formation, is applied by us to the strata of dominantly marine origin above the Lytle Sandstone in the Dry Cimarron Valley. We designate a reference section of the Glencairn Formation in the Dry Cimarron Valley (units 10–17 of our section D: Figs. 4, 5A, F–H). In addition, we coin the term Long Canyon Sandstone Bed for the basal sandstone(s) of the Glencairn Formation in the Dry Cimarron Valley.

The Glencairn is generally a slope-forming unit that is intermittently exposed along the Dry Cimarron Valley from around Tollgate Canyon, New Mexico to north of Boise City, Oklahoma (Stovall, 1943, pl. 2; Baldwin and Muehlberger, 1959, pls. 1a–b). In most of the Union County portion of the valley, the Glencairn is much covered by colluvium; however, from R37E eastward into Oklahoma many well exposed slopes of Glencairn are available beneath escarpments and buttes capped by the Mesa Rica Sandstone (e.g., Fig. 5A) and in railroad and highway cuts (e.g., Fig. 9B, D).

The Glencairn Formation in the Dry Cimarron Valley is as much as 22 m of sandstone, shale, mudstone and siltstone that contain fossils of marine invertebrates dominated by shells of *Texigryphaea*. Of the 77.5 m of Glencairn Formation we measured in the Dry Cimarron Valley (Fig. 4), 41.1 m are sandstone (53%), 16.4 m are shale (21%), 10.5 m are mudstone (13%) and 9.5 m are siltstone (12%). Glencairn sandstones are generally massive to bioturbated, shades of yellow, gray, orange and brown, fine grained, quartzose and well indurated. Some are extremely fossiliferous (Fig. 4). Shale in the Glencairn is gray, silty/sandy, noncalcareous and locally fossiliferous. Mudstone and siltstone are similar to the shale.

The lowermost Glencairn immediately above the Lytle is as much as 3 m of sandstone that we name here the Long Canyon Sandstone Bed. The type section of the Long Canyon Sandstone Bed is units 4–8 of section B (Figs. 4, 6) at Long Canyon. Here, the Long Canyon Sandstone Bed is 3 m of massive, laminar and bioturbated sandstone that contain abundant casts of *Texigryphaea* shells and other marine invertebrates in the uppermost bed (Figs. 4, 6D). These sandstones are yellowish brown to dark yellowish orange, quartzose and generally medium to coarse grained. In all sections we examined in the Dry Cimarron Valley where the Lytle-Glencairn contact is exposed, the Long Canyon Sandstone Bed is present. Cooley (1955, pl. 4) referred to the *Texigryphaea* occurrences at the top of the Long Canyon Sandstone Bed as the "*Gryphaea* zone," and used it to correlate his measured stratigraphic sections in the Dry Cimarron Valley. Long (1966) referred to the Long Canyon Sandstone Bed as the "basal Glencairn sandstone" (Fig. 3) and correlated it with the Plainview Sandstone Member of the South Platte Formation in north-central Colorado (cf. Waagé, 1955, 1961).

Above the Long Canyon Sandstone Bed, the Glencairn is dominated by interbedded sandstone, shale, mudstone and siltstone until, in some sections (sections C and D of Fig. 4) a distinctive upper facies of oxidized siltstone and sandstone is reached. This facies contains no marine invertebrate fossils, but on Black Mesa (locality 4: Appendix 1) it contains fossil plants.

The Mesa Rica Sandstone overlies the Glencairn Formation with sharp, erosional disconformity throughout the Dry Cimarron Valley. Locally, there is as much as 1 m of relief on this surface (Fig. 7C–D), and there may be considerably more relief over a broader area, although available stratigraphic data are insufficient to demonstrate this. At most locations, the Mesa Rica-Glencairn contact is a clear break between Glencairn siltstone, mudstone or sandstone and the overlying yellowish brown, crossbedded and well indurated quartzarenite of the Mesa Rica (e.g., Fig. 5H). However, at other locations (e.g., Fig. 9C), the basal lithology of the Mesa Rica is a sedimentary breccia of siltstone clasts ripped-up from the underlying Glencairn in a quartzarenite matrix.

Mesa Rica Sandstone (Dakota Group)

The basal sand complex of the Dakota Group immediately above the Glencairn Formation in the Dry Cimarron Valley is identified by us as the Mesa Rica Sandstone. Dobrovolny and Summerson (in Dobrovolny et al., 1946) originally coined the name Mesa Rica Sandstone for "a white or brownish-buff, crossbedded, medium- or coarse-grained sandstone that is massive or cliff-forming" above the Tucumcari Shale in Quay County, east-central New Mexico. The unit was named for Mesa Rica, a large mesa in northeastern Guadalupe County and southeastern San Miguel County, New Mexico. Recognition of the Mesa Rica Sandstone at least as far north as Clayton has been well established (e.g., Mankin, 1958; Gilbert and Asquith, 1976; Gage and Asquith, 1977; Mateer, 1985). More recently, Lucas et al. (1986) applied the term Mesa Rica Sandstone to strata immediately above the Glencairn in the dam spillway at Clayton Lake, about 42–50 km south of the Dry Cimarron Valley. This northward extension of the term Mesa Rica was justified by lithologic similarity of the outcrops at Clayton Lake and similar stratigraphic sequence compared with the Cretaceous strata in east-central New Mexico. We invoke the same reasoning to extend the term Mesa Rica into the Dry Cimarron Valley. Furthermore, subsurface and surface data from outcrops along the Canadian escarpment in Harding and southern Union Counties (e.g., Mankin, 1958) demonstrate physical continuity of the Mesa Rica in east-central New Mexico with the unit we term Mesa Rica in the Dry Cimarron Valley.

The Mesa Rica in the Dry Cimarron Valley is a cliff- and bench-forming unit that forms most of the caprock of the canyons carved by

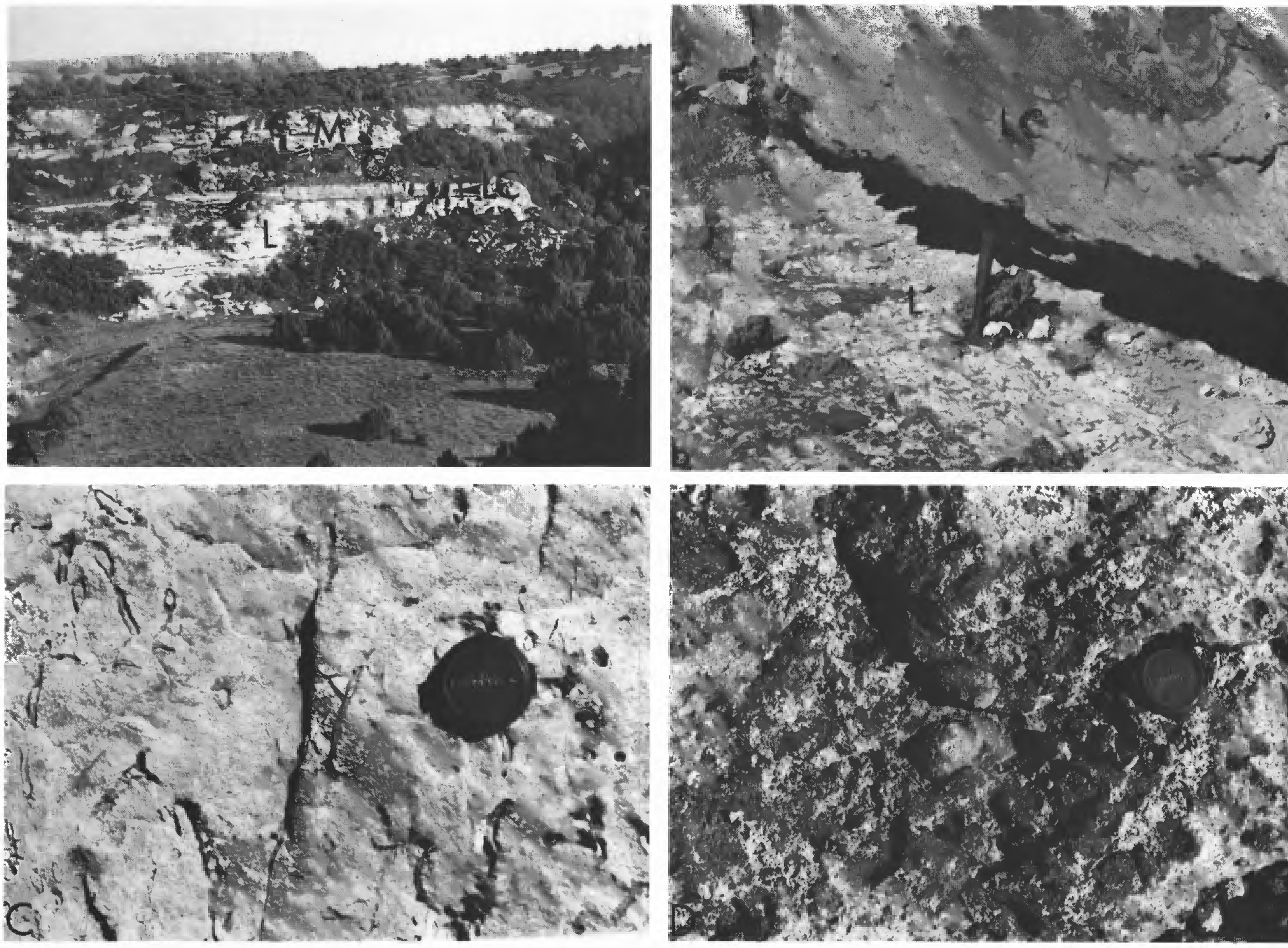


FIGURE 6. Photographs of the Cretaceous section at Long Canyon, New Mexico (section B of Figure 4). A, Overview of the section. B, Basal contact of Long Canyon Sandstone Bed on Lytle Sandstone (Fig. 4, units 3, 4 and 5 of section B). C–D, *Texigryphaea* valves and bioturbation in Long Canyon Sandstone Bed (Fig. 4, unit 8 of section B). Abbreviations are: G = Glencairn Formation, L = Lytle Sandstone, LC = Long Canyon Sandstone Bed and M = Mesa Rica Sandstone.

the Dry Cimarron River and its tributaries. It is well exposed from Folsom, New Mexico to north of Boise City, Oklahoma (as the majority of the "Dakota" of Stovall, 1943, pl. 2 and Baldwin and Muehlberger, 1959, pls. 1a–b).

In the Dry Cimarron Valley, the Mesa Rica Sandstone is as much as 33 m of yellowish orange, grayish orange and yellowish brown quartzarenite. Dominant bedforms are planar and trough crossbeds. As noted above, some sedimentary breccias composed of Glencairn clasts are present at the base of the Mesa Rica locally. Beds of quartzite-quartz gravel also are present in some sections. In general, the Mesa Rica sandstone in the Dry Cimarron Valley corresponds well to the fluvial-dominated portions of the Mesa Rica farther south, described by Gilbert and Asquith (1976) and Kisucky (1987).

Pajarito Formation (Dakota Group)

Above the Mesa Rica Sandstone in the Dry Cimarron Valley are as much as 20 m of interbedded sandstone, siltstone and shale that Stovall (1943) termed the "middle shale" of the Dakota "Sandstone." Because of lithologic similarity and stratigraphic position we assign these strata to the Pajarito Formation, extending this term northward from east-central New Mexico for the same reasons we extended the term Mesa Rica Sandstone. Dobrovolny and Summerson (in Dobrovolny et al., 1946) introduced the name Pajarito Shale for "soft brown sandstone alternating with gray shale that contains *Ostrea quadriplicata*" exposed in Quay County, east-central New Mexico. The name Pajarito was derived from Pajarito Creek, an intermittent stream headed in eastern Guadalupe County that joins the Canadian River in the Pablo Montoya Grant of eastern San Miguel County.

The Pajarito Formation is poorly exposed in the Dry Cimarron Valley. Only on the tops of the escarpments lining the valley, or well up tributary canyons, are low-lying, largely covered outcrops of the Pajarito usually found. Three excellent exposures, studied by us, are in Tollgate Canyon (section A, Fig. 4), in South Carrizo Creek (section F, Fig. 4; Fig. 9F) and just north of Boise City (cf. Schoff and Stovall, 1943, section 16).

In the Dry Cimarron Valley, the Pajarito Formation is dominantly sandstone. We measured 17.8 m of Pajarito Formation (Fig. 4) and found 12.0 m to be sandstone (67%), 4.4 m (25%) to be shale and 1.4 m to be siltstone. The sandstones are dominantly massive to bioturbated, pale orange and yellowish brown quartzarenites. The shales and siltstones are gray and, locally, contain lignitic seams. The maximum thickness of the Pajarito Formation in the Dry Cimarron Valley is about 20 m.

The Mesa Rica-Pajarito contact is transitional and intertonguing in east-central New Mexico (e.g., Kisucky, 1987). Although we lack the data to demonstrate this, the Mesa Rica-Pajarito contact appears to be similar in the Dry Cimarron Valley. At single outcrops, the contact is drawn between the highest persistent bed of Mesa Rica quartzarenite and the overlying shale/siltstone/mudstone of the Pajarito Formation.

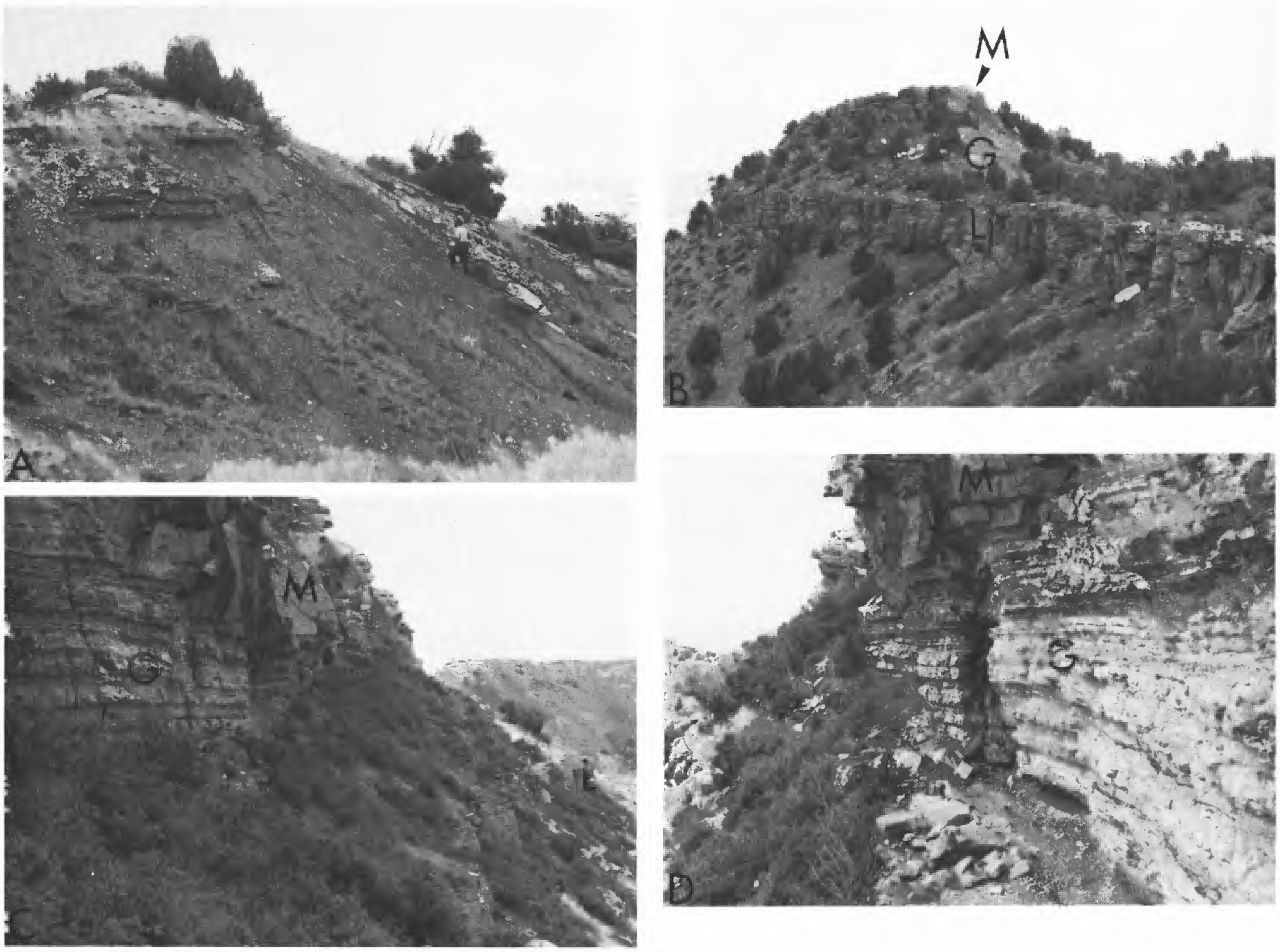


FIGURE 7. Some outcrops of Cretaceous strata in Union County, New Mexico. A, The Glencairn Formation at control point 3 (UNM locality 1339). The man is standing at the fossiliferous level in the shale/sandstone slope. B, The Morrison (upper part), Lytle, Glencairn and Mesa Rica formations at control point 2 (UNM locality 1340). C–D, Cretaceous strata at stratigraphic control point 18 (Cooley, 1955, section 8). Note channel of basal Mesa Rica Sandstone into underlying Glencairn Formation. Abbreviations are: G = Glencairn Formation, L = Lytle Sandstone, M = Mesa Rica Sandstone.

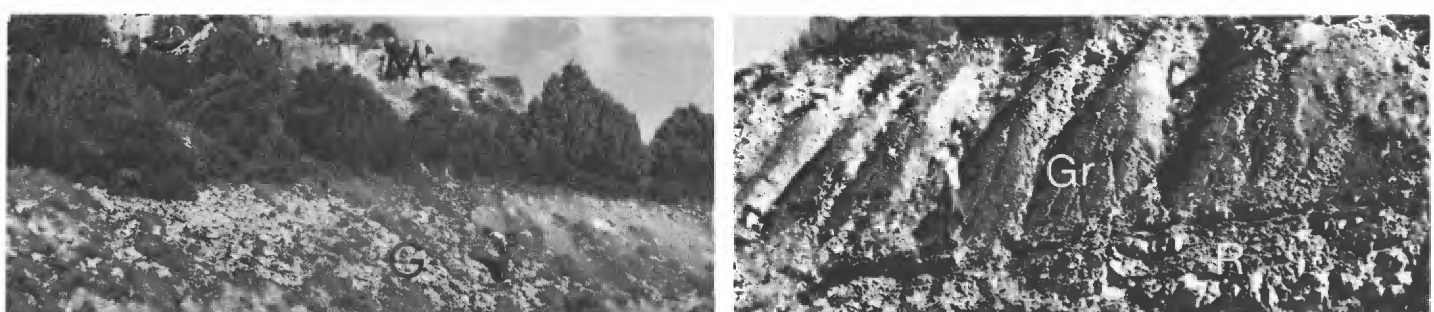


FIGURE 8. Photographs of Cretaceous strata in Tollgate Canyon. A, The Lytle, Glencairn and Mesa Rica sandstones on the western side of NM Highway 551 just south of section A (Fig. 4). B, Overview of part of section A (Fig. 4), showing the upper part of the Pajarito Formation, the Romeroville Sandstone and the lower part of the Graneros Shale. Abbreviations are: G = Glencairn Formation, Gr = Graneros Shale, L = Lytle Sandstone, LC = Long Canyon Sandstone Bed, M = Mesa Rica Sandstone, P = Pajarito Formation and R = Romeroville Sandstone.

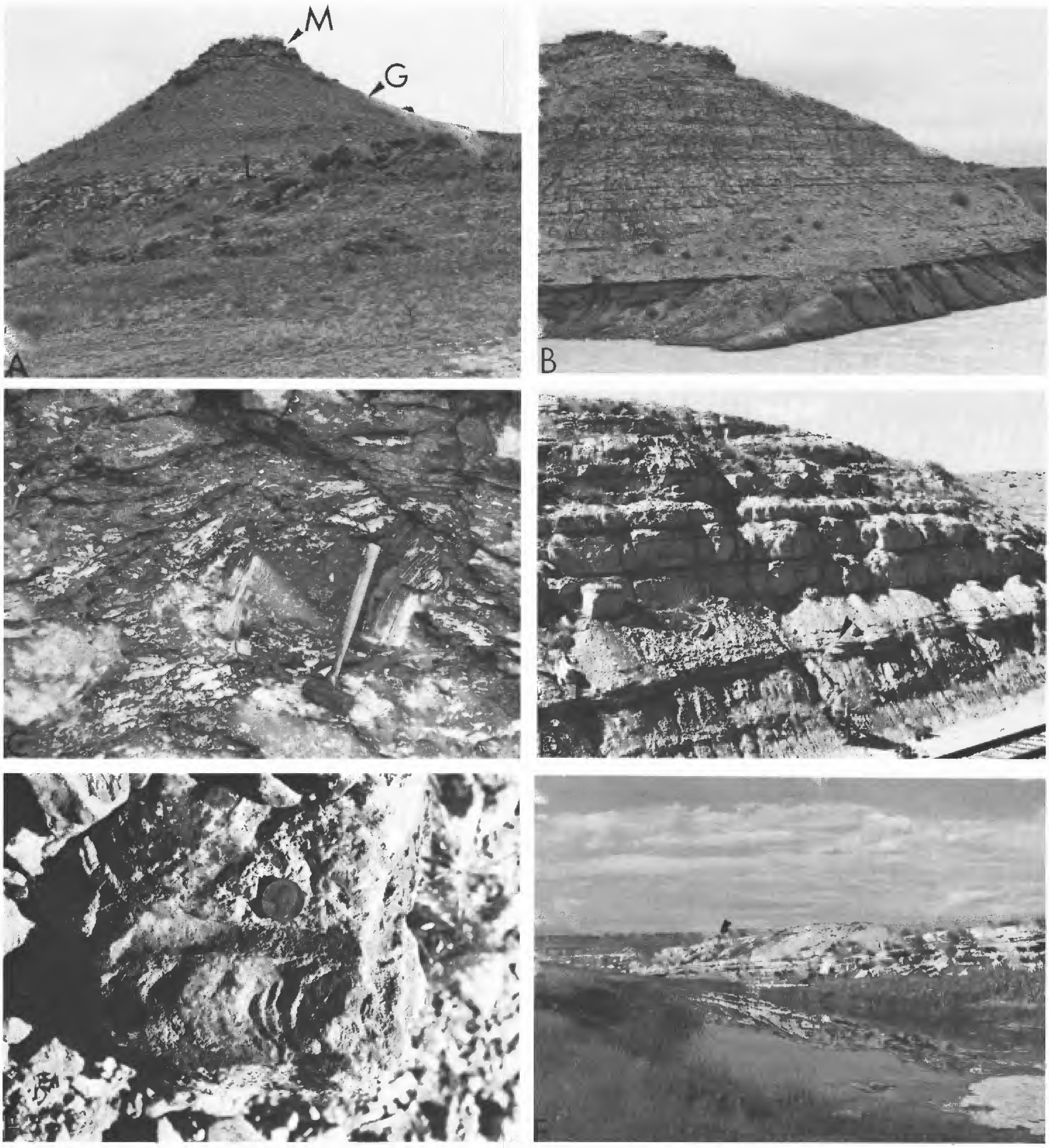


FIGURE 9. Some outcrops of Cretaceous strata in Cimarron County, Oklahoma. A, Section G (Fig. 4) from the Morrison Formation through the Mesa Rica Sandstone. B, Glencairn strata at section E (Fig. 4). C, Sedimentary breccia in basal Mesa Rica Sandstone at control point 15 (UNM locality 1333). D, Glencairn strata at section H (Fig. 4). The sandstone (arrow) just above the man is the fossiliferous horizon of UNM locality 1336. E, *Rhizocorallium* in a sandstone of the Glencairn Formation at UNM locality 1337. F, The Pajarito Formation at section F (Fig. 4). The dinosaur-footprint horizon (UNM locality 1480) is indicated by an arrow. Abbreviations are: G = Glencairn Formation, L = Lytle Sandstone, M = Mesa Rica Sandstone.

Romeroville Sandstone (Dakota Group)

The tripartite nature of the Dakota Group throughout northeastern New Mexico has been discussed by many workers (e.g., Mankin, 1958; Baldwin and Muehlberger, 1959; Wanek, 1962; Jacka and Brand, 1972; Gilbert and Asquith, 1976; Bejnar and Lessard, 1976; Gage and Asquith, 1977; Mateer, 1985; Lucas and Kues, 1985; Lucas et al., 1986). In a formal nomenclature, the lower sand complex is the Mesa Rica, the medial "shale" sequence is the Pajarito and the upper sand is either Dakota in a restricted sense, or it is unnamed (Wanek, 1962; Lucas and Kues, 1985). An informal nomenclature refers to the entire tripartite sequence as the Dakota Sandstone, identifying the lower sand complex as the "lower braided alluvial interval," the medial "shale" as the "meander-belt interval" and the upper sand as the "marine sand interval" (e.g., Jacka and Brand 1972, 1973; Gilbert and Asquith, 1976). We favor here a modification of the formal nomenclature for this stratigraphic interval. Thus, we term the entire interval Dakota Group and recognize three included formations: Mesa Rica Sandstone, Pajarito Formation and Romeroville Sandstone (Fig. 3). The name Romeroville Sandstone was first used in a manuscript by Lucas (unpublished). The name is from Romeroville, San Miguel County, New Mexico, about 8 km south of Las Vegas on Interstate 25. The type section of the Romeroville Sandstone was measured on the northern highway cut at Romeroville Gap ("Dakota" of Lucas et al., 1985, fig. 2.29 and "D" of fig. 2.30C).

Excellent exposures of the Romeroville Sandstone are present just south of the Dry Cimarron at Clayton Lake (Lucas et al., 1986) and Corrumpa Creek (Muehlberger et al., 1961; Lucas et al., 1987). In the Dry Cimarron Valley, the Romeroville is less well exposed, being generally confined to the upper reaches of tributary canyons. Here, the Romeroville reaches a maximum thickness of 8 m, and typically is laminar, planar crossbedded and bioturbated, pale orange-gray to yellowish gray quartzarenite and minor gray siltstone (Fig. 4, section A; Fig. 8B). In some sections, however, the Romeroville apparently is not present between the Pajarito and Graneros (Kauffman et al., 1977, fig. 3, section 1). The Pajarito-Romeroville contact is drawn at the top of the highest siltstone, mudstone or shale of the Pajarito underneath a relatively thick quartzarenite at the base of the Romeroville. Gray, usually bentonitic shale marks the base of the Graneros Shale above Romeroville quartzarenite.

Graneros Shale

Stovall (1943) first recognized the presence of Gilbert's (1896) Graneros Shale in the Dry Cimarron Valley at South Carrizo Creek, Cimarron County, Oklahoma. Baldwin and Muehlberger (1959) first identified the Graneros Shale in the New Mexico portion of the Dry Cimarron Valley.

Kauffman et al. (1977; also see Kauffman et al., 1969) studied the Graneros Shale in the drainage of South Carrizo Creek. Here, they recognized three units in the Graneros: (1) a lower shale member that is approximately 20 m of olive gray to dark gray, sandy-silty mudstone and shale; (2) the Thatcher Limestone Member, 0.15 to 0.21 m of thin-bedded, slightly glauconitic calcarenite containing fine-grained quartz sand; and (3) an upper shale member that is about 7.2 m of silty clay-shale. Invertebrate mega- and microfossils from the Graneros Shale at South Carrizo Creek indicate an early Cenomanian age, principally the *Ostrea beloiti* biostratigraphic zone (Kauffman et al., 1977, fig. 5).

Baldwin and Muehlberger (1959) presented data on the Graneros Shale at Tollgate Canyon, the only well-exposed section of the Graneros Shale in the Union County portion of the Dry Cimarron Valley. Here, they found the Graneros Shale to be about 38 m of shale and limestone (Baldwin and Muehlberger, 1959, fig. 11, pl. 2, section 1).

We made no effort to study the Graneros Shale in the Dry Cimarron Valley, nor did we systematically collect fossils from it. At Tollgate Canyon, we measured 8.4 m of the lower Graneros, up to a sandy limestone that Baldwin and Muehlberger (1959, p. 61) termed the "felted limestone."

Greenhorn Formation

As with the Graneros, we made no attempt to study systematically the Greenhorn Formation in the Dry Cimarron Valley. Stovall (1943) first applied the term Greenhorn to strata in the Dry Cimarron Valley. Again, as with the Graneros, the best exposed sections of the Greenhorn in the Dry Cimarron Valley are at South Carrizo Creek (Kauffman et al., 1969, 1977) and Tollgate Canyon (Baldwin and Muehlberger, 1959; Hattin, 1987).

In brief, the Lincoln, Hartland and Bridge Creek Limestone Members of the Greenhorn are present in the Dry Cimarron (Kauffman et al., 1977; Hattin, 1987) and are dominantly rhythmically-bedded, chalky limestones and calcareous shales. Invertebrate fossils indicate these strata span the Cenomanian-Turonian boundary.

Stratigraphic nomenclature

The stratigraphic nomenclature of Cretaceous strata exposed in the Dry Cimarron Valley has undergone significant modification since Lee's (1902) initial studies (Fig. 3). This is particularly true of the Lower Cretaceous strata. In the preceding discussion we have employed the following changes:

1. We abandon the term Purgatoire as a formation to encompass the Lytle Sandstone and Glencairn Formation. Stose (1912, p. 4) coined the name Purgatoire Formation for exposures in the Purgatoire River canyon near Mesa de Maya in southeastern Colorado. He applied this name to a lower sandstone (almost two-thirds of the thickness of the Purgatoire) and an upper, interbedded shale and sandstone sequence with a marine invertebrate fauna of "Comanchean" age. Thus, Stose avowedly created the name Purgatoire to encompass the "Comanchean" strata below the Dakota and above the Morrison. Finlay's (1916, pp. 7–8) names Lytle and Glencairn, coined for the lower sand and upper marine interval, respectively, of the Purgatoire are logical formation names, but we see little logic in subsuming them as members in a Purgatoire Formation (or as formations in a Purgatoire Group). Not only are the Lytle and Glencairn remarkably dissimilar lithologically, but they are separated by a disconformity, "the most significant physical break within the entire [Lower Cretaceous] sequence" (Long, 1966, p. 15). The Lytle and Glencairn are readily mapped separately at 1:24,000

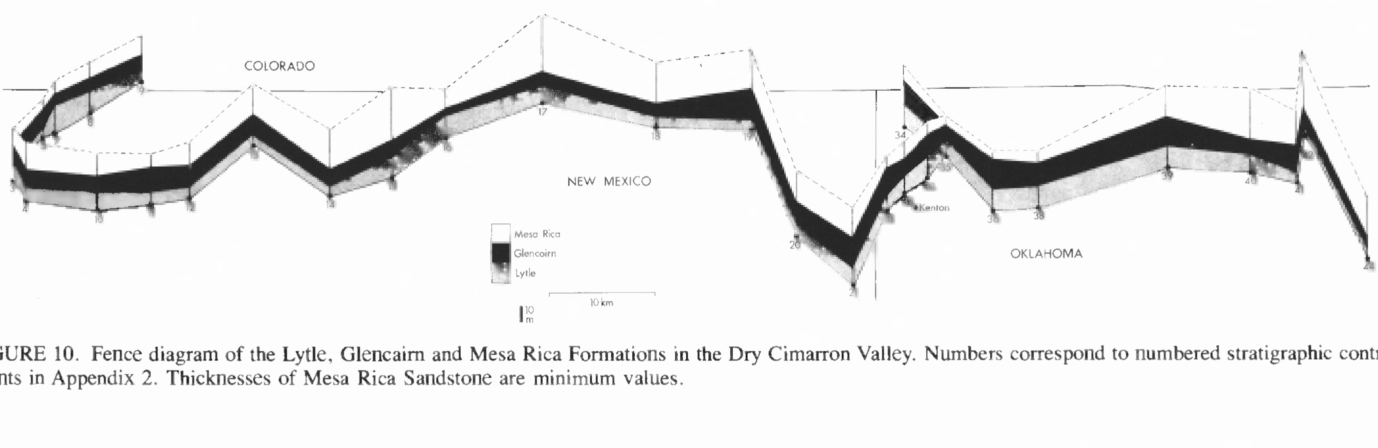


FIGURE 10. Fence diagram of the Lytle, Glencairn and Mesa Rica Formations in the Dry Cimarron Valley. Numbers correspond to numbered stratigraphic control points in Appendix 2. Thicknesses of Mesa Rica Sandstone are minimum values.

scale throughout southeastern Colorado, northeastern New Mexico and northwestern Oklahoma. Therefore, we suggest that Lytle and Glencairn be elevated to formational rank and the term Purgatoire be abandoned.

2. We use the term Lytle Sandstone instead of Cheyenne Sandstone for the oldest Cretaceous strata in the Dry Cimarron Valley. As has been well demonstrated by Latta (1946, 1948) and Franks (1975), the Cheyenne is confined to a 48-km-long outcrop belt and small adjacent subcrop in south-central Kansas. It is not physically continuous with strata termed Lytle in southeastern Colorado, northeastern New Mexico and northwestern Oklahoma (Cimarron County) (McLaughlin, 1954; Scott, 1970b). Therefore, there is no justification for using the term Cheyenne in the Dry Cimarron Valley.

3. We use the term Glencairn Formation instead of Glencairn Shale because the Glencairn contains significant amounts of lithologies other than shale. Indeed, in the Dry Cimarron Valley, about 50% of the Glencairn is sandstone.

4. We do not use the term Kiowa in the Dry Cimarron Valley because of the relatively sandy marine section here, more similar to the Colorado Glencairn than to the Kansas Kiowa (also see Scott, 1970b).

5. We coin the term Long Canyon Sandstone Bed for the basal, transgressive sand complex of the Glencairn in the Dry Cimarron Valley. We consider this unit to be homotaxial with the Plainview Sandstone Member of the South Platte Formation (Waagé, 1955) to the north in Colorado and the Campana sandstone bed of the Tucumcari Shale (Holbrook et al., 1987) to the south in east-central New Mexico. Rather than applying one name to these sand complexes, or raising them to formational rank, we prefer a localized, bed-level nomenclature of these thin, often intermittent, transgressive, basal sand complexes of the Skull Creek-Kiowa cyclothem on the southwestern side of the Albian seaway.

6. We use the term Dakota Group to encompass the tripartite sequence between the Glencairn and Graneros. Furthermore, we apply the east-central New Mexico names Mesa Rica and Pajarito to the lower and middle parts of this sequence, as discussed above, and the new name Romeroville is applied to the upper part of this sequence. We believe this use of the term Dakota is logical and consistent with the stratigraphic relationships we have examined, in marked contrast to the proposals made by Mateer (1987) with regard to Dakota Group stratigraphy.

In a general discussion of the Albian-lower Cenomanian stratigraphic interval from Wyoming to New Mexico, Mateer (1987) views the stratigraphy of northeastern New Mexico in a way that is quite different from our conclusions and those of most previous workers in this region. He includes the Lytle, Glencairn/Tucumcari, Mesa Rica, Pajarito and Romeroville (Dakota Formation, restricted) formations within the Dakota Group, and extends the Muddy Formation of Wyoming and Colorado to New Mexico to include the last three formations mentioned above. We believe Mateer's suggestions (and those of Gustason and Kauffman, 1985, which are essentially identical) regarding the stratigraphic nomenclature of northeastern New Mexico to be, at best, ill-advised.

In southeastern Colorado and northeastern New Mexico, the lower part of the "Dakota" of early workers (Lytle and Glencairn formations) has long been considered part of the Albian Purgatoire Formation of Stose (1912), with the term Dakota limited to the predominantly sandstone units above. Similarly, in Kansas the Dakota Formation or Group has been restricted to the interval above the Albian Cheyenne and Kiowa formations (Purgatoire equivalents) since the 1940's (Bayne et al., 1971). In view of more than 100 years of study and refinement of the stratigraphy of this large area, expansion of the term Dakota Group to essentially its nineteenth-century definition is a retrogressive step that neither clarifies the stratigraphic relationships nor improves regional correlation of the units involved. Furthermore, such expansion of the Dakota Group concept to embrace an inland, fluvial sandstone complex (Lytle), marine shale (Glencairn/Tucumcari) and an array of deltaic, fluvial, delta plain and shoreline sandstones/mudrocks (Mesa Rica, Pajarito, Romeroville) runs contrary to accepted stratigraphic concepts. A group is a well recognized lithostratigraphic unit "defined to express the natural relationships of associated formations" (North American Commission on Stratigraphic Nomenclature, 1983, p. 858). Put somewhat differently, "the term [group] is applied most commonly to a sequence of two or more contiguous associated formations with significant unifying lithologic features in common" (Hedberg, 1976, p. 34). Clearly the strata between the Morrison and Graneros that Gustason and Kauffman (1985) and Mateer (1987) would unite in the Dakota Group are not closely similar to each other lithologically. Instead, they represent three, very different depositional episodes during Albian-Cenomanian time. Their resulting lithologic disparity renders it difficult to understand their inclusion in a single, Dakota Group, unless we are to use this term in the same broad fashion that it was used by some nineteenth-century stratigraphers.

The Dakota Group as used in this paper preserves the meaning of the term used for decades by previous workers (usually as Dakota Sandstone or Formation) in northeastern New Mexico and adjacent areas. The unit, with its three formations, represents the regressive phase of the Kiowa-Skull Creek eustatic cycle and the very beginning of the subsequent Greenhorn cycle (but see Weimer, 1984), an event that deposited predominantly shoreline and fluvial sands throughout a large area of the Western Interior. As so defined, the Dakota Group excludes offshore shales with diverse marine faunas both below (Kiowa, Glencairn, Tucumcari formations) and above (Graneros, lower Mancos formations). It is lithologically and paleontologically distinct from over- and underlying units and represents an easily correlatable package of sediments deposited during a limited segment of a eustatic cycle.

We emphatically reject Mateer's attempt to extend the Muddy Formation into northeastern and east-central New Mexico and neighboring areas. The Muddy Formation was first formally defined by Paull (1962) in the Bighorn basin of northern Wyoming. It consists of a heterogenous and laterally variable sequence of sediments representing deltaic, bar, beach and back-bar, alternating continental-littoral-marine and neritic facies. As a number of delta systems prograded into the Western Interior seaway in Wyoming and Colorado during Albian time, correlation of specific lithofacies from one area (delta) to another is not surprisingly difficult or impossible, as Mateer admits. In contrast, the facies associated with the delta system in northeastern New Mexico (Mesa Rica, Pajarito, Romeroville formations) comprise three units that are laterally continuous, prominently exposed and easily recognizable throughout northeastern and east-central New Mexico and adjacent areas. The tripartite nature of this sequence bears no resemblance to the Muddy Formation in its type area or to the Muddy interval in intermediate areas like the Denver basin, which Mateer (1987) describes as "a complex local facies pattern which . . . [is] difficult to trace north and south directly."

Mateer would also include the Mesa Rica, Pajarito and Romeroville formations of northeastern New Mexico as members within the Muddy Formation because the Muddy is a formation in Colorado and "a hierarchical change across the New Mexico-Colorado state line is . . . undesirable." This rationale is simply irrelevant: the three units are locally of considerable thickness and are mappable on a scale of 1:24,000 (e.g., Dobrovolny et al., 1946; Wanek, 1962). They have been considered formations by workers in east-central New Mexico since Griggs and Read (1959), and often are thicker and more extensively exposed than underlying units (Lytle, Tucumcari/Glencairn) which Mateer inconsistently maintains as formations. In summary, extending the term Muddy Formation some 250 to 400 km from central Colorado (and 1,000+ km from its type area) into northeastern and east-central New Mexico, where the stratigraphy of that interval is considerably different and where a useful and well-established series of stratigraphic names is already in place contributes nothing to a better understanding of any aspect of the units involved.

Mateer (1987) also states that several regional disconformities within the Albian-early Cenomanian sequence, which represent "lengthy periods of substantial erosion" are recognizable from Wyoming to New Mexico. Deposition of the Dakota Group is considered to be largely by aggradation during eustatic sea-level rise, with only the sandy intervals of the upper Tucumcari and Glencairn formations representing regressive deposition in New Mexico. Neither of these two ideas is supported by the stratigraphic and sedimentologic evidence in northeastern New Mexico and adjacent areas.

Among the disconformities mentioned by Mateer are ones between the Glencairn/Tucumcari and Mesa Rica, between the lower and upper Muddy Formation (presumably between the Pajarito and Romeroville formations in New Mexico) and between the Muddy Formation (Dakota Group in northeastern New Mexico) and the Graneros Shale. The disconformity between the Tucumcari and Mesa Rica is said to be between two sandstones (the lower one with Albian marine fossils), both of which we would include in the lower Mesa Rica Sandstone. Mateer's argument for including the fossiliferous sandstone in the Tucumcari is that "the top of the Tucumcari Formation should include beds containing a typical molluscan fauna, regardless of lithology." However, sandstone casts and molds of late Albian marine invertebrates (especially *Scabrotrigonia* and *Mortoniceras*) are found within the Mesa Rica Sandstone several meters above its basal, fossiliferous sandstone (Griggs and Read, 1959; Kues et al., 1985). Clearly, because lithological rather than paleontological criteria must be used in the definition of lithostratigraphic units, Mateer's suggestion is inappropriate. More importantly (and regardless of where the formational boundary lies), detailed study of the Tucumcari-Mesa Rica sequence has shown: (1) that this disconformity is rather minor, representing an interval of time within the *Mortoniceras equidistans* range zone (Kues et al., 1985; Payne et al., 1986), and (2) that the Tucumcari/Glencairn to Pajarito sequence represents a genetically related prograding delta system that produced a relatively smooth, regressive progression of environments during the late Albian that lacks major disconformities (Kisucky, 1987). The onset of the transgressive phase of the next cycle (related to eustatic sea-level rise) is preserved only in the overlying Romeroville Sandstone and Graneros Shale. Contrary to Mateer's assertions, a significant disconformity within the upper part of the Dakota Group is not present in northeastern New Mexico; the delta-plain facies of the Pajarito Formation interfingers and/or is conformable with sandstones both above and below. Mateer's claim of a regional disconformity between the Dakota Group and the overlying Graneros Shale is inexplicable in view of the fact that the Dakota is conformable with the Graneros across wide areas of the Western Interior (e.g., Kauffman et al., 1978) or spectacularly intertongues with it, as is the case in northwestern New Mexico (e.g., Cobban, 1977).

PALEONTOLOGY AND AGE OF LYTLE SANDSTONE

Other than fragments of petrified wood and nondescript burrows, we observed no fossils in the Lytle Sandstone of the Dry Cimarron Valley. To our knowledge, no fossils have been reported from the Lytle by previous workers in this area. Thus, the age of the Lytle in the Dry Cimarron must be inferred from its stratigraphic position and regional stratigraphic relationships.

The Lytle clearly must be older than the overlying, late Albian Glencairn Formation. The Morrison Formation beneath the Lytle is usually considered to be of Late Jurassic age. In fact, typical Late Jurassic dinosaurs (e.g., *Apatosaurus, Allosaurus, Camarasaurus* and *Stegosaurus*) have been collected in the uppermost Morrison, as high as 6 m below the Lytle Sandstone, in Cimarron County, Oklahoma (Stovall, 1938, 1943; West, 1978). Although these dinosaurs are of Late Jurassic age (probably Tithonian) it is not clear that the end of the Late Jurassic is encompassed by the Morrison Formation in the Dry Cimarron. Indeed, in some parts of the Western Interior the uppermost Morrison Formation apparently includes strata of Early Cretaceous age (e.g., Douglass and Johnson, 1984; Bowman et al., 1986). Therefore, stratigraphic position indicates a possible range of latest Jurassic-late Albian for the Lytle Sandstone in the Dry Cimarron Valley.

Regional stratigraphic relationships, however, strongly suggest that the Lytle is of Early Cretaceous age. Particularly compelling is palynological evidence that the upper Cheyenne Sandstone of south-central Kansas is of late Albian age (Ward, 1986). The Cheyenne is lithologically very similar to and occupies the same stratigraphic position as the Lytle in the Dry Cimarron. Indeed, correlation of the Lytle and the Cheyenne has long been accepted, and, as noted above, their identification as a single stratigraphic unit has been accepted by some workers. Thus, correlation of the Lytle and Cheyenne suggests a middle-late Albian age for the former in the Dry Cimarron. This age is consistent with broader stratigraphic relationships which suggest the Lytle is homotaxial with other fluvial units (e.g., Cedar Mountain, Burro Canyon, Cloverly) in the Western Interior that lie between the Morrison and the oldest marine deposits of the Skull Creek cyclothem (late Albian).

Assignment of an Albian age to the Lytle Sandstone in the Dry Cimarron Valley suggests that there is a significant disconformity at its base. This disconformity encompasses part of the Albian, the entire Aptian, Barremian and "Neocomian" and, perhaps, part of the Tithonian, a hiatus of at least 30 m.y. The duration of this disconformity, however, depends on a correct assessment of the youngest age of the Morrison Formation in the Dry Cimarron Valley, a subject that still demands further investigation.

PALEONTOLOGY OF GLENCAIRN FORMATION

Introduction

The Glencairn Formation in the Dry Cimarron area contains a moderately diverse, bivalve-dominated marine invertebrate fauna. The few previous studies of the Glencairn fauna, primarily brief discussions and taxonomic lists, have demonstrated its late Albian age, similarity to faunas of the upper Kiowa Formation in Kansas and Tucumcari Shale to the south, and general paleobiogeographic/paleoenvironmental relationships with contemporaneous faunas along the western shore of the southern Western Interior seaway. Here, we summarize the Glencairn fauna of the Dry Cimarron Valley, add new information based on study of collections made from Union County, New Mexico and Cimarron County, Oklahoma, illustrate some of the characteristic taxa and discuss the composition, age, environment and paleobiogeography of this fauna. Special attention is given to the paleobiology of *Texigryphaea*, numerically the dominant taxon in the Glencairn in this area. Specimens illustrated and discussed in this paper are reposited in the University of New Mexico (UNM) Department of Geology paleontology collection.

Previous studies

The first report of a Lower Cretaceous marine fauna (*Gryphaea corrugata*) from the Dry Cimarron area was made by W. T. Lee at the December 1902 meeting of the Geological Society of America (Stanton, 1905). Later, Stanton joined Lee in tracing this fossiliferous horizon through southeastern Colorado, northeastern New Mexico and the Oklahoma panhandle, and the wide distribution of Comanchean strata in these areas became recognized. Stanton (1905) summarized these localities and provided faunal lists for them. In the Dry Cimarron, Stanton (1905, p. 664) reported 13 species of molluscs from 50 to 60 ft of "dark shales with layers of brown flaggy sandstones and bands of somewhat calcareous yellow sandstone" east of Garrett post office (near UNM locality 1338), Cimarron County, Oklahoma (Table 1). Rothrock (1925), Bullard (1928) and Stovall (1943) briefly discussed the paleontology of the Glencairn in Cimarron County, mentioned several additional fossiliferous exposures, but added no new taxa to the list presented by Stanton (1905). Bullard correlated the Glencairn (as the upper member of the Purgatoire) with the Kiowa Formation of Kansas and the Kiamichi-basal Duck Creek formations of Texas; Stovall assigned these beds to the Kiowa.

On the New Mexico side of the Dry Cimarron, the Glencairn was found to be less fossiliferous than in Oklahoma. Stanton (1905) noted that fossils become less abundant to the west, until near Folsom only a small mactroid bivalve was found. Both Cooley (1955) and Baldwin and Muehlberger (1959), who measured numerous Cretaceous sections in Union County, reported little more than *Texigryphaea* at a few localities. Long (1966), in his excellent comprehensive study of the basal Cretaceous units in southeastern Colorado, discussed the Glencairn at two localities just north of the New Mexico-Colorado boundary in tributaries of the Dry Cimarron, and reported only six species of bivalves (Table 1). More recently Scott (1970b, 1974, 1975, 1977, 1986a) incorporated observations on the Dry Cimarron Glencairn fauna into a regional synthesis of the stratigraphy and paleobiogeography of the late

TABLE 1. Taxa reported from the Glencairn Formation in the Dry Cimarron area of Union County, New Mexico, Cimarron County, Oklahoma and Las Animas County, Colorado. ST = "Garrett post office" locality (near UNM locality 1338) of Stanton (1905); L = Long's (1966) sections 25 and 26, Las Animas County, Colorado; SC = Scott's (1974 and written commun., 1985) three localities in Cimarron County. The last three columns indicate the occurrence of a species in the Tucumcari Shale (T) of east-central New Mexico, in exposures of the Kiowa Formation in south-central Kansas (SK) and in the Kiowa of central Kansas (NK).

	ST	L	SC	1330	1331	1332	1334	1336	1337	1338	1339	1340	1341	1342	Present in T	SK	NK
FORAMINIFERA																	
Cribratina texana (Conrad)						x									x	-	-
PORIFERA																	
Entobia cf. E. microtuberum Stephenson											x				-	-	-
E. sp. (= Cliona sp.)			x	x	x	x	x	x	x	x	x				x	x	-
ANNELIDA																	
Serpula cragini Twenhofel					x				x	x					x	x	-
GASTROPODA																	
Acmaea sohli Scott			x												-	x	-
Amberleya mudgeana (Meek)											x				x	x	x
Drepanochilus kiowana (Cragin)	x		x												x	x	x
Otostoma marcouana (Cragin)				x											-	x	x
Turritella seriatim-granulata Roemer	x		x												x	-	-
T. cf. T. belviderei (Cragin)						x									x	x	x
AMMONOIDEA																	
Eopachydiscus marcianus (Shumard)	x				x										x	-	-
Idiohamites fremonti (Marcou)	x														-	-	-
Mojsisovicziinae, indet.			x			x											
BIVALVIA																	
?Arcopagella sp.										x							
Botula sp.			x	x	x	x		x	x	x	x				x	x	-
Breviarca? habita Stephenson			x												x	x	?
B. subovata Scott			x												x	-	x
Corbula? smolanensis (Twenhofel & Tester)			x												x	x	x
Corbula sp.			x			x											
cf. Crassinella semicostata Scott										x					-	x	x
Cucullaea recedens Cragin		x													x	x	-
Cyprimeria kiowana Cragin		x													-	x	x
C. texana (Roemer)			x												x	x	-
Gervillia invaginata (White)	x														-	-	-
Homomya sp.							x										
Idonearca vulgaris Morton		x															
Inoceramus bellvuensis Reeside			x						x						x	x	-
I. comancheanus Cragin	x	x							x						x	x	
I. sp. indet.				x								x		x			
Lopha quadriplicata (Shumard)	x					x		x	x	x				x	x	x	x
Lopha subovata (Shumard)	x				x										x	x	x
L. aff. L. subovata (Shumard)					x					x							
Lucina cf. L. juvenis Stanton			x												-	-	-
Neithea occidentalis (Conrad)						x	x			x	x				x	x	-
Nucula coloradoensis Stanton			x			x									x	x	-
N. sp.			x														
Nuculana mutata Stephenson			x												x	x	x
Ostrea cf. O. rugosa Scott			x												-	-	x
Ostreidae (epizoans)				x	x	x	x	x	x	x	x						
Pholadomya aff. P. sanctisabae Roemer	x							x		x					-	-	-
Pholadomya sp.			x			x											
Pinna cf. P. comancheana Cragin								x							x	x	-
Plicatula aff. P. dentonensis Cragin										x					-	-	-
P. incongrua Conrad	x					x		x		x	x	x			x	x	-
P. sp.			x		x		x	x	x								
Protocardia cf. P. filosa (Conrad)							x								-	x	-
P. multistriata (Shumard)	x[1]				x										x	-	-
P. texana (Conrad)		x													x	x	x
P. sp. indet.				x		x		x		x							
Pycnodonte? sp.									x								
Scabrotrigonia emoryii (Conrad)	x		x		x	x	x		x	x	x	x			x	x	x
Texigryphaea aff. T. pitcheri (Morton)				x	x	x	x	x	x				x	x	x	x	-
T. tucumcarii (Marcou)	x[2]	x[2]		x	x	x	x	x	x	x	x	x	x	x	x	-	-
T. cf. T. washitaensis (Hill & Vaughan)				x	x				x	x					x	-	-
T. spp.			x														
Veniella? sp.									x								
BRACHIOPODA																	
Discinisca? sp.								x									
VERTEBRATA							x										
Fish scales/teeth, indet.				x				x	x								
Fish jaw fragment								x									

1. As P. multilineata, "apparently an unintended emendation of P. multistriata" (Scott, 1986b)

2. Cited at T. corrugata, but almost certainly referring to specimens here treated as T. tucumcarii.

Albian southern Western Interior seaway. He obtained (R. W. Scott, written commun., 1985) about 20 mollusc species from three localities in Cimarron County (Table 1), but remarked upon "the virtual absence of marine invertebrates in the Glencairn of northeastern New Mexico" (Scott, 1977, p. 176).

Localities

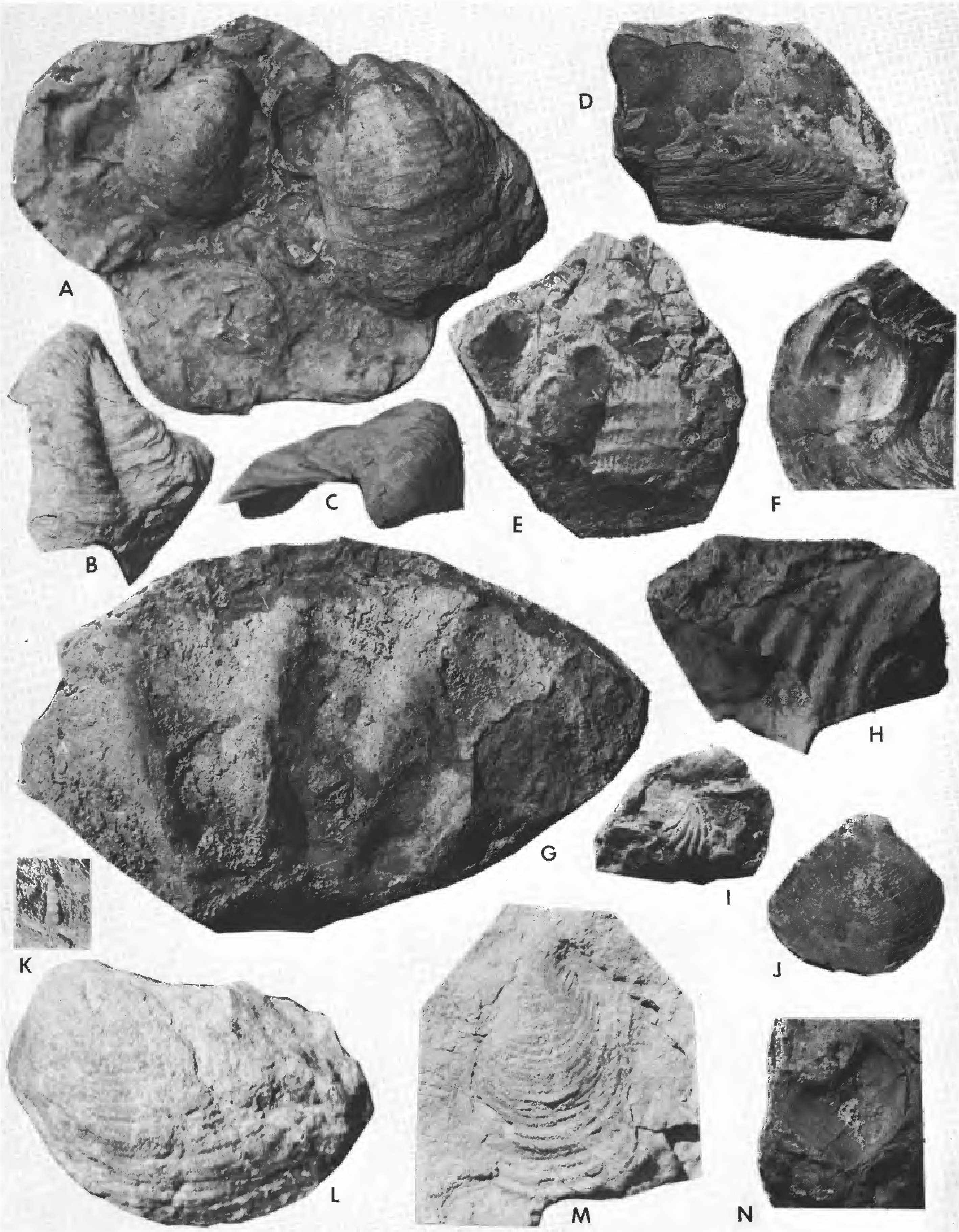
Fossils have been reported or collected from numerous Glencairn localities in the Dry Cimarron area of Union County, New Mexico, Cimarron County, Oklahoma and Las Animas County, Colorado (Fig. 2; Appendix 1). During this study collections were made from 12 localities in Union and Cimarron Counties, spanning the entire length of the Dry Cimarron from Long Canyon eastward to the Boise City area, a distance of about 120 km.

Distribution and preservation

The Dry Cimarron Glencairn biota, based on previous reports and collections made for this study, includes more than 50 species of marine invertebrates, predominantly bivalves (Table 1). By far the most abundant and characteristic species is *Texigryphaea tucumcarii*, which is present in large numbers at some outcrops. Typically most specimens originate from a thin, densely-packed, brown muddy sandstone unit that normally is near the middle of the Glencairn but in some localities is not far above the base (see preceding discussion and Fig. 4). Assemblages of *Texigryphaea* are analyzed in a following section of this paper. Most of the other elements of the Glencairn fauna are also from sandy intervals; the dark gray shale that forms a significant part of the formation is sparsely fossiliferous. Plant fragments are present in sandstones at the top of the Glencairn at a few localities.

Collection and study of the Glencairn biota is hindered by paucity of well-exposed outcrops in the western (New Mexico) half of the Dry Cimarron, and by the often rather poor preservation of the fossils. In Union County the Glencairn interval is conspicuous throughout the Dry Cimarron area as a slope between the underlying Lytle and overlying Mesa Rica cliff-forming sandstones, high on mesas and buttes. However, the Glencairn is usually covered by detritus eroded from the Mesa Rica, and few New Mexico Glencairn localities are exposed, fossiliferous outcrops. The gentle eastward regional dip of Mesozoic strata brings the Glencairn to road level in Cimarron County, Oklahoma, where numerous road and railraod cuts provide fresh exposures. Thus, most information about Glencairn paleontology presented here is necessarily based on collections from Cimarron County.

Most Glencairn fossils are not well preserved compared to similar assemblages in the Tucumcari and Kiowa formations. *Texigryphaea* valves are almost ubiquitously iron-oxidized, which imparts a characteristic orange color and easily eroded and fragmented earthy texture to the fossils. In some valves replacement of the original shell material was incomplete, producing voids and occasional geodization. At some localities, particularly in the western part of the Dry Cimarron, only steinkerns and molds of *Texigryphaea* are present. The single exception to this destructive mode of preservation occurs at UNM locality 1337, north of Boise City, where well-preserved unaltered valves erode from


A
B
C
D
E
F
G
H
I
J
K
L
M
N

an elongate, bull-dozed mound of Glencairn sediments. Iron-oxide replacement of calcareous shells in the Dry Cimarron Glencairn appears to be a local phenomenon probably related to ground-water conditions. Collections of *Texigryphaea* from near Two Buttes, southeastern Colorado, some 80 km north of the Dry Cimarron, show no iron-oxide replacement. Many other Glencairn fossils are similarly poorly preserved; small bivalves, for example, are typically represented by molds and steinkerns.

Because of these factors of poor exposure and preservation, together with the apparent rarity of many taxa and restriction of many species to thin intervals within the formation, a comprehensive study of the Glencairn fauna would require a large expenditure of time to obtain reasonably well preserved, identifiable specimens from each lithofacies of the formation. In this study we concentrated our attention on the *Texigryphaea*-rich fossiliferous sandstone units (lower shoreface environment of Scott, 1974). The sparsely fossiliferous, dark-gray shale intervals of the Glencairn were not thoroughly sampled. This facies represents an open bay environment dominated by small, infaunal detritus feeders, especially nuculoid bivalves (Scott, 1974).

FIGURE 12. *Adkinsites diazi* Young (×0.5), a specimen owned by the Kenton, Oklahoma General Store and earlier reputed to be from the Dry Cimarron area.

The Glencairn fauna

The Dry Cimarron Glencairn fauna is dominated by bivalves, and *Texigryphaea* accounted for more than 90% of all specimens collected (Table 1). As might be expected, the Glencairn fauna includes many taxa present in contemporaneous units to the south (Tucumcari Shale) and to the northeast (Kiowa Formation), but is less diverse than the faunas of either of those formations.

Correlation of the Glencairn with the Tucumcari and Kiowa formations has been determined on the basis of ammonoids and bivalves. Scott (1970b) assigned the Glencairn to the bivalve zones of *Inoceramus comancheanus* and *I. bellvuensis* and to a sequence of ammonoid zones ranging from *Craginites serratescens* to *Drakeoceras lasswitzi*, essentially equivalent to the upper Albian Duck Creek to Denton formations of northern Texas. Ammonoids unfortunately are extremely rare in the Dry Cimarron Glencairn; Scott (written commun., 1985) reported only unidentified mojsisoviczinids, and Stanton (1905) found *Idiohamites fremonti* and *Eopachydiscus brazoensis* (= *E. marcianus*, fide Kennedy et al., 1983). A fragment of *E. marcianus* (Fig. 11G) is the only positively identified ammonoid discovered during the present study.

Farther to the north (Horse Creek, Baca County, Colorado—about 60 km north of the Dry Cimarron) the ammonoids *E. marcianus*, *Engonoceras uddeni*, *Goodhallites* cf. *G. minima*, *I. fremonti* and *I.* sp. occur in the Glencairn (Cobban, 1987). *Engonoceras uddeni* is a lower to middle Kiowa species (Scott, 1970a), and *I. fremonti* is a basal Duck Creek form (Cobban, 1987), whose zone is between that of *Adkinsites bravoensis* and *Eopachydiscus marcianus* (Kauffman, 1975, fig. 4). *Eopachydiscus marcianus* is confined to the Duck Creek in Texas, where it co-occurs with but does not range as high as *Mortoniceras equidistans* (Cobban, 1985). It is also present with *M. equidistans* in the lower Mesa Rica Sandstone of the Tucumcari area (Cobban, 1985; Kues et al., 1985). Taken together, the ammonoids suggest an age no younger than the *M. equidistans* zone (upper Duck Creek of northeastern Texas) for the Glencairn. Several Glencairn bivalves (e.g., *Lopha quadriplicata*, *L. subovata*, *Scabrotrigonia emoryi*, *Plicatula incongrua*) do range into units above the Duck Creek in Texas, however.

The age of earliest Glencairn deposition in the Dry Cimarron area has been unclear. Scott (1970b) did not find positive evidence of the occurrence of the *Adkinsites bravoensis* zone (Kiamichi, lower Kiowa) in the Oklahoma panhandle. However, he reported a specimen of *A. bravoensis*, purportedly from near Kenton, in the Kenton General Store. We examined an ammonoid specimen from this store (Fig. 12) and identified it as *A. diazi*, an assignment corroborated by Keith Young (written commun., 1986). *Adkinsites diazi* is an *A. bravoensis*-zone species known from eastern and southwestern Texas and Mexico (Young, 1966). We doubt that this specimen came from the Kenton area because it is a steinkern composed of a light gray, dense limestone—a lithology we have not encountered in the Glencairn of the Dry Cimarron area. This has been confirmed by the store owner in 1986 (R. W. Scott, written commun., 1987). We collected a small fragment of an ammonoid that may be *A. bravoensis* (Fig. 11H) from the lower part of the Glencairn east of Kenton (UNM locality 1332). If *A. bravoensis* is present in the Glencairn here it indicates either the presence of that zone as it has been defined in Texas, or that this species ranges into younger sediments than its zone, as is the case in Texas (Young, 1966; Scott, 1970b).

The remainder of the Dry Cimarron Glencairn fauna consists primarily of species known from the Tucumcari and/or Kiowa formations (Table 1). Among the gastropods, *Amberleya mudgeana* and *Otostoma marcouana* are reported from the Glencairn for the first time. Although Stanton (1905) and Scott (1974) reported *Turritella seriatimgranulata* from the Glencairn of Cimarron County, the only turritellids we observed were a few poorly preserved specimens with an ornamentation closer to that of *T. belviderei*, from near the base of the formation at UNM locality 1332. Low gastropod diversities are characteristic of Albian units in Colorado and New Mexico (Scott, 1975).

With the exception of *Texigryphaea*, discussed below, bivalve species are uncommon and poorly preserved, but comprise most of the diversity of the Glencairn fauna. The two characteristic southern Western Interior Albian inoceramids, *Inoceramus comancheanus* (Fig. 11M) and *I. bellvuensis*, are represented by partial molds and shell fragments. Discrimination between the two species was hesitantly done on the basis of size and pattern of concentric ornamentation because the shape of complete valves, a more reliable distinguishing feature, could not be ascertained. Co-occurrence of these species in the Glencairn has also been reported near Two Buttes, Colorado, and in equivalent units to the west (Scott, 1970b). *Lopha quadriplicata* (Fig. 11N) is moderately common

FIGURE 11. Fossils from Glencairn Formation, Dry Cimarron area, Cimarron County, Oklahoma. A, *Texigryphaea tucumcarii* (typical form), external views of two left valves in stable position (convex surface up) on slab, UNM 9580, 9581, UNM locality 1336, ×0.5. B, C, *T.* aff. *T. pitcheri*, external and umbonal views of incomplete left valve, UNM 9582, UNM locality 1337, ×0.67. D, E, *Pinna* cf. *P. comancheana*, fragments of parts of valve showing broad radial costae and finer growth lines, UNM 9583, 9584, UNM locality 1336, ×1. F, ?*Pycnodonte* sp., left valve cemented to external surface of *Texigryphaea* right valve, UNM 9585, UNM locality 1337, ×1. G, *Eopachydiscus marcianus*, fragment of steinkern showing simple broad ribs, UNM 9586, UNM locality 1331, ×0.5. H, Mojsisoviczinae, cf. *Adkinsites bravoensis*, fragment of steinkern, UNM 9587, UNM locality 1332, ×0.67. I, *Plicatula incongrua*, UNM 9588, UNM locality 1338, ×1. J, *Pholadomya* sp., steinkern, UNM 9589, UNM locality 1332, ×1. K, *Cribratina texana*, UNM 9590, UNM locality 1332, ×1.25. L, *Homomya* sp., steinkern, UNM 9591, UNM locality 1334, ×1. M, *Inoceramus comancheanus*, mold of left valve, UNM 9592, UNM locality 1338, ×1. N, *Lopha quadriplicata*, interior of left valve, UNM 9593, UNM locality 1338, ×1.25.

at some localities, but is much less abundant than in some intervals of the Tucumcari Shale. Fragments up to 150 mm long of a large, plicate, thick-shelled *Lopha* are referred to *L. subovata*. On these specimens the plications are sharp, lamellate and reach a width of 30 mm at the margins of the valves. One large specimen (*L.* aff. *L. subovata*) has a rather convex valve and narrow, widely-spaced plications—significantly different from the usual broad plications that generally characterize *L. subovata* in the Glencairn and Tucumcari formations. However, Stanton (1947) reported wide variation in the size and shape of plications in *L. subovata;* thus, this specimen may be a variant of that species.

Small fragments of a pinnid bivalve were collected at a single locality north of Boise City. Ornamentation appears to consist of about 10 fine, sharp, widely spaced radial costae, crossed by less prominent but sharp growth lines (Fig. 11D, E). Most pinnids reported from the Albian of Texas and the southern Western Interior have been assigned to *Pinna comancheana*, but the detailed features of this species are not well known. Cragin's (1894b) original description was somewhat vague, and the types have never been illustrated, but the ornamentation was described as "rather remote radial costellae and somewhat less conspicuously raised remote concentric lirae," which indicates a pattern similar to that of the Glencairn specimens. Cragin (1894b) noted the presence of *P. comancheana* in the Tucumcari Shale, and specimens in the UNM collections from that formation (some reaching a length of 150 mm) appear to be the same species as the Glencairn specimens.

On the other hand, Adkins (1928, pl. 18, fig. 6) illustrated a poor specimen of what he called *P. comancheana* from the Fredericksburg Group of Texas that possessed about 9 broadly rounded radial ribs that were wider than the interspaces between them—very different from the Glencairn specimens. Better described and illustrated is *P. guadalupae*, a species from Albian units at Cerro de Cristo Rey, near El Paso (Böse, 1910). This species may be a synonym of *P. comancheana*, although Böse differentiated his species by the absence of a keel. The ornamentation of the Glencairn specimens is very similar to that of *P. guadalupae*. Given these taxonomic uncertainties, the Glencairn *Pinna* is assigned to *P.* cf. *P. comancheana*. Although Cragin (1894b) described the species from the Kiowa, neither Twenhofel (1924) nor Scott (1970a) discovered specimens in that formation, and the genus was not previously known from the Glencairn.

Plicatula incongrua (Fig. 11I) is present at several localities. This species is small (up to about 10 mm in height) and possesses about eight well defined, subnodular, radial costae. Similar specimens, but with generally smoother, less nodose costae occur in the Tucumcari Shale. Scott (1970a) reported the closely similar *P. senescens* from the Kiowa but noted that it may be a synonym of *P. incongrua*. A second type of *Plicatula* resembles *P. incongrua* but has spinose ribs. One specimen, much larger (20 mm high; 17 mm long) and with more radial costae (17–20) than *P. incongrua,* was collected from UNM locality 1339. The costae are rounded, closely-spaced, increase by bifurcation to produce narrow secondary ribs and possess obscure nodes where crossed by growth lines. This specimen resembles *P. dentonensis* Cragin, from the Fort Worth and Denton formations of Texas (Perkins, 1960). Fragmentary specimens of *Neithea occidentalis,* a widespread pectinid, are minor elements of the Glencairn fauna at a few localities. *Scabrotrigonia emoryi* and steinkerns of *Protocardia* are moderately abundant in Glencairn sandstones.

Probably several species of pholadomyids occur in the Glencairn, but poor preservation (as molds and distorted steinkerns) prevents positive identification. *Pholadomya* is represented by relatively small, incomplete molds. The most complete specimen (Fig. 11J) displays about 20 broadly rounded radial ribs broken into isolated rows of nodes by concentric lirae of nearly equal magnitude across the anterior half of the valves. This ornamentation is similar to that of several Albian species (e.g., *P. sanctisabae, P. shattucki, P.*? *belviderensis*). *Homomya* is represented in the UNM collections by one large (height = 50 mm; length = 69 mm; width = 41 mm), nearly complete steinkern (Fig. 11L), having numerous coarse concentric growth lines and high, strongly anterior beaks. This specimen is unlike the specifically indeterminate examples of the genus reported from the Kiowa (Scott, 1970a) and the Tucumcari-Mesa Rica (Kues et al., 1985). It most closely resembles such species as *H. cymbiformis* (Perkins, 1960) and *H. bravoensis* (Böse, 1910) from the Albian of Texas and Mexico.

One poorly preserved small bivalve has a distinctly triangular shape and about nine strong, widely-spaced concentric lamellae, an ornamentation pattern similar to that of *Veniella* or *Astarte*. The report of *Idonearca vulgaris* from the Colorado Dry Cimarron localities (Long, 1966) is perplexing. To our knowledge this species has not been reported from any other Albian units in Texas or the southern Western Interior.

At one locality in Cimarron County (UNM locality 1332) a thin, ledge-forming, light gray, very fine-grained, silty to slightly calcareous sandstone occurs about 4 m below the main *Texigryphaea* horizon, near the base of the Glencairn (Fig. 4, section G, locality 1332B). This unit contains a fauna that is somewhat different from that of the upper *Texigryphaea* sandstone. Small turritellid gastropods (*Turritella* cf. *T. belviderei*), the large foraminifer *Cribratina texana* (Fig. 11K), *Nucula* cf. *N. coloradoensis* and corbulid bivalves are present, together with some specimens of *Texigryphaea, Scabrotrigonia* and *Lopha quadriplicata*. The specimens of *Corbula* are relatively common, small (length = 4–5 mm), possess a well developed, elongate posterior rostrum, and have about seven prominent concentric folds along the lower half of their valves. They do not appear to be referable to any of the species reported by Scott (1970a) from the Kiowa, or by Adkins (1918) from the Weno Formation of Texas.

Remains of non-molluscan, free-living organisms are rare in the Glencairn. One specimen of the circular, cap-shaped inarticulate brachiopod *Discinisca*? sp. was observed, and small fragments of indeterminate fish scales and teeth are present in sandstone units at several localities. The only possibly identifiable vertebrate material is a fragment of a fish jaw bearing several teeth.

A variety of organisms utilized the valves of *Texigryphaea* as an attachment site or bored into them, including oysters, serpulid worms, acrothoracic barnacles, boring sponges and boring bivalves (*Botula*). Our subjective impression is that epizoan infestation was not as pronounced on Glencairn texigryphaeas as on texigryphaeas from the Tucumcari Shale. Only rarely were densely-covered or bored shells observed in the Glencairn, and many shells showed little or no indication of infestation. In contrast to Tucumcari epizoan assemblages, no bryozoans were observed on Glencairn shells.

Both ostreids and pycnodonts are attached to other shells. Most ostreids are valves of variable but roughly circular shape and small to moderate (up to 35 mm in diameter) size, that appear to be an unidentified species of *Ostrea*. The typical *Ostrea* species in the Glencairn and equivalent units in Colorado (*O. larimerensis* Reeside and *O. noctuensis* Reeside) were free-living, relatively large forms with very thin shells (Reeside, 1923), and neither species is known in the Dry Cimarron Glencairn. *Ostrea rugosa* Scott and *O. arcuata* Scott, of the Kiowa Formation, seem also to lack early growth stages that are cemented for a significant length of time; the attachment scar of *O. rugosa*, for example, is reported to be small (Scott, 1970a).

Crassostrea kiowana (Cragin) possesses a large elongate shell, but Twenhofel (1924, p. 77) noted that in "young forms, the entire valve is frequently attached, and these young forms are commonly attached to older individuals, so that a group has the same general appearance as a group of *Ostrea congesta* from the Niobrara Formation." The fact that mature valves of *C. kiowana* have never been reported from the Glencairn, plus the circular, rather than elongate shape of the Glencairn oysters, suggest that the Glencairn epizoan oysters are probably not juveniles of *C. kiowana*. They are here merely referred to as *Ostrea* sp.

The pycnodont group of cemented oysters is superficially similar to the ostreids, but is much less abundant. These oysters are characterized by a vesicular shell, expressed most conspicuously around the periphery of the attachment area (Fig. 11F). Vesicular shell construction is a distinguishing feature of the Pycnodontinae, the subfamily that includes the common Upper Cretaceous *Pycnodonte*, as well as *Texigryphaea* (Stenzel, 1971), whereas ostreid shells lack a vesicular structure. *Texigryphaea* spat normally remained attached to a hard substrate for only a very short time (Stenzel, 1971); attachment scars on left valves of Dry Cimarron Glencairn texigryphaeas only very rarely exceeded 3 mm in diameter. The vesicular shell structure, large area of attachment and presence of small sinuous chomata along the commissure suggest that these cemented left valves may be *Pycnodonte*. Alternatively, they could be unusual specimens of *Texigryphaea* that remained cemented for a long period of time.

Tubular, branching borings of clinoid sponges are common on some *Texigryphaea* valves. Although borings of this type have been called *Cliona* by many workers, Bromley (1970) pointed out that the only available name for Mesozoic and Tertiary borings attributed to clionid sponges is *Entobia*. A few *Texigryphaea* valves are completely riddled with these borings, which are preserved as purplish, sandy phosphatic casts within the shell or exposed as networks of interconnected tubes where the shell has been dissolved. These casts are remarkably similar to structures in bivalve shells from the Maastrichtian Navarro Group of Texas, which Stephenson (1941) called *Cliona microtuberum*.

We did not attempt identification of the few poorly preserved plants collected from the uppermost Glencairn near the eastern tip of Black Mesa (UNM locality 1333). Stovall (1943) believed this locality to be in the lower member of the "Dakota" (Mesa Rica Sandstone) but the plants occur at the top of the Glencairn slope, beneath the massive, conglomeratic, cliff-forming Mesa Rica Sandstone.

Texigryphaea

The large gryphaeid genus *Texigryphaea* is by far the most abundant invertebrate in the Dry Cimarron Glencairn. Approximately 850 specimens of *Texigryphaea* were collected from 11 localities (Table 1) in Union and Cimarron Counties in order to study their morphology, variability and relationships to assemblages in the Tucumcari Shale. Specimens from eight of the localities, mostly in Cimarron County, were intensively studied and measured. Most of the Glencairn specimens are *T. tucumcarii* (Marcou); a few are provisionally assigned to *T.* cf. *T. washitaensis* (Hill and Vaughan), and a few appear to be related to *T. pitcheri* (Morton), which Hill and Vaughan (1898) considered to be *T. corrugata* (Say).

In order to define the morphological variability of the assemblage as many as 14 different measurements of relatively complete left valves were made (Fig. 13). Measured parameters were chosen to reflect important valve dimensions and structures, and in general follow those utilized by other workers (e.g., Hallam, 1968; Hallam and Gould, 1975) in biometric studies of European Jurassic species of *Gryphaea*. Terminology, however, follows Stenzel (1959, 1971) and Fay (1975), instead of that employed by Hallam and Gould (1975); for example, height of valve as used here is the dimension called length by Hallam and Gould. Some subjective observations were also made of valve features that were not measured, such as degree of beak deflection, and beak position relative to resilifer and bourrelet portions of the hingeline. Each measured specimen was examined for epizoan organisms, although poor preservation and matrix coverage precluded any detailed statistical treatment of epizoan distribution and abundance on *Texigryphaea* valves. The majority of left valves collected were so fragmentary that height and length measurements could not be made, but about 225 left valves were measured. Of these, 17% were preserved in a state of articulation with their right valves. This work is part of a larger study of all species of *Texigryphaea* throughout Texas and the southern Western Interior, in progress by one of us (BSK).

In this study of Glencairn texigryphaeas, specimens from all localities are grouped into a single statistical population. This approach is reasonable because the localities are in close proximity within an area about 50 km wide, and the occurrence of *Texigryphaea* within the Glencairn at each locality is similar. Most specimens were derived from a thin, muddy, fine-grained sandstone unit in the lower half of the formation (Fig. 4), in which shells were densely associated. The substrate upon which these bivalves lived, judging from in-situ observations and examination of the matrix adhering to displaced valves, was predominantly dark gray to grayish-brown, muddy to silty fine-grained sand, grading to sandy mud. A few specimens were derived from dark gray mudstones with little sand, immediately above or below the main *Texigryphaea* horizon. These observations accord with those of Scott (1974) for his *Texigryphaea-Lopha* biostrome community, which represents transported-disturbed neighborhood assemblages within an offshore, lower shoreface, normal marine environment.

The Dry Cimarron Glencairn texigryphaeas are fairly variable morphologically. Mature valves fall into four main morphologically distinct groups, with juvenile (height less than 30 mm) valves considered separately as a fifth group. Each of the four groups of mature valves is gradational with one or more of the other groups, and in some cases boundaries recognized between them are arbitrary. The two most common and intimately gradational groups are the typical and broad forms of *Texigryphaea tucumcarii,* which together constitute 65% of the total valves (Table 2). A lower, arcuate form, here called *T.* aff. *T. pitcheri,*

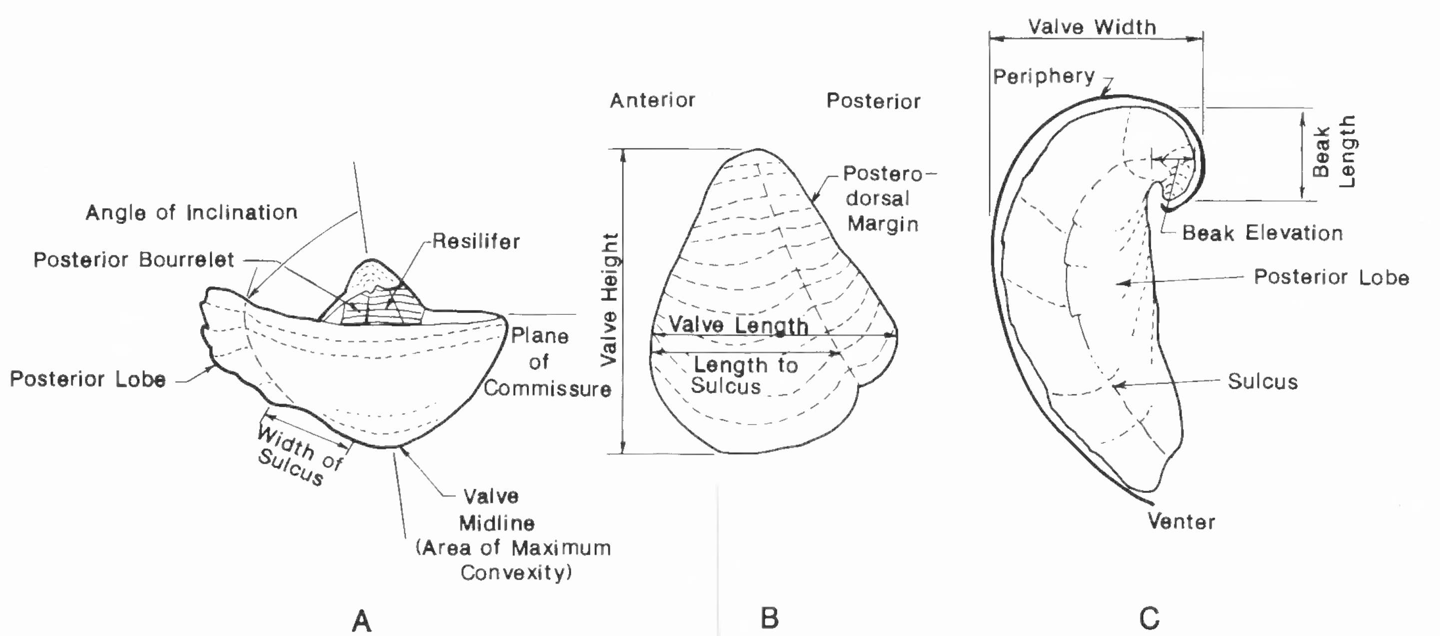


FIGURE 13. Left valve of *Texigryphaea,* basal margin (A), external (B) and side (C) views, showing structures and measured dimensions (adapted from Stenzel, 1959 and Fay, 1975).

TABLE 2. Summary of left valve proportions of forms of *Texigryphaea* from the Glencairn of the Dry Cimarron area. Abbreviations: N, number of measured specimens; L, length of valve; H, height of valve; W, width of valve; P, periphery (beak to venter curvature); BL, beak length; BE, beak elevation above commissure; SW, width of sulcus; SD, depth of sulcus; DA, distance from anterior margin to sulcus (length to sulcus); HW, width of hingeline; A, angle of umbo inclination; NNM, number of specimens not measured; T, total number of specimens; %, percent of total specimens belonging to each form.

	N	L/H	W/H	P/H	BL/H	BE/H	SW/L	SD/SW	DA/L	HW/L	A	NNM	T	%
T. tucumcarii (typical)	69	.78	.44	1.62	.22	.16	.25	.10	.76	.32	85°	114	183	29
T. tucumcarii (broad)	75	.90	.45	1.63	.23	.16	.26	.11	.73	.35	85°	151	226	36
T. aff. T. pitcheri	17	.94	.44	1.67	.25	.19	.26	.12	.68	.32	76°	20	37	6
T. cf. T. washitaensis	6	.94	.50	1.71	.23	.15	.22	-	-	-	100°	5	11	2
Juvenile valves	55	.93	.47	1.54	.13	.08	.24	.10	.75	.36	88°	121	176	28

accounts for 6% of the total valves, and *T.* cf. *T. washitaensis* represents 2% of the total. The other 27% of the specimens are juvenile valves, most of them undoubtedly *T. tucumcarii*. Summary measurements and proportions for each group are presented in Table 2, and representative specimens of each group are illustrated in Figures 11 and 14.

About 90% of the identifiable mature *Texigryphaea* left valves in the Dry Cimarron Glencairn are *T. tucumcarii*. This species was established by Marcou (1855) for specimens collected from the Tucumcari Shale at Pyramid Mountain, Quay County, New Mexico. The validity of this species and its relationships to *T. pitcheri* (Morton) were the subject of an acrimonious nineteenth-century debate (see Kues, 1985, for historical summary). Hill and Vaughan (1898) considered it a variety of *T. corrugata* (their name for *T. pitcheri*), but most twentieth-century workers (e.g., Stenzel, 1959; Fay, 1975; Kues et al., 1985; Scott, 1986a) have considered *T. tucumcari* to be a valid species, limited to the western side of the Albian southern Western Interior seaway.

The Glencairn *T. tucumcarii* specimens considered here display approximately the same range and types of morphological variation as specimens from the Tucumcari Shale. In general the left valve of this species is characterized by large size (some exceed 100 mm in height), an umbonal plane that is slightly inclined posteriorly to essentially perpendicular to the plane of the commissure (mean angle of inclination = 85°), a relatively small, short beak (mean beak length/valve height = 0.22), a weakly to moderately developed posterior sulcus and a narrow to flange-like posterior lobe. The beak is moderately to not-at-all deflected posteriorly and overhangs the posterior half of the hingeline resilifer. Very rapidly during growth, within about 5–10 mm of the end of the beak, the umbo became essentially vertical, and the area of maximum valve convexity (valve midline) through subsequent growth maintained a straight to gently arcuate profile perpendicular to the hingeline. In other words, coiling of the post-juvenile valve tended toward planispiral. The left valve of *T. tucumcarii* is thus broadly rounded across the midline and has a relatively deep, oval to round shape.

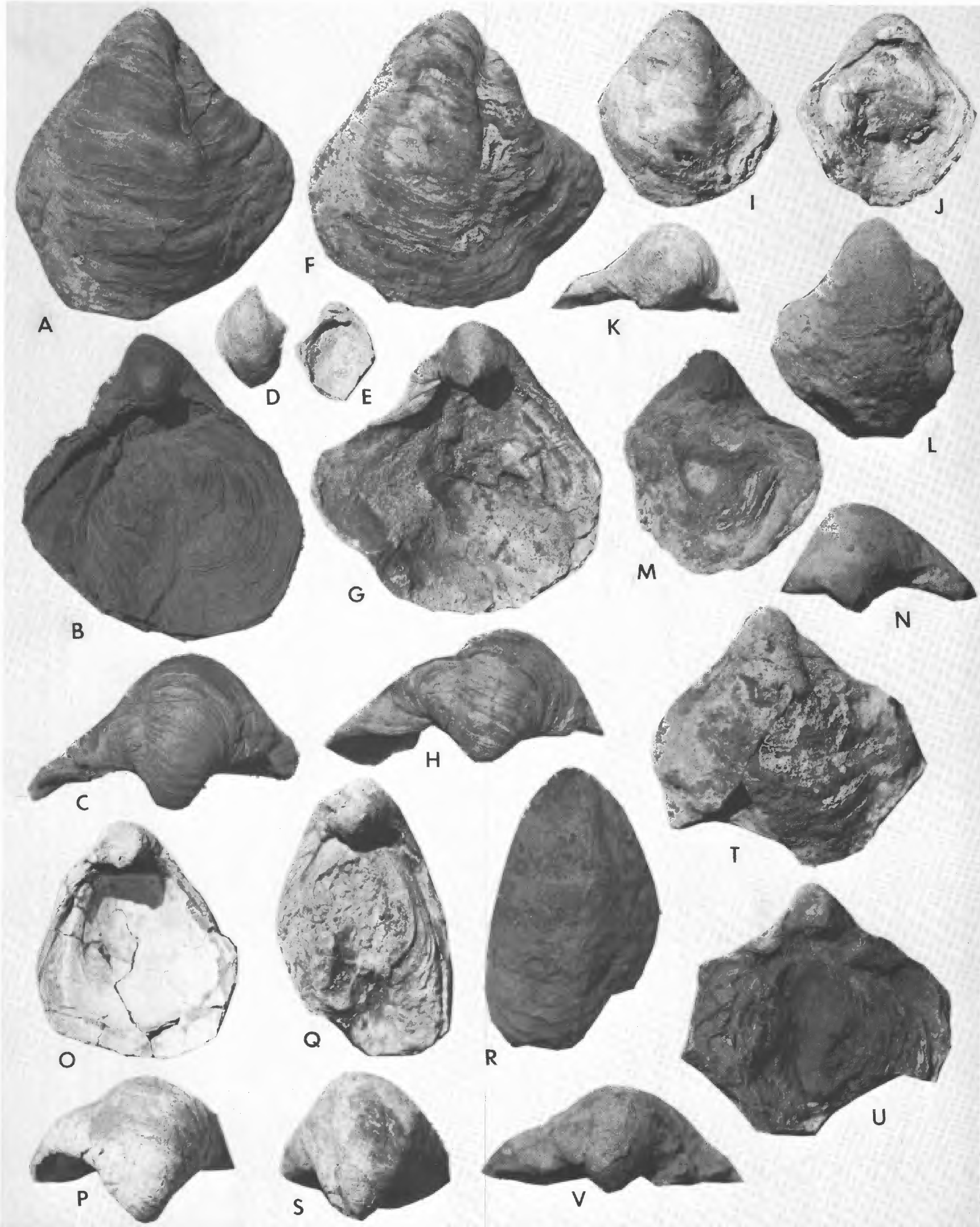
Two major morphological patterns present in about equal abundance were observed in collections from Union and Cimarron Counties. The first (typical form) has a left valve with an oval, tear-drop, or vaguely triangular commissure, straight midline and no extension of the posterior lobe (Fig. 14O). In most specimens the postero-dorsal margin is straight to gently convex and projects from the hingeline at about the same angle as the antero-dorsal margin, producing a shell that is nearly symmetrical across the midline from the anterior to posterior margins. The mean length/height ratio is 0.78 (Table 2). This form includes the holotype of the species (Fay, 1975, fig. 23; Kues et al., 1985) and similar individuals. An extreme development of this form is a small number of exceptionally narrow, elongate valves (mean length/height ratio = 0.64; see Fig. 14Q–S).

The second form (broad form; Figs. 14A–C, F–J, T–V) is characterized by a round to posteriorly extended commissure (mean valve length/height ratio = 0.90). The posterior lobe is lower and more extended than in the typical form, and the sulcus is slightly farther from the posterior margin (DA/L = 0.73, compared with 0.76 for the typical form). The midline is straight to gently arcuate. In some individuals (e.g., Fig. 14F–H) the posterior lobe is extended, due to much faster addition of new shell material along the postero-dorsal margin than along the antero-dorsal margin during growth. This pattern of growth was evidently initiated relatively early, as a few juvenile specimens display greatly extended posterior flanges. Degree of beak-to-venter curvature of the valves, umbonal angle, beak deflection and beak size in both forms are nearly identical (Table 2). Although isolated specimens of these two forms may appear to be quite different, large collections of left valves display complete intergradation.

A third form (Fig. 11B, C), here called *T.* aff. *T. pitcheri*, comprising about 7% of the mature *Texigryphaea* specimens, differs from *T. tucumcarii* in several subtle ways. The umbonal plane is more inclined posteriorly away from vertical (mean angle = 76°). The line of maximum valve convexity describes a moderately curved arc from the umbo to the venter; the valve grew in a low, conispiral pattern. The posterior lobe is extended both posteriorly and in some specimens upward so that it rises much higher than the beak above the hingeline. The beak tends to be moderately deflected and to terminate above the posterior edge of the resilifer. The sulcus appears subjectively to be somewhat better developed than in *T. tucumcarii*, and its distance from the posterior valve margin is slightly greater (mean DA/L = 0.68). Together, these features result in a left valve that is slightly lower and broadly arcuate in shape compared to the oval deep valves of *T. tucumcarii*. The development of the characters noted above is variable within a suite of specimens, and intergradation occurs with the broad form of *T. tucumcarii*, to the extent that some specimens can only arbitrarily be assigned to one form or the other. Small numbers of this arcuate form also occur in the Tucumcari Shale (Kues et al., 1985, figs. 8C–D).

Valves of this general shape have been assigned to *T. corrugata* or *T. pitcheri* by some workers (e.g., Kauffman, 1977, pl. 2, fig. 3). The

FIGURE 14. *Texigryphaea* from Glencairn Formation, Dry Cimarron area, Union County, New Mexico and Cimarron County, Oklahoma. A–C, *T. tucumcarii* (broad form), ventral, dorsal and umbonal views of an articulated specimen, UNM 9572, UNM locality 1337, ×1. D, E, *T. tucumcarii*, external and internal views of a juvenile left valve, UNM 9573, UNM locality 1339, ×1. F–H, *T. tucumcarii* (broad form), external, internal and umbonal views of left valve, UNM 9574, UNM locality 1337, ×1. I–K, *T. tucumcarii*, ventral, dorsal and umbonal views of an articulated immature specimen, UNM 9575, UNM locality 1337, ×1. L–N, *T.* cf. *T. washitaensis*, ventral, dorsal and umbonal views of a specimen with posterior margin broken off, UNM 9576, UNM locality 1337, ×1. O, P, *T. tucumcarii* (typical form), interior and umbonal views of left valve, UNM 9577, UNM locality 1339, ×0.67. Q–S, *T. tucumcarii* (unusually narrow specimen), dorsal, ventral and umbonal views of articulated specimen, UNM 9578, UNM locality 1332, ×0.67. T–V, *T. tucumcarii* (broad form), ventral, dorsal and umbonal views of an unusually wide articulated specimen, UNM 9579, UNM locality 1330, ×0.67.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V

holotype of *T. pitcheri* is a small specimen about 22 mm high (Stanton, 1947, pl. 10, figs. 4, 5; Fay, 1975, figs. 19, 20). Considerable changes in shape and expression of some morphological features occur during the growth of *Texigryphaea*, and juveniles of most species are not as distinct as mature individuals. These factors, plus lack of information about the nature of mature valves from the type area and stratigraphic horizon of *T. pitcheri* (Caddo Formation of the Fort Towson area, southeastern Oklahoma: Fay, 1975) make it difficult to relate mature *Texigryphaea* valves to the immature holotype of *T. pitcheri*. Because of these uncertainties, and the broad concept of *T. corrugata* (= *T. pitcheri*) utilized by Hill and Vaughan (1898), *T. pitcheri* has been widely reported from many late Albian formations in Texas and the southern Western Interior. However, as few of these reports were accompanied by adequate descriptions of illustrations, uncertainties remain concerning the exact nature of the valves to which the names *T. corrugata* and *T. pitcheri* have been applied. Stanton's (1905) original report of *T. corrugata* in the Dry Cimarron Glencairn, for example, almost certainly refers to specimens of *T. tucumcarii,* which at that time was considered to be synonymous with or a variety of *T. corrugata*.

Also unclear is the taxonomic validity of several species of *Texigryphaea*. Scott (1970a), for example, suggested that the five species and subspecies present in the Kiowa Formation of southern Kansas represented ecophenotypes that reflected variations in substrate firmness, implying that all might be variants within a single biological species. Fay (1978) stated that *T. pitcheri* appears to be the young form of *T. tucumcarii*. At present we do not comment on these taxonomic questions, believing further study of all species from a wide geographic area is required to answer them. For convenience, the arcuate form discussed above is referred to here as *T.* aff. *T. pitcheri,* both because similar valves have been assigned to *T. pitcheri* by other authors and to emphasize that these specimens are distinct from both forms of *T. tucumcarii* in some features. Although uncommon in the Dry Cimarron Glencairn, this form is much more abundant in the Glencairn east of Two Buttes, Colorado (Kues, 1987).

A fourth form of *Texigryphaea*, comprising about 3% of the mature valves, is similar in several features to *T. washitaensis*. This species is widespread in the Duck Creek through Main Street formations in Texas and southeastern Oklahoma, and often is the only or dominant texigryphaea present in a formation. It has not been reported from the Kiowa Formation; Fay (1975) and we have observed a few specimens in the Tucumcari Shale that are probably *T. washitaensis*.

Left valves of *T. washitaensis* are generally broad, deep, fairly strongly convex from beak to venter and small to medium in size. They are also rather sharply rounded (but not carinate) across the midline, and many possess an extended antero-dorsal margin that is nearly parallel to the hingeline, producing an anterior "wing" or flange comparable to the posterior flange. The umbonal plane is vertical or inclined anteriorly rather than posteriorly as in other species of *Texigryphaea*. Among the cotypes of the species, however, are rather narrow and arcuate forms (e.g., Stanton, 1947, pl. 16, figs. 3, 7), and there is a high degree of variability in the expression of the anterior flange. Variation in large assemblages of *T. washitaensis,* particularly from formations in which it is the only texigryphaea present, has not been studied. The species is reported to grade into *T. pitcheri* in the Duck Creek Formation near Denison, Texas (Hill and Vaughan, 1898).

The left valves assigned to *T.* cf. *T. washitaensis* from the Dry Cimarron Glencairn (Fig. 14L–N) possess an anterior flange and display a mean umbonal angle of 100° (umbonal plane anteriorly inclined). The beak-to-venter curvature of left valves (mean P/H = 1.71; mean W/H = .50) is greater than in other forms of Glencairn texigryphaeas. Morphologically, this form grades evenly into medium-sized examples of the broad form of *T. tucumcarii*. The presence of a few *T. washitaensis*-like valves in both the Glencairn and Tucumcari is probably best explained as resulting from ecologically-controlled variation within assemblages of *T. tucumcarii,* rather than immigration of *T. washitaensis* across the Western Interior seaway from eastern Texas. It is possible that forms having the *T. washitaensis* morphology developed separately, becoming very successful in the east, in favorable ecological conditions (possibly related to quiet, carbonate environments) that were greatly restricted in the west.

Juvenile and immature left valves (Fig. 14D, E, I–K) are typically inflated, nearly symmetrical across the midline, have a vertical umbonal plane and lack or possess only an obscure sulcus. The beaks are invariably small and low, and do not or just barely overhang the hingeline. The small beaks and umbos account for the relatively low curvature of juvenile valves (mean P/H = 1.54). The beaks for a few mm may be strongly deflected posteriorly but during subsequent growth curve sharply toward a vertical position relative to the plane of the commissure. Normally the juvenile valve begins to develop characteristics of the mature valve when a height of about 20–30 mm is attained, but a few specimens appear to have maintained a juvenile morphology much longer. As previously mentioned, development of a posterior flange and deep sulcus began early in some specimens, as shell material was secreted rapidly along the posterior margin. These individuals probably represent juveniles of *T.* aff. *T. pitcheri* or the broad form of *T. tucumcarii*.

Young, post-larval texigryphaeas were generally attached to a hard substrate for only a very short time before becoming free living (Stenzel, 1971). Of those Glencairn specimens (of all sizes) on which the tip of the beak could be seen clearly, 94% displayed a small (3 mm or less) flat area or shallow pit marking the attachment site, and 6% possessed an attachment scar greater than 3 mm in length. On one unusual specimen an enormous attachment scar distorted the entire beak and umbo areas.

Variability among the geographically restricted, contemporaneous assemblages of *Texigryphaea* in the Dry Cimarron Glencairn is probably related to minor variations in ecological conditions, especially substrate, within their marine habitat. We did not study the paleoecology of these bivalves in detail, but the following general suggestions seem reasonable in view of what is known about the morphology and ecology of *Texigryphaea* and related genera of similar shape. *Texigryphaea* lived with its left valve partially embedded in the substrate (convex surface downward) and the commissure more or less horizontal (Stenzel, 1971). Its suspension-feeding habit necessitated a life position in which the flow of inhalant and exhalant water currents was unimpeded and uncontaminated by sediment particles; thus the commissure was elevated above the substrate.

Species of *Texigryphaea* inhabited a wide range of substrates, including nearshore shallow sands within the wave zone (Scott, 1970a), shallow, possibly euryhaline muds (Flatt, 1976), lower shoreface muddy sands (Scott, 1974) and offshore, relatively deep, soft to oozy muds (Laughbaum, 1960; Stenzel, 1971). Our observations suggest that the Dry Cimarron texigryphaeas lived in normal marine salinity, a moderate distance offshore on a muddy sand to sandy mud substrate. In situ assemblages at several localities suggest conditions of low to moderate turbulence; less than half the specimens observed were preserved in an articulated state, and many were in their hydrodynamically stable position (convex surface of left valve up), having been flipped over from their living position (e.g., Fig. 11A).

Hallam (1968) and Hallam and Gould (1975) discussed the relationships between valve shape and ecology in an analysis of phyletic sequences of British Jurassic gryphaeas. Among their conclusions were that although valve curvature (coiling) was a necessary adaptation to a muddy substrate, it imposed an instability upon the shell that was modified by development of a sulcus, an extended posterior lobe and thickening of the shell in the umbo region. Greatest stability was ultimately attained by development of a large, broad, relatively flat shell, the morphological end-point in both Jurassic lineages studied by these authors. Scott (1970a) suggested that valve shapes displayed by several species and subspecies of Kiowa texigryphaeas were ecophenotypic responses to different conditions of substrate firmness.

Both the broad and typical (narrower) forms of *T. tucumcarii* have left valves curved from beak to venter to an equal and moderate degree and reach large sizes. The deep, oval, elongate left valve of the typical form of *T. tucumcarii* would appear to be best adapted for a relatively soft substrate, into which the bivalve could sink until it was stabilized by the surrounding sediments. Too soft or fluid a substrate, however, would have endangered the ability of the animal to maintain its commissure above the sediment surface. Extension of the posterior lobe into a flange, resulting in a broader shell (broad form) was a likely response to an environment producing greater instability of the left valve. The additional stability conferred by an extended flange would have been useful in a higher energy environment and/or on a firmer substrate than that on which the typical form lived. Sediment firmness within the lower shoreface *Texigryphaea*-habitat was affected by the abundance of sand grains mixed with substate mud. Greater amounts of sand would have tended to stabilize an initially soft mud substrate, and would also reflect a near-shore, shallower-water, higher-engery environment. The two gradational forms of *T. tucumcarii*, then, probably represent ecological variation within a species that inhabitated a modest range of substrate and turbulence conditions in an offshore marine environment.

The left valve of *T.* aff. *T. pitcheri*, with its inclined umbonal plane, is lower and more arcuate than the left valve of *T. tucumcarii*. This shape is best suited for stability on a relatively firm substrate. The lateral curvature of the valve that produces the arcuate shape would have spread the weight of the bivalve over a greater area than a straight, deep, elongate shell. On a soft, muddy substrate, however, the shells of *T.* aff. *T. pitcheri*, with their commissure closer to the sediment surface, would have been subject to sinking and influx of sedimentary material into the mantle cavity.

Texigryphaea cf. *T. washitaensis*, on the other hand, has a relatively strongly convex, deep left valve that would have been unstable on a firm substrate but stable within relatively soft sediments. The development of an anterior in addition to a posterior flange would have added to its ability to maintain its position even in fairly soft muds. Although not evident on Glencairn specimens, typical representatives of *T. washitaensis* have thin shells compared to other species (Hill and Vaughan, 1898), a characteristic consistent with life in a quiet, muddy-substrate environment, possibly in deeper water, as Laughbaum (1960) suggested for this species. In contrast, the low, massive, heavily keeled and subspinose left valve of *T. navia* (not present in the Glencairn or Tucumcari formations) almost certainly represents an adaptation for stability while laying on, rather than partially embedded in, a very firm substrate, in high energy conditions.

MESA RICA SANDSTONE PALEONTOLOGY

Rothrock (1925) reported plants from the Dakota Sandstone of Cimarron County, and Nöe (1925) identified and illustrated them. Later, Stovall (1943) noted that these occurrences were in the lower part of the Dakota (Mesa Rica Sandstone of this paper). Altogether these authors obtained plant material (leaves, unidentifiable stems and logs) from 11 localities (Appendix 1, nos. 15, 25–34), representing a total of six species of angiosperms. Little can be said concerning the stratigraphic distribution of these plants through the Mesa Rica, as this information was not given by the workers who reported them. We visited one locality (east end of Black Mesa, UNM locality 1333) and found plant fragments only in the uppermost sandstone unit of the Glencairn Formation. It is possible that other localities reported to be within the "lower member of the Dakota" are actually Glencairn occurrences.

The plants identified by Nöe (1925) represent a mixed list including species known from approximately coeval units elsewhere, and forms identified as species characteristic of much younger units. For example, *Quercus groenlandica* Heer is an early Tertiary species known from Alaska, Canada and Greenland, and *Platanus guillelmae* Goeppert is an Upper Cretaceous to lower Tertiary species (La Motte, 1944, 1952). It is doubtful that these two species actually occur in the Albian of the Dry Cimarron area. *Alismaphyllum victormasoni* (Ward) was originally described from the Albian of Virginia. *Sterculia snowii* (now *S. towneri* [Lesquereaux]: La Motte, 1944) occurs also in the Cheyenne Sandstone of south-central Kansas (Berry, 1922) and in an Albian unit, possibly the basal Mesa Rica, in the Tucumcari area (a specimen called *S. drakei* by Cummins, 1892). *Sterculia mucronata* Lesquereaux also occurs in the Cheyenne Sandstone, and *Salix flexuosa* Newberry is present in the "Dakota Sandstone" along Whetstone Creek, eastern Colfax County, New Mexico (Newberry, 1898) and is widely distributed elsewhere in lower Upper Cretaceous units (Knowlton, 1919).

Too little is known of the sparse Albian floras of northeastern New Mexico and western Oklahoma to permit their use in detailed correlation with other areas. Of interest, in view of the fact that only angiosperms have been reported previously from Albian units in the Dry Cimarron, is the presence of coniferous foliage in the collection we made from the uppermost Glencairn at Black Mesa. These are plants that are similar in appearance to *Sequoia condita* Lesquereaux of Berry (1922) from the Cheyenne Sandstone of south-central Kansas.

Stovall (1943) reported fragmentary specimens of teleost fish about 7 inches in length from the lower sandstone member of the Dakota at a locality about 1 mi south of Kenton, but we have not relocated this locality.

PAJARITO FORMATION PALEONTOLOGY

The "middle shale member of the Dakota Sandstone" (Pajarito Formation of this paper) represents a delta plain environment with few preserved fossils. Some beds within the Pajarito are typically rich in carbonized organic fragments or lignite, and at one locality (UNM locality 1480) dinosaur footprints are present (Fig. 9F). These dinosaur footprints are described by Lucas et al. (in press), who assign them to *Amblydactylus*, an ichnogenus of ornithopod dinosaurs also known from the Pajarito Formation at Clayton Lake (Gillette and Thomas, 1985; Lucas et al., 1986). Found throughout the Cretaceous section, *Amblydactylus* footprints are of no apparent biostratigraphic value at present.

Stovall (1943) listed nine taxa (Table 3) of marine molluscs from the Pajarito at a locality about 12 to 13 km north of Boise City, Cimarron County, Oklahoma (Appendix 1, no 37). We attempted to relocate this fossil bed but were unsuccessful. All of the species mentioned by Stovall were discussed by Meek (1876), who reported five of them (*Arcopagella mactroides*, *Leptosolen conradi*, *Tellina subscitula*, *Yoldia microdonta*, and *Margarita mudgeana*) from the Dakota group 12 mi southwest of Salina, Kansas, and the remaining two species (*Cyrena dakotensis*, *Mactra siouxensis*) from the Dakota near the mouth of the Big Sioux River (Sioux City, Iowa, area). Prosser (1897) and Twenhofel (1924) recognized the Kansas species as part of the fauna of the "Mentor beds," a sandstone facies of the upper Kiowa Formation, and the locality (near Spring Creek, Salina County, Kansas) is within the Kiowa outcrop area in central Kansas (Scott, 1970a). Logan (1897) reported several of these species from the upper part of the Dakota, but Stanton (1922) and Hattin (1967) determined that Logan had erred in the identification

TABLE 3. Taxa reported by Stovall (1943) from the middle member of the Dakota (Pajarito Formation of this paper) in Cimarron County, Oklahoma.

BIVALVIA
Arcopagella mactroides Meek
Corbula sp. indet.
Cyrena dakotensis Meek and Hayden
Leptosolen conradi Meek
Mactra siouxensis Meek and Hayden
Ostrea sp. indet.
Tellina subscitula Meek
Yoldia microdonta Meek
GASTROPODA
Margarita mudgeana Meek

and stratigraphic placement of his collections. None of the species reported by Stovall (1943) were recorded by Hattin (1967) from the upper, early Cenomanian part of the Dakota Sequence in north-central Kansas.

From the preceding discussion, most of the species identified by Stovall from the middle shale member of the Dakota are late Albian Kiowa species. The local occurrence of a marine fauna in this predominantly nonmarine unit is unusual but not unprecedented. Near the type locality of the formation, in the Tucumcari Basin, a thin lens of *Lopha quadriplicata*—a marine species also present in the slightly older Tucumcari Shale—characterizes the Pajarito at one locality (Dobrovolny et al., 1946; Kues et al., 1985).

PALEOBIOGEOGRAPHY

Of the Cretaceous units exposed in the Dry Cimarron Valley, only the Glencairn is sufficiently fossiliferous to allow detailed paleobiogeographical comparison with contemporaneous units in neighboring areas. The Glencairn Formation was deposited along the western shore of the Western Interior seaway during the transgressive and beginning of the regressive phases of the late Albian Kiowa-Skull Creek eustatic cycle. This transgression joined northern and southern arms of the seaway in southeastern Colorado (Scott, 1977; Kauffman, 1984), creating a continuous area of marine and near-marine environments extending from Texas to Canada. In eastern New Mexico, southeastern Colorado, Kansas and Western Oklahoma late Albian communities constitute a Southern Western Interior province, derived from northward migration of Tethyan fauna along eastern and western endemic centers (Scott, 1977, 1986a). In central Colorado and northward the depauperate fauna of the Glencairn and equivalents were dominated numerically by species characteristic of the cool-temperate Northern Interior subprovince, but contain a significant component of southern immigrants as well, a consequence of faunal mixing in the area of the junction of the northern and southern arms of the seaway (Gustason and Kauffman, 1985). Scott (1986a) reported in the Southern Western Interior province a higher degree of endemism in the east (33%) than in the west (18%), noted the relatively high similarity (44–49%) of both eastern and western faunas with Tethyan (Caribbean province) faunas and recognized the high degree of similarity between eastern and western faunas. For example, in Scott's tabulation, 71% of the western taxa (chiefly from the Glencairn and Tucumcari formations) are present also in his eastern endemic center (chiefly Kiowa Formation).

The Glencairn Formation in the Dry Cimarron area contains the highest faunal diversity within the area of Glencairn exposure. Elements of communities inhabiting open sea (prodelta), and lower, middle and upper shoreface environments are preserved within the Glencairn (Scott, 1974) in Cimarron County and extreme eastern Union County. The relatively high diversity, and presence of such stenohaline invertebrates as ammonoids, *Texigryphaea,* and a variety of epizoans suggest normal marine salinity and a generally offshore (open sea to lower shoreface) habitat for most of the Glencairn fauna. West of UNM locality 1339 (about 7 km west of the New Mexico-Oklahoma border), diversity declines abruptly. At Shiprock (UNM locality 1340) and Travesser Park (UNM locality 1341) sparse, poorly preserved *Texigryphaea* and a few other bivalves (e.g., *Scabrotrigonia, Plicatula, Inoceramus*) are all that are present in hematized, fine- to medium-grained sandstone units in the Glencairn.

At the western end of the Dry Cimarron, in Long Canyon (UNM locality 1342), fossils are confined to the basal sandstone unit of the Glencairn (Long Canyon Sandstone Bed) and are preserved entirely as molds and steinkerns. A few texigryphaeas occur in a massive, hard sandstone (bed 6) that contains numerous narrow, vertical, tubular burrows (*Skolithos*), and a few *Ophiomorpha* (Fig. 6E). Above this, in Bed 8, a thin concentration of densely packed *Texigryphaea* molds and steinkerns are present at the top of the basal Glencairn sandstone sequence, in quartzose, medium- to coarse-grained conglomeratic sandstone (Fig. 6D). These remains are randomly oriented, and some are on edge perpendicular to the bedding plane. This sequence represents an upper shoreface/beach environment into which waves transported and concentrated the shells from the offshore, deeper environment to the east in which *Texigryphaea* lived. No megafossils were observed in the overlying dark-gray shale facies of the Glencairn at this locality. A similar occurrence of *Texigryphaea,* with a few other bivalves, was reported by Long (1966) a few km to the north. The Long Canyon fossiliferous sandstones appear to represent very near-shore deposits that were immediately west of the westernmost extent of the *Texigryphaea* habitat within the Glencairn sea.

The occurrence of the Glencairn to the west of the Dry Cimarron area is restricted to several thin exposures reported by Long (1966) along the eastern side of the Sangre de Cristo Mountains in south-central Colorado. In these areas the Glencairn thins to the south (to about 2.4 m at Long's locality 30, about 10 km north of the New Mexico-Colorado border), contains no megafossils and sparse foraminiferans. The presence of the Glencairn or Purgatoire south of these localities has not been adequately demonstrated. Several authors (Smith and Ray, 1943; Griggs et al., 1948; Wanek and Read, 1956; Griggs and Northrop, 1956; Clark, 1966; Clark and Read, 1972; Staatz, 1986) have suggested the possible presence of Purgatoire units at the base of what they called the Dakota Formation in Colfax and eastern Taos Counties. Wood et al. (1953) reported 40 to 146 ft of Purgatoire in eastern Colfax County. Most of these authors suggested or applied the term Purgatoire to a basal sandstone and middle thin shale below an upper Dakota sandstone unit. However, the tripartite division of the "Dakota" in these areas, and in the Las Vegas and Mora regions (Northrop et al., 1946; Jacka and Brand, 1972; Bejnar and Lessard, 1976; Gilbert and Asquith, 1976; Baltz and O'Neill, 1984, 1986) is the Mesa Rica-Pajarito-Romeroville sequence that is well exposed in the Tucumcari, Roy and Dry Cimarron areas. Palynological evidence suggests an Albian age for most of this sequence in the Las Vegas area (Baltz and O'Neill, 1986). No Glencairn-equivalent marine shale/sandstone sequence, and no diagnostic late Albian megafossils or foraminiferans are known west or southwest of Union County in northeastern New Mexico.

Regressive shoreline and distributary facies of the Mesa Rica Sandstone and equivalents (e.g., "braided alluvial interval" of the Dakota) along the eastern side of the Sangre de Cristo Mountains (Colfax County to Las Vegas area) and southeastward delineate the approximate position of the late Albian shoreline in northeastern New Mexico (Fig. 15). Occurrences of *Texigryphaea,* representing an offshore, lower shoreface environment, are clustered in the area around Tucumcari to the south

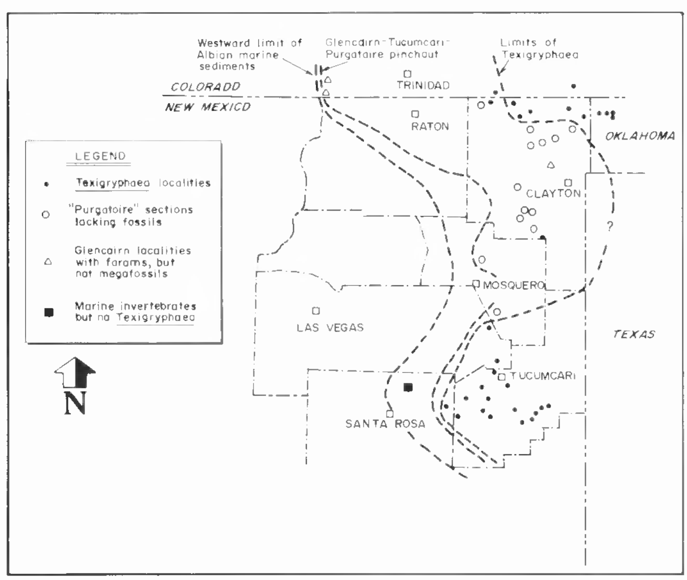


FIGURE 15. Map of northeastern New Mexico, showing distribution of *Texigryphaea* occurrences, Tucumcari-Glencairn exposures, and inferred westward limit of Albian marine sediments.

and in the Dry Cimarron to the north. In the intervening area, in Harding and southern Union Counties, conditions suitable for the existence of *Texigryphaea* and other benthic invertebrates were apparently not present, although Glencairn or Purgatoire sediments are present.

A partial barrier, such as a shoal between the Tucumcari and western Dalhart basins, would account for this discontinuity in the distribution of *Texigryphaea* and would also explain the eastward deflection of the Tucumcari-Glencairn pinch-out line in this area (Fig. 15). Kisucky (1987) demonstrated that Early Cretaceous sedimentation patterns in eastern New Mexico were strongly influenced by a reactivation of basement features initially established in the late Paleozoic. During the Early Cretaceous the Bravo Dome, an eastward extension of the Sierra Grande uplift, separated the Tucumcari and western Dalhart basins. Topographic expression of the Bravo Dome was apparently not great, but this structure did deflect sedimentation of the Mesa Rica delta into northern and southern lobes. It is likely that it also resulted in an eastward bulge of nonmarine and associated deltaic and nearshore shallow marine sediments that projected into the Albian seaway, separating deeper, *Texigryphaea*-bearing environments of the south (Tucumcari area) from the north (Dalhart basin/Dry Cimarron Glencairn deposits).

Lack of Albian exposures to the east, in the Texas Panhandle, precludes a discussion of the eastward extent of this partial barrier. However, the close similarity of the Glencairn and Tucumcari invertebrate faunas, and the close correspondence in the morphology and relative abundance of the various forms of *Texigryphaea* in both formations suggest that the barrier did not significantly hinder faunal interchange from south to north. Migration routes along this part of the western shoreline of the Albian sea were merely deflected eastward around the barrier into Texas.

To the north and northwest of the Dry Cimarron in Colorado, Glencairn faunal diversity also declines. South of Two Buttes town, along Horse Creek, Cobban (1987) identified 13 mollusc species, and Kues (1987) reported fewer at a locality north of Two Buttes town. This area, some 60 to 80 km north of the Oklahoma-Colorado border, marks the northernmost occurrences of *Texigryphaea* and most ammonoids on the western side of the Western Interior seaway, and the southeasternmost occurrence of the northern endemic oysters *Ostrea larimerensis* and *O. noctuensis*. To the west, along the Purgatoire, Apishapa and Huerfano Rivers, a sparse Glencairn fauna includes *Lingula, Inoceramus comancheanus, Scabrotrigonia emoryi, Protocardia texana, Pleuriocardia kansasense, Pholadomya sanctisabae, Leptosolen conradi* and a few other indeterminate bivalves, together with a few species of foraminiferans (Stanton, 1905; Stose, 1912; Waagé, 1953; Long, 1966). In the Cañon City embayment, southwest of Colorado Springs, only *Lingula* was reported by Long, although a few other invertebrates such as *Inoceramus* are also present (Stanton, 1905; Reeside, 1923; Scott, 1970b; Basan and Scott, 1979; Gustason and Kauffman, 1985). Gustason and Kauffman's (1985) statement that Long reported *Texigryphaea corrugata, Eopachydiscus bravoensis* and *Inoceramus comancheanus* from this area is incorrect, however. Glencairn equivalents in the South Platte Formation (of Waagé), along the east side of the Front Range from Denver to the Wyoming border, contain only a few species of bivalves and rare, indeterminate ammonoids (Reeside, 1923; Waagé, 1955), representing an extremely depauperate Albian fauna. Reeside (1923) and Gustason and Kauffman (1985) likewise reported only a few poorly preserved Albian molluscs (including possibly *E. marcianus*) from the sandstone sequence (Muddy Formation) above the Glencairn.

Previous workers (e.g., Reeside, 1923; Long, 1966; Gustason and Kauffman, 1985) have discussed the sharp decline in diversity from the northeastern New Mexico-southeastern Colorado-western Oklahoma area to central and northern Colorado. A southwestern extension of the transcontinental arch across southeastern Colorado may have been the main physical and biogeographic barrier between the northern cool temperate and southern warm temperate to subtropical faunas (Gustason and Kauffman, 1985). After this barrier was breached briefly with the joining of the northern and southern arms of the seaway, a few ecologically tolerant components of the two faunas became mixed through much of Colorado, forming low-diversity paleocommunities in shallow environments of subnormal salinity, partial oxygen depletion and/or increased turbidity (Gustason and Kauffman, 1985). Scott (1977, 1986a) included these mixed faunas in his Southern Western Interior province, whereas Kauffman (1984) considered these faunas and those of northeastern New Mexico and Kansas to belong to a separate Central Interior subprovince within a North American province.

Taxa derived from the southern part of the seaway were apparently more successful in migrating north than northern taxa were in moving south. The late Albian faunas of central and northern Colorado, up to 200 km or more northwest of the position of the transcontinental arch, are composed about equally of northern and southern taxa. A significant northern influence (e.g., *Ostrea larimerensis* and *O. noctuensis*) penetrated only as far southeast as the Two Buttes, Colorado area, a short distance southeast of the arch. The only "northern" species present in the Dry Cimarron Glencairn of northeastern New Mexico and western Oklahoma is *Inoceramus bellvuensis*. *I. bellvuensis* is an endemic evolutionary derivative of *I. comancheanus*, which originally entered central and northern Colorado from the south (Gustason and Kauffman, 1985).

As noted above, the Glencairn fauna is less diverse than that of both the Tucumcari Shale and Kiowa Formation, but shares a majority of its species with these formations. Table 4 summarizes the occurrence of Dry Cimarron Glencairn taxa present in the Tucumcari Shale, and in the southern (Belvidere area, Kansas) and northern (central Kansas) outcrop areas of the Kiowa Formation. The best developed Glencairn faunas (Cimarron County, Oklahoma) are about 200 km north of typical Tucumcari faunas and about 300 km west of south-central Kansas Kiowa faunas. The Dry Cimarron Glencairn fauna is very similar both to Tucumcari (71%) and southern Kiowa (66%) faunas, but only 34% of the Glencairn taxa are present in the northern Kiowa faunas. A few mollusc species present in the Glencairn and equivalent units in central and northern Colorado have not been reported in the Glencairn in the Dry Cimarron area. When these taxa are included, the similarity figures are little changed (i.e., Glencairn-Tucumcari = 64%; Glencairn-southern Kiowa = 60%; Glencairn-northern Kiowa = 38%). The nearly equal high degree of similarity between the Glencairn and the Tucumcari and southern Kiowa faunas is not surprising, considering the location of the Dry Cimarron Glencairn nearly midway between areas of Tucumcari and southern Kiowa exposures.

Of additional interest is the fact that the degree of similarity between the Dry Cimarron Glencairn fauna and southern Kiowa fauna (included by Scott, 1977, 1986a, in his eastern endemic center) far exceeds the similarity between the southern and northern Kiowa faunas. Scott (1970a) reported that, of the 120 megainvertebrate species known from the Kiowa, 49 are restricted to southern Kansas, 36 to central Kansas, and only 35, or 29% of the total Kiowa species, occur in both areas. This suggests that the central Kansas Kiowa fauna by itself represents an isolated endemic center, with relatively few taxa in common with the southern Kiowa or Glencairn faunas.

TABLE 4. Summary of distribution of Dry Cimarron Glencairn species in the Tucumcari Shale (T), and exposures of the Kiowa Formation in south-central Kansas (SK) and central Kansas (NK).

	G	G + T	G + SK	G + NK	G + T + SK	G + T + SK + NK	G + SK + NK	G + T + NK
Gastropods	6	1	1	–	–	3	1	–
Ammonoids	2	1	–	–	–	–	–	–
Bivalves	30	3	1	1	11	6	2	1
Other	3	1	–	–	2	–	–	–
TOTAL	41	6	2	1	13	9	3	1

SUMMARY:

Total Dry Cimarron Glencairn species also present in Tucumcari = 29 = 71%

Total Dry Cimarron Glencarin species also present in southern Kiowa = 27 = 66%

Total Dry Cimarron Glencairn species also present in northern Kiowa = 14 = 34%

Within the Southern Western Interior province, physical and biotic factors affecting distribution and diversity did not vary much from east to west. Differences between eastern and western paleocommunities were relatively minor and in part related to the absence of a lagoonal-estuarine-marsh environment in the west (Scott, 1975, 1986a). Biological factors, such as separate northward migration routes by some taxa along the east and west sides of the seaway, and local speciation events also contributed in a minor way to regional faunal differences within the Southern Western Interior province. The differences in the species of *Texigryphaea* between the western Glencairn and Tucumcari formations and the eastern southern Kiowa exposures is perhaps the best example of this effect. In general, interchange between communities on the western and eastern sides of the seaway as far north as southeastern Colorado and south-central Kansas proceeded with few restrictions, as is indicated by the high degree of similarity between the communities in both areas.

Distribution of salinity-sensitive invertebrates in the Southern Western Interior province during Albian time suggests that lowered salinities existed in the northeastern part of the province (central Kansas) and through the area northwest of the transcontinental arch, including all but the southeast corner of Colorado. The taxonomic composition changes significantly and diversity moderately decreases from southern to central Kansas. In addition, westward diversity decreases radically (Glencairn and equivalent formations through most of Colorado). Low salinity estuarine and marsh communities (*Crassostrea, Brachidontes*, pteriid-mytilid) developed in the east in central Kansas (Scott, 1986a) but have not been recognized in the western part of the Southern Western Interior province. *Texigryphaea*, a Tethyan-derived, stenohaline genus (Stenzel, 1971) extends northward to Two Buttes on the west and to southern Kansas on the east side of the province—a distribution first emphasized by Stanton (1922). Scott (1970a) postulated a gradient from normal to less-than-normal salinities from southern to central Kansas, based on restriction of such stenohaline invertebrates as echinoids, corals, *Texigryphaea*, sponges and *Serpula* to the southern Kiowa exposures.

Although ammonoids are nowhere abundant in the area of Glencairn and Kiowa exposures, their distribution also supports the idea of lowered salinities to the north. Only a single late Albian species, *Engonoceras belviderense*, is known from central Kansas, whereas five species have been reported from the southern Kansas Kiowa Formation. A similar pattern characterizes the western part of the seaway; at least four ammonoid species have been reported from the Glencairn in southeastern Colorado (Cobban, 1987) but only rare, fragmentary, unidentifiable Albian remains have been reported from the central to northern Colorado part of the seaway (Reeside, 1923; Long, 1966).

In summary, the Dry Cimarron Glencairn fauna is quite similar to both the Tucumcari Shale and southern Kansas Kiowa faunas, but has far fewer taxa in common with Kiowa faunas in central Kansas. The diversity and composition of the Southern Western Interior fauna changes significantly across an east-west line parallel to and approximately 50 km north of the northern New Mexico and northern Oklahoma borders. South of this line, faunas on both the western and eastern sides of the seaway were fairly diverse, lived in normal marine conditions, exhibited a high degree of interchange (and thus are taxonomically very similar) and were distinctly Tethyan in aspect, being derived predominantly from the Caribbean province to the south. North of this line, salinity within the seaway decreased, limiting megafossil and foraminiferan faunas but locally enhancing the evolution of endemic species. In central Kansas, on the northeastern margin of the Southern Western Interior province, a distinctive fauna developed in slightly lowered salinity, characterized by absence or great reduction of several stenohaline groups that are common to the south, presence of recognizable estuarine and brackish communities, several endemic species, and a relatively low (and approximately equal) level of similarity to southern faunas on both sides of the seaway. Toward the northwest, through much of Colorado, lowered salinity and other factors prevented northward migration of most southern species, resulting in a severely depleted fauna composed of mixed northern and southern elements with several endemic species.

This scenario differs somewhat from that proposed by Scott (1977, 1986a) which recognized eastern and western endemic centers throughout the Southern Western Interior province. The relatively high level of endemic species (33%) reported by Scott in his eastern endemic center reflects predominantly species restricted to the Kiowa Formation in central Kansas (Scott, 1977), which we recognize also as an endemic center. South of the salinity-break, however, we do not see sufficient differences between western and eastern faunas to justify recognition of western and eastern endemic centers. In fact, the similarity between western and eastern faunas in the southern part of the province is greater than is indicated by Scott (1986a) for the time represented by the *Adkinsites bravoensis* to *Mortoniceras equidistans* zones. Albian exposures in west-central Texas and east-central New Mexico, on the western side of the seaway, contain such species as *Texigryphaea navia*, *Ceratostreon texana*, *Pinna comancheana* and possibly *Cucullaea*? *herculea* (Brand, 1953; Kues, 1986) that were considered by Scott to be eastern endemic center forms absent in the western endemic center. More detailed studies of the western Southern Western Interior province faunas (Tucumcari, Glencairn, Kiamichi-Duck Creek formations), comparable to Scott's (1970a) study of Kiowa faunas, are required to assess better the biogeographic relationships of these faunas.

ACKNOWLEDGMENTS

We thank S. Hayden, A. Hunt and P. Reser for assistance in the field. R. W. Scott reviewed an earlier version of this paper.

REFERENCES

Adkins, W. S., 1918, The Weno and Pawpaw formations of the Texas Comanchean: University of Texas, Bulletin 1856, pp. 1–172.

Adkins, W. S., 1928, Handbook of Texas Cretaceous fossils: University of Texas, Bulletin 2838, 385 pp.

Baldwin, B. and Muehlberger, W. R., 1959, Geologic studies of Union County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 63, 171 pp.

Baltz, E. H. and O'Neill, J. M., 1984, Geologic map and cross-sections of the Mora River area, Sangre de Cristo Mountains, Mora County, New Mexico: U.S. Geological Survey, Miscellaneous Investigations Map I-1456.

Baltz, E. H. and O'Neill, J. M., 1986, Geologic map and cross-sections of the Sapello River area, Sangre de Cristo Mountains, Mora and San Miguel Counties, New Mexico: U.S. Geological Survey, Miscellaneous Investigations Map I-1575.

Basan, P. B. and Scott, R. W., 1979, Morphology of *Rhizocorallium* and associated traces from the Lower Cretaceous Purgatoire Formation, Colorado: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 28, pp. 5–23.

Bayne, C. K., Franks, P. C. and Ives, W., Jr., 1971, Geology and ground-water resources of Ellsworth County, Kansas: Kansas State Geological Survey, Bulletin 201, 84 pp.

Bejnar, C. R. and Lessard, R. H., 1976, Paleocurrents and depositional environments of the Dakota Group, San Miguel and Mora Counties, New Mexico: New Mexico Geological Society, Guidebook 27, pp. 157–163.

Berry, E. W., 1922, The flora of the Cheyenne Sandstone of Kansas: U.S. Geological Survey, Professional Paper 129-I, pp. 197–231.

Böse, E., 1910, Monografia geologica y paleontologica del Cerro de Muleros: Instituto Geologico de Mexico, Boletin 25, 191 pp.

Bowman, S. A. B., Bowman, J. T. and Drake, R. E., 1986, Interpretation of the Morrison Formation as a time-transgressive unit: Fourth North American Paleontological Convention, Abstracts with Programs, p. 5.

Brand, J. P., 1953, Cretaceous of Llano Estacado of Texas: Bureau of Economic Geology, The University of Texas, Report of Investigations, no. 20, 59 pp.

Bromley, R. G., 1970, Borings as trace fossils and *Entobia cretacea* Portlock, as an example; *in* Crimes, T. P. and Harper, J. C., eds., Trace fossils: Liverpool, Seel House Press, pp. 49–90.

Bullard, F. M., 1928, Lower Cretaceous of western Oklahoma: Oklahoma Geological Survey, Bulletin 47, 116 pp.

Clark, K. F., 1966, Geology of the Sangre de Cristo Mountains and adjacent areas between Taos and Raton, New Mexico: New Mexico Geological Society, Guidebook 17, pp. 56–65.

Clark, K. F. and Read, C. B., 1972, Geology and ore deposits of Eagle Nest area, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 94, 152 pp.

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., 1985, The Lower Cretaceous ammonite *Schloenbachia leonensis* Conrad, var. *equidistans* Cragin: U.S. Geological Survey, Bulletin 1641-A, 4 pp.

Cobban, W. A., 1987, An ammonoid fauna from the Glencairn Shale Member of the Lower Cretaceous Purgatoire Formation, Baca County, Colorado: New Mexico Geological Society, Guidebook 38.

Cooley, B. B., 1955, Areal geology of Dry Cimarron Canyon, Union County, New Mexico [M.S. thesis]: Austin, University of Texas, 93 pp.

Cragin, F. W., 1889, Notes on the region south of the Great Bend of the Arkansas: Washburn College, Natural History Bulletin, v. 2, pp. 33–37.

Cragin, F. W., 1894a, Description of invertebrate fossils from the Comanche series in Texas, Kansas, and Indian Territory: Colorado College Studies, 5th Annual Publication, pp. 49–69.

Cragin, F. W., 1894b, New and little known Invertebrata from the Neocomian of Kansas: American Geologist, v. 14, pp. 1–12.

Cummins, W. F., 1892, Notes on the geology of the country west of the plains: Geological Survey of Texas, Third Annual Report, pp. 201–223.

Darton, N. H., 1905, Discovery of the Comanche Formation in southeastern Colorado: Science, v. 22, p. 120.

Darton, N. H., 1928, "Red beds" and associated formations in New Mexico, with an outline of the geology of the state: U.S. Geological Survey, Bulletin 794, 356 pp.

DeFord, R. K., 1927, Areal geology of Cimarron County, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 11, pp. 753–755.

Dobrovolny, E., Bates, R. L. and Summerson, C. H., 1946, Geology of northwestern Quay County, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Preliminary Map 62.

Douglass, D. N. and Johnson, G. D., 1984, Isochronous interpretation of fluviatile-lacustrine paleoenvironments, Morrison and Cloverly formations (Jurassic-Cretaceous), central Wyoming; *in* Reif, W.-E. and Westphal, F., Third symposium on Mesozoic terrestrial ecosystems: Tübingen, Attempto Verlag, pp. 79–84.

Fay, R. O., 1975, The type species of *Mortoniceras* and the holotype specimens of Lower Cretaceous *Texigryphaea* of the southwestern United States: Oklahoma Geology Notes, v. 35, pp. 43–57.

Fay, R. O., 1978, Stratigraphy and general geology of Custer County: Oklahoma Geological Survey, Bulletin 114, pp. 3–46.

Finlay, G. I., 1916, Colorado Springs folio Colorado: U.S. Geological Survey, Geologic Atlas of the United States, no. 203, 15 pp.

Flatt, C. D., 1976, Origin and significance of the oyster banks in the Walnut Clay Formation, central Texas: Baylor Geological Studies, no. 30, 47 pp.

Franks, P. C., 1975, The transgressive-regressive sequence of the Cretaceous Cheyenne, Kiowa, and Dakota Formations of Kansas: Geological Association of Canada, Special Paper 13, pp. 469–521.

Gage, J. E. and Asquith, G. B., 1977, Sedimentology of Mesa Rica Sandstone in Tucumcari basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 157, 14 pp.

Gilbert, G. K., 1896, The underground water of the Arkansas Valley in eastern Colorado: U.S. Geological Survey, Annual Report 17, pp. 551–601.

Gilbert, J. L. and Asquith, G. B., 1976, Sedimentology of braided alluvial interval of Dakota Sandstone, northeastern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 150, 16 pp.

Gillette, D. D. and Thomas, D. A., 1985, Dinosaur tracks in the Dakota Formation (Aptian-Albian) at Clayton Lake State Park, Union County, New Mexico: New Mexico Geological Society, Guidebook 36, pp. 283–288.

Goddard, E. N., Trask, P. D., DeFord, R. K., Rove, O. N., Singewald, J. T., Jr. and Overbeck, R. M., 1979, Rock-color chart: Boulder, Geological Society of America.

Griggs, R. L. and Northrop S. A., 1956, Stratigraphy of the plains area adjacent to the Sangre de Cristo Mountains, New Mexico: New Mexico Geological Society, Guidebook 7, pp. 134–138.

Griggs, R. L. and Read, C. B., 1959, Revisions in stratigraphic nomenclature in Tucumcari-Sabinoso area, northeastern New Mexico: American Association of Petroleum Geologists Bulletin, v. 43, pp. 2003–2007.

Griggs, R. L., Northrop, S. A. and Wood, G. H., Jr., 1948, Geology: New Mexico Bureau of Mines and Mineral Resources, Ground-Water Report 1, pp. 17–45.

Gustason, E. R. and Kauffman, E. G., 1985, The Dakota Group and the Kiowa-Skull Creek cyclothem in the Canon City-Pueblo area, Colorado: SEPM Trip Guidebook No. 4, 1985, mid-year meeting, Golden, pp. 72–89.

Hallam, A., 1968, Morphology, paleoecology and evolution of the Genus *Gryphaea* in the British Lias: Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences, v. 254, pp. 91–128.

Hallam, A. and Gould, S. J., 1975, The evolution of British and American Middle and Upper Jurassic *Gryphaea:* a biometric study: Proceedings of the Royal Society of London, Series B, Biological Sciences, v. 189, pp. 511–542.

Hattin, D. E., 1967, Stratigraphic and paleoecologic significance of macroinvertebrate fossils in the Dakota Formation (Upper Cretaceous) of Kansas; *in* Teichert, C. and Yochelson, E. L., eds., Essays in paleontology and stratigraphy: Department of Geology, University of Kansas, Special Publication 2, pp. 570–589.

Hattin, D. E., 1987, Pelagic/hemipelagic rhythmites of the Greenhorn Limestone (Upper Cretaceous) of northeastern New Mexico and southeastern Colorado: New Mexico Geological Society, Guidebook 38.

Hedberg, H. D., ed., 1976, International stratigraphic guide: New York, John Wiley & Sons, 200 pp.

Hill, R. T. and Vaughan, T. W., 1898, The Lower Cretaceous gryphaeas in the Texas region: U.S. Geological Survey, Bulletin 151, 139 pp.

Holbrook, J., Wright, R. and Kietzke, K., 1987, Stratigraphic relationships at the Jurassic-Cretaceous boundary in east-central New Mexico: New Mexico Geological Society, Guidebook 38.

Jacka, A. D. and Brand, J. P., 1972, An analysis of the Dakota Sandstone in the vicinity of Las Vegas, New Mexico and eastward to the Canadian River Valley: New Mexico Geological Society, Guidebook 23, pp. 105–107.

Jacka, A. D. and Brand, J. P., 1973, The San Jon section of the Tucumcari Shale, Mesa Rica Sandstone, and Pajarito Shale; *in* Phillips, D. A., ed., Guidebook of interpretation of depositional environments from selected exposures of Paleozoic and Mesozoic rocks in north-central New Mexico: Amarillo, Panhandle Geological Society, pp. 44–48.

Kauffman, E. G., 1975, Dispersal and biostratigraphic potential of Cretaceous benthonic Bivalvia in the Western Interior: Geological Association of Canada, Special Paper 13, pp. 163–194.

Kauffman, E. G., 1977, Illustrated guide to biostratigraphically important Cretaceous macrofossils, Western Interior basin, U.S.A.: The Mountain Geologist, v. 14, pp. 225–274.

Kauffman, E. G., 1984, Paleobiogeography and evolutionary response dynamic in the Cretaceous Western Interior seaway of North America: Geological Association of Canada, Special Paper 27, pp. 273–306.

Kauffman, E. G., Cobban, W. A. and Eicher, D. L., 1978, Albian through lower Coniacian strata, biostratigraphy and principal events, Western Interior United States: Annales du Museum d'Histoire Naturelle de Nice, Tome 23, pp. 1–52.

Kauffman, E. G., Hattin, D. E. and Powell, J. D., 1977, Stratigraphic, paleontologic, and paleoenvironmental analysis of the Upper Cretaceous rocks of Cimarron County, northwestern Oklahoma: Geological Society of America, Memoir 149, 150 pp.

Kauffman, E. G., Powell, J. D. and Hattin, D. E., 1969, Cenomanian-Turonian facies across the Raton Basin: The Mountain Geologist, v. 6, pp. 93–118.

Kennedy, W. J., Wright, C. W. and Chancellor, G. R., 1983, The Cretaceous ammonite *Eopachydiscus* and the origin of the Pachydiscidae: Palaeontology, v. 26, pp. 655–662.

Kent, D. V. and Gradstein, F. M., 1985, A Cretaceous and Jurassic geochronology: Geological Society of America Bulletin, v. 96, pp. 1419–1427.

King, P. B. and Beikman, H. M., 1974, Geologic map of the United States: U.S. Geological Survey, scale 1:2,500,000.

Kisucky, M. J., 1987, Sedimentology, stratigraphy and paleogeography of the Mesa Rica delta system, Tucumcari basin, eastern New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 115 pp.

Knowlton, F. H., 1919, A catalogue of the Mesozoic and Cenozoic plants of North America: U.S. Geological Survey, Bulletin 696, 815 pp.

Kues, B. S., 1985, Stratigraphy of the Tucumcari area: a historical account: New Mexico Geological Society, Guidebook 36, pp. 119–140.

Kues, B. S., 1986, Paleontology and correlation of a Lower Cretaceous (Albian) outlier in Roosevelt County, New Mexico: New Mexico Geology, v. 8, pp. 88–94.

Kues, B. S., 1987, *Texigryphaea* in the Glencairn Formation near Two Buttes, Colorado, with notes on an assemblage of *Texigryphaea* from the Kiowa Formation of southern Kansas: New Mexico Geological Society, Guidebook 38.

Kues, B. S., Lucas, S. G., Kietzke, K. and Mateer, N. J., 1985, Synopsis of Tucumcari Shale, Mesa Rica Sandstone and Pajarito Shale paleontology, Cretaceous of east-central New Mexico: New Mexico Geological Society, Guidebook 36, pp. 261–280.

La Motte, R. S., 1944, Supplement to catalogue of Mesozoic and Cenozoic plants of North America, 1919–37: U.S. Geological Survey, Bulletin 924, 330 pp.

La Motte, R. S., 1952, Catalogue of the Cenozoic plants of North America through 1950: Geological Society of America, Memoir 51, 381 pp.

Latta, B. F., 1946, Cretaceous stratigraphy of the Belvidere area, Kiowa County, Kansas: Kansas Geological Survey, Bulletin 64, pp. 217–260.

Latta, B. F., 1948, Geology and groundwater resources of Kiowa County, Kansas: Kansas Geological Survey, Bulletin 65, 151 pp.

Laughbaum, L. R., 1960, A paleoecologic study of the upper Denton Formation, Tarrant, Denton, and Cooke Counties, Texas: Journal of Paleontology, v. 34, pp. 1183–1197.

Lee, W. T., 1901, The Morrison Formation of southeastern Colorado: Journal of Geology, v. 9, pp. 343–352.

Lee, W. T., 1902, The Morrison shales of southern Colorado and northern New Mexico: Journal of Geology, v. 10, pp. 36–58.

Lee, W. T., 1903, Age of the Atlantosaurus Beds: Science, v. 17, pp. 292–293.

Lee, W. T., 1904, Age of the Atlantosaurus Beds: Geological Society of America Bulletin, v. 14, pp. 531–532.

Logan, W. N., 1897, The Upper Cretaceous: The University Geological Survey of Kansas, v. 2, pp. 202–231.

Long, C. S., Jr., 1966, Basal Cretaceous strata, southeastern Colorado [Ph.D. dissertation]: Boulder, University of Colorado, 479 pp.

Lucas, S. G. and Kues, B. S., 1985, Stratigraphic nomenclature and correlation chart for east-central New Mexico: New Mexico Geological Society, Guidebook 36, pp. 341–344.

Lucas, S. G., Hunt, A. P. and Kues, B. S., 1987, First-day road log, from Clayton to Seneca, Moses, Mexhoma, Kenton, Wedding Cake Butte, Travesser Park, Clayton Lake and back to Clayton: New Mexico Geological Society, Guidebook 38.

Lucas, S. G., Kietzke, K. K. and Hunt, A. P. 1985, The Jurassic System in east-central New Mexico: New Mexico Geological Society, Guidebook 36, pp. 213–242.

Lucas, S. G., Hunt, A. P. Kietzke, K. K. and Wolberg, D. L., 1986, Cretaceous stratigraphy and biostratigraphy, Clayton Lake State Park, Union County, New Mexico: New Mexico Geology, v. 8, pp. 60–65.

Lucas, S. G., Hunt, A. P. and Kietzke, K. K., in press, Stratigraphy and age of Cretaceous dinosaur footprints, northeastern New Mexico and northwestern Oklahoma; *in* Morales, M., ed., Dinosaur tracks and traces: Flagstaff, Museum of Northern Arizona Press.

Mankin, C. J., 1958, Stratigraphy and sedimentary petrology of Jurassic and pre-Graneros Cretaceous rocks, northeastern New Mexico [Ph.D. dissertation]: Austin, University of Texas, 208 pp.

Marcou, J., 1855, Résumé éxplicatif d'une carte géologique des Etâts-Unis et des provinces anglaises de l'Ámerique du Nord, avec un profil géologique allant de la vallée du Mississippi aux cotes du Pacifique et une planche des fossiles: Societé Géologique de France, Bulletin, series 2, v. 12, pp. 813–936.

Mateer, N. J., 1985, Pre-Graneros Cretaceous stratigraphy of northeastern New Mexico: New Mexico Geological Society, Guidebook 36, pp. 243–246.

Mateer, N. J., 1987, The Dakota Group of northeastern New Mexico and southern Colorado: New Mexico Geological Society, Guidebook 38.

McLaughlin, T. G., 1954, Geology and groundwater resources of Baca County, Colorado: U.S. Geological Survey, Water-Supply Paper 1256, 232 pp.

Meek, F. B., 1876, A report on the invertebrate Cretaceous and Tertiary fossils of the Upper Missouri Country: Washington, Government Printing Office, 629 pp.

Muehlberger, W. R., Baldwin, B. and Foster, R. W., 1961, High Plains northeastern New Mexico Raton-Capulin Mountain-Clayton: Socorro, New Mexico Bureau of Mines and Mineral Resources, 107 pp.

Newberry, J. S., 1898, The later extinct floras of North America: U.S. Geological Survey, Monograph 35, 295 pp.

Nöe, A. C., 1925, Dakota Sandstone plants from Cimarron County, Oklahoma: Oklahoma Geological Survey, Bulletin 34, pp. 93–107.

North American Commission on Stratigraphic Nomenclature, 1983, North American stratigraphic code: American Association of Petroleum Geologists Bulletin, v. 67, pp. 841–875.

Northrop, S. A., Sullwold, H. H., Jr., MacAlpin, A. J. and Rogers, C. P., Jr., 1946, Geologic maps of a part of the Las Vegas basin and of the foothills of the Sangre de Cristo Mountains, San Miguel and Mora Counties, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Preliminary Map 54.

Parker, B. H., 1933, Clastic plugs and dikes of the Cimarron Valley area of Union County, New Mexico: Journal of Geology, v. 41, pp. 38–51.

Paull, R. A., 1962, Depositional history of the Muddy Sandstone, Big Horn basin, Wyoming: Wyoming Geological Association, Guidebook 17, pp. 103–117.

Payne, L. C., Lucas, S. G., Kisucky, M. J., Kietzke, K. K., Kues, B. S. and Wright, R., 1986, Albian-Cenomanian (Cretaceous) stratigraphy and biostratigraphy, east-central New Mexico: Geological Society of America, Abstracts with Programs, v. 18, p. 401.

Perkins, B. F., 1960, Biostratigraphic studies in the Comanche (Cretaceous) Series of northern Mexico and Texas: Geological Society of America, Memoir 83, 138 pp.

Prosser, C. S., 1897, The Upper Permian and Lower Cretaceous: The University Geological Survey of Kansas, v. 2, pp. 51–194.

Reeside, J. B., Jr., 1923, The fauna of the so-called Dakota Formation of northern central Colorado and its equivalent in southeastern Wyoming: U.S. Geological Survey, Professional Paper 131-H, pp. 199–207.

Rothrock, E. P., 1925, Geology of Cimarron County, Oklahoma: Oklahoma Geological Survey, Bulletin 34, 110 pp.

Schoff, S. L. and Stovall, J. W., 1943, Measured stratigraphic sections in Cimarron County: Oklahoma Geological Survey, Bulletin 64, pp. 247–263.

Scott, R. W., 1970a, Paleoecology and paleontology of the Lower Cretaceous Kiowa Formation, Kansas: The University of Kansas, Paleontological Contributions, Article 52 (Cretaceous 1), 94 pp.

Scott, R. W., 1970b, Stratigraphy and sedimentary environments of Lower Cretaceous rocks, southern Western Interior: American Association of Petroleum Geologists Bulletin, v. 54, pp. 1225–1244.

Scott, R. W., 1974, Bay and shoreface benthic communities in the Lower Cretaceous: Lethaia, v. 7, pp. 315–330.

Scott, R. W., 1975, Patterns of Early Cretaceous molluscan diversity in south-central United States: Lethaia, v. 8, pp. 241–252.

Scott, R. W., 1977, Early Cretaceous environments and paleocommunities in the southern Western Interior: The Mountain Geologist, v. 14, pp. 155–168.

Scott, R. W., 1986a, Biogeographic influences on Early Cretaceous paleocommunities, Western Interior: Journal of Paleontology, v. 60, pp. 197–207.

Scott, R. W., 1986b, Paleobiology of Early Cretaceous protocardiids, Caribbean Province: Journal of Paleontology, v. 60, pp. 1186–1211.

Smith, J. F., Jr. and Ray, L. L., 1943, Geology of the Cimarron Range, New Mexico: Geological Society of America Bulletin, v. 54, pp. 891–924.

Staatz, M. N., 1986, Geologic map of the Pine Buttes quadrangle, Colfax County, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map GQ-1591.

Stanton, T. W., 1905, The Morrison Formation and its relations with the Comanche Series and the Dakota Formation: Journal of Geology, v. 13, pp. 657–669.

Stanton, T. W., 1922, Some problems connected with the Dakota Sandstone: Geological Society of America Bulletin, v. 33, pp. 255–272.

Stanton, T. W., 1947, Studies of some Comanche pelecypods and gastropods: U.S. Geological Survey, Professional Paper 211, 256 pp.

Stenzel, H. B., 1959, Cretaceous oysters of southwestern North America: El Sistema Cretacico, Congreso Geologico International, XX Sesion, Cuidad de Mexico, 1956, pp. 15–37.

Stenzel, H. B., 1971, Oysters; *in* Moore, R. C., ed., Treatise on invertebrate paleontology, Part N, Volume 3, Mollusca G., Bivalvia: Lawrence, University of Kansas and Geological Society of America, pp. 953–1224.

Stephenson, L. W., 1941, The larger invertebrate fossils of the Navarro Group of Texas: University of Texas, Publication 4101, 641 pp.

Stose, G. W., 1912, Apishapa folio Colorado: U.S. Geological Survey, Geologic Atlas of the United States, no. 186, 12 pp.

Stovall, J. W., 1938, The Morrison of Oklahoma and its dinosaurs: Journal of Geology, v. 46, pp. 596–600.

Stovall, J. W., 1943, Stratigraphy of the Cimarron Valley (Mesozoic rocks): Oklahoma Geological Survey, Bulletin 64, pp. 43–100.

Stovall, J. W. and Savage, D. E., 1939, A phytosaur in Union County, New Mexico, with notes on the stratigraphy: Journal of Geology, v. 47, pp. 759–766.

Twenhofel, W. H., 1924, Geology and invertebrate paleontology of the Comanchean and "Dakota" Formations of Kansas: State Geological Survey of Kansas, Bulletin 9, 135 pp.

Waagé, K. M., 1953, Refractory clay deposits of south-central Colorado: U.S. Geological Survey, Bulletin 993, 104 pp.

Waagé, K. M., 1955, Dakota Group in northern Front Range foothills, Colorado: U.S. Geological Survey, Professional Paper 274-B, pp. 15–51.

Waagé, K. M., 1961, Stratigraphy and refractory clay rocks of the Dakota Group along the northern Front Range, Colorado: U.S. Geological Survey, Bulletin 1102, 154 pp.

Wanek, A. A., 1962, Reconnaissance geologic map of parts of Harding, San Miguel and Mora Counties, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Map OM-208.

Wanek, A. A. and Read, C. B., 1956, Third day, Taos to Eagle Nest and Elizabethtown: New Mexico Geological Society, Guidebook 7, pp. 82–95.

Ward, J. V., 1986, Early Cretaceous angiosperm pollen from the Cheyenne and Kiowa Formations (Albian) of Kansas, U.S.A.: Paleontographica (B), v. 202, pp. 1–81.

Weimer, R. J., 1984, Relation of unconformities, tectonics, and sea-level changes, Cretaceous of Western Interior, U.S.A.; *in* Schlee, J. S., ed., Interregional unconformities and hydrocarbon accumulation: American Association of Petroleum Geologists, Memoir 36, pp. 7–36.

West, E. S., 1978, Biostratigraphy and paleoecology of the lower Morrison Formation of Cimarron County, Oklahoma [M.S. thesis]: Wichita, Wichita State University, 61 pp.

Wood, G. H., Jr., Northrop, S. A. and Griggs, R. L., 1953, Geology and stratigraphy of Koehler and Mount Laughlin quadrangles and parts of Abbott

and Springer quadrangles, eastern Colfax County, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Map OM-141.
Young, K., 1966, Texas Mojsisoviczinae (Ammonoidea) and the zonation of the Fredericksburg: Geological Society of America, Memoir 100, 225 pp.

APPENDIX 1—FOSSIL LOCALITIES

This list includes localities in the Dry Cimarron drainage area of Union County, New Mexico, Cimarron County, Oklahoma and Las Animas County, Colorado, at which Albian fossils were collected or observed by us (UNM locality numbers) or reported by previous workers.

LAS ANIMAS COUNTY, COLORADO

1. NE wall of small tributary flowing S into Long Canyon, NW¼, sec. 18, T35S, R56W, Las Animas County, Colorado; Glencairn invertebrates; section 26 of Long (1966).
2. Carrizo Creek, SE¼, sec. 4, T34S, R51W, Las Animas County, Colorado; Glencairn invertebrates; section 25 of Long (1966).

UNION COUNTY, NEW MEXICO

3. In saddle between a pair of small buttes, SE¼ SE¼ NE¼, sec. 34, T31N, R36E; Glencairn invertebrates; UNM locality 1339; section 16 of Baldwin and Muehlberger (1959).
4. Near NE tip of Shiprock, just S of NM-325, SE¼ NW¼ NE¼, sec. 33, T32N, R35E; Glencairn invertebrates; UNM locality 1340; section 14 of Baldwin and Muehlberger (1959); at or near section 8 of Cooley (1955).
5. Mesa along W side of Travesser Canyon, about 0.6 mi W of NM-370, NE¼ NW¼ SW¼ SW¼, sec. 12, T31N, R32E; Glencairn invertebrates; UNM locality 1341.
6. Pipeline Canyon, Burchard Ranch, NW¼ NE¼, sec. 20, T31N, R32E; Glencairn invertebrates; section 1 of Cooley (1955).
7. Milady Canyon, Henry Brown Ranch, SW¼ NW¼, sec. 3, T32N, R31E (NOTE: coordinates given by Cooley, 1955, are incorrect; his reference map shows the locality in T31N); Glencairn invertebrates; section 4-a of Cooley (1955).
8. Long Canyon, NW¼ NW¼ NE¼, sec. 3, T31N, R29E; unspecified fossils in Purgatoire; section 4 of Baldwin and Muehlberger (1959).
9. Long Canyon, NW¼ NE¼ NW¼, sec. 2, T31N, R29E; unspecified fossils in Purgatoire; section 5a of Baldwin and Muehlberger (1959).
10. N side of Long Canyon, along prominent Lytle-to-Mesa Rica cliff face, SW¼ SE¼ SW¼, sec. 35, T32N, R29E; Glencairn invertebrates; UNM locality 1342.
11. Long Canyon, SW¼ NE¼ SW¼, sec. 30, T32N, R30E; unspecified fossils in Purgatoire; section 6 of Baldwin and Muehlberger (1959).

CIMARRON COUNTY, OKLAHOMA

12. Roadcut and slopes of hill (101 Hill), 4.7 mi E of Kenton, NE¼ SW¼, sec. 18, T5N, R2E; Glencairn invertebrates; UNM locality 1330; also Stovall (1943).
13. Roadcut and hill to E, just N of Morrison dinosaur quarry and monument and 9.3 mi E of Kenton, SW¼ NE¼ SW¼, sec. 35, T5N, R2E; Glencairn invertebrates; UNM locality 1331.
14. Roadcut and hill to N, 7.2 mi E of Kenton, SE¼ NE¼, sec. 16, T5N, R2E; Glencairn invertebrates; UNM locality 1332.
15. E tip of Black Mesa, SE¼ NW¼ NW¼, sec. 34, T6N, R1E; upper Glencairn plants; UNM locality 1333; at or near one of Stovall's (1943) plant localities in "lower member of Dakota."
16. Roadcut, 1.7 mi E of Kenton, center, line between NE¼ and SE¼, NE¼, sec. 15, T5N, R1E; Glencairn invertebrates; UNM locality 1334.
17. Cut along stock pond, W side of road to Black Mesa State Park, 1.2 mi S of intersection with highway running E from Kenton, NE¼ SW¼, sec. 19, T5N, R2E; Glencairn invertebrates; UNM locality 1335.
18. At bridge on Carrizo Creek, W of Kenton, sec. 18, T5N, R1E; Glencairn invertebrates; section 19 of Stovall (1943).
19. Near the old townsite of Mineral, secs. 12, 13, T4N, R1E; Glencairn invertebrates (Bullard, 1928).
20. Railroad cut, just W of US-287/385, about 9 mi N of Boise City, SW¼ SW¼ NW¼ and NW¼ NW¼ SW¼, sec. 34, T5N, R5E; Glencairn invertebrates; UNM locality 1336; also Stovall (1943).
21. Just W of and below US-287/385 and railroad, 7.7 mi N of center of Boise City, NW¼ SE¼, sec. 4, T4N, R5E; Glencairn invertebrates; UNM locality 1337.
22. Wolf Mountain, a short distance E of US-287/385, E½, sec. 27, T5N, R5E; Purgatoire invertebrates (Rothrock, 1925; Bullard, 1928; Stovall, 1943).
23. SW corner, sec. 31, T5N, R6E; Purgatoire invertebrates (Rothrock, 1925).
24. Roadcut, SE¼ NW¼ SE¼, sec. 25, T6N, R4E; Glencairn invertebrates; UNM locality 1338; at or near "Garrett Post Office" locality of Stanton (1905), Rothrock (1925), Bullard (1928) and Stovall (1943).
25. Near site of old Fort Nichols, E½, sec. 2, T3N, R1E; Mesa Rica plants (Rothrock, 1925; Stovall, 1943).
26. 1.5 mi SW of Black Mesa State Park, W of old townsite of Mineral, NE¼, sec. 14, T4N, R1E; Mesa Rica plants (Rothrock, 1925; Nöe, 1925; Stovall, 1943).
27. 2.5 mi SW of Black Mesa State Park, sec. 15, T4N, R1E; Mesa Rica plants (Nöe, 1925).
28. W side of bend in Dry Cimarron, sec. 9, T5N, R4E; Mesa Rica petrified logs (Stovall, 1943).
29. SE of Sugarloaf Mountain, sec. 19, T5N, R5E; Mesa Rica plants (Nöe, 1925).
30. Near confluence of Pedro and Lane Canyons, sec. 16, T6N, R2E; Mesa Rica plants (Nöe, 1925; Stovall, 1943).
31. NE side of Gallinas Canyon, near SE corner NE¼, sec. 24, T6N, R2E; Mesa Rica plants (Rothrock, 1925).
32. N side of Dry Cimarron, sec. 32, T6N, R3E; Mesa Rica plants (Nöe, 1925).
33. N side of Dry Cimarron, sec. 33, T6N, R3E; Mesa Rica plants (Nöe, 1925).
34. N side of Dry Cimarron, sec. 33, T6N, R4E; Mesa Rica plants (Nöe, 1925; Stovall, 1943).
35. 1 mi S of Kenton (sec. 21, T5N, R1E); Mesa Rica teleost fish (Stovall, 1943).
36. Sec. 26, T4N, R1E; Pajarito invertebrates (Stovall, 1943).
37. Secs. 4 and 9, T4N, R5E; Pajarito invertebrates (Stovall, 1943).
38. East-facing bank of south Carrizo Creek, NE¼ NE¼ NW¼, sec. 7, T4N, R2E, Cimarron County, Oklahoma; Pajarito dinosaur footprints, UNM locality 1480.

APPENDIX 2—LOCATION OF MEASURED SECTIONS

1. Baldwin and Muehlberger (1959, pl. 2) section 1: NE¼ NE¼ NW¼, sec. 8, T31N, R29E, Union County, New Mexico.
2. This paper, section A (see Appendix 3).
3. Baldwin and Muehlberger (1959, pl. 2) section 2: NW¼ SW¼, sec. 16, T31N, R29E, Union County, New Mexico.
4. Baldwin and Muehlberger (1959, pl. 2) section 3: SE¼, sec. 21, T31N, R29E, Union County, New Mexico.
5. Baldwin and Muehlberger (1959, pl. 2) section 4: NW¼ NW¼ NE¼, sec. 3, T31N, R29E, Union County, New Mexico.
6. Baldwin and Muehlberger (1959, pl. 2) section 5a: NW¼ NE¼ NW¼, sec. 2, T31N, R29E, Union County, New Mexico.
7. This paper, section B (see Appendix 3).
8. Baldwin and Muehlberger (1959, pl. 2) section 6: SW¼ NE¼ SW¼, sec. 30, T32N, R30E, Union County, New Mexico.
9. Long (1966, pp. 449–452) section 26: NE¼, sec. 18, T35S, R56W, Las Animas County, Colorado.
10. Cooley (1955, pp. 71–74) section 5 (also Baldwin and Muehlberger, 1959, pl. 2, section 7): NW¼ NE¼, sec. 30, T31N, R30E, Union County, New Mexico.
11. Cooley (1955, pp. 60–64) section 3: NE¼ SE¼, sec. 22, T31N, R30E, Union County, New Mexico.
12. Cooley (1955, pp. 57–59) section 2: SE¼ NE¼, sec. 24, T31N, R30E, Union County, New Mexico.
13. Cooley (1955, pp. 65–67) section 4a (also Baldwin and Muehlberger, 1959, pl. 2, section 8a): SW¼ NW¼, sec. 3, T31N, R31E, Union County, New Mexico.
14. Cooley (1955, pp. 49–56) section 1 (also Baldwin and Muehlberger, 1959, pl. 2, section 9): NW¼ NE¼, sec. 20, T31N, R32E, Union County, New Mexico.
15. This paper, section C (see Appendix 3). The same section as Cooley (1955, pp. 75–79) section 6 and Baldwin and Muehlberger (1959, pl. 2) section 10a.
16. Scott (1970b, p. 1244, fig. 2) section N10: cliff north of NM Highway 325, sec. 32, T32N, R33E, Union County, New Mexico.
17. Cooley (1955, pp. 80–82) section 7 (also Baldwin and Muehlberger, 1959, pl. 2, section 12): NE¼ SW¼, sec. 20, T32N, R34E, Union County, New Mexico.
18. Cooley (1955, pp. 85–87) section 8 (also Baldwin and Muehlberger, 1959, pl. 2, section 14): NW¼ NE¼, sec. 32, T32N, R35E, Union County, New Mexico.
19. Baldwin and Muehlberger (1959, pl. 2) section 15: SE¼ NE¼, sec. 31, T32N, R36E, Union County, New Mexico.
20. Baldwin and Muehlberger (1959, pl. 2) section 16: SE¼ SE¼ NW¼, sec. 34, T31N, R36E, Union County, New Mexico.

21. Lucas et al. (1987, fig. 1.6) Road Canyon section (measured by John Holbrook): NW1/4 NE1/4, sec. 18, T30N, R37E, Union County, New Mexico.
22. Schoff and Stovall (1943, p. 252) section 13: secs. 17–18, T4N, R1E, near Swede Creek, Cimarron County, Oklahoma.
23. Schoff and Stovall (1943, p. 252) section 13: sec. 33, T4N, R1E, Cimarron County, Oklahoma (only Mesa Rica Sandstone ["lower sandstone member of Dakota"]).
24. This paper, section F (see Appendix 3).
25–30. Kauffman et al. (1977, figs. 1, 3) sections of Graneros and Greenhorn formations. Their sections 1 (near center, sec. 7, T4N, R2E), 2 (east line SE1/4, sec. 7, west line SW1/4, sec. 8 and west line NW1/4, sec. 17, T4N, R2E) and 3 (NW1/4, sec. 18, T4N, R2E), Cimarron County, Oklahoma.
31. Schoff and Stovall (1943, p. 255) section 19: sec. 18, T5N, R1E, Cimarron County, Oklahoma, at bridge on Carrizo Creek.
32. Schoff and Stovall (1943, pp. 254–255) section 18: sec. 8, T5N, R1E, Cimarron County, Oklahoma, 1 mi NW of Kenton.
33. Schoff and Stovall (1943, p. 254) section 17: SE1/4, sec. 4, T5N, R1E, 1.5 mi NE of Kenton, Cimarron County, Oklahoma.
34. Schoff and Stovall (1943, pp. 259–260) section 30: secs. 20/29, T6N, R1E, Cimarron County, Oklahoma.
35. Schoff and Stovall (1943, pp. 260–261) section 31: sec. 34, T6N, R1E, Cimarron County, Oklahoma ("vicinity of Robber's Roost, from water level of North Carrizo Creek, west of old foundation, up to the hill to the northeast").
36. This paper, section D (see Appendix 3).
37. This paper, section E (see Appendix 3).
38. This paper, section G (see Appendix 3).
39. Rothrock (1925, pl. 2) section: SW1/4 corner, sec. 2, T5N, R3E, Cimarron County, Oklahoma.
40. Rothrock (1925, pl. 2) section: center, sec. 4, T5N, R4E, Cimarron County, Oklahoma.
41. Rothrock (1925, pl. 2) section: NW1/4, sec. 12, T5N, R4E, Cimarron County, Oklahoma.
42. Stanton (1905, p. 664) section at Garrett Post Office: sec. 25, T6N, R4E, Cimarron County, Oklahoma.
43. This paper, section H (see Appendix 3).
44. Schoff and Stovall (1943, pp. 253–254) section 16: secs. 4, 9 and 16, T4N, R5E, Cimarron County, Oklahoma ("railroad cut north of Boise City").
45. Schoff and Stovall (1943, p. 257) section 23: SE1/4, sec. 34, T5N, R5E, Cimarron County, Oklahoma ("fourth hill south of Wolf Mountain").

APPENDIX 3—STRATIGRAPHIC SECTIONS

The stratigraphic sections in Figure 4 are described here. These sections were measured with a 1.5-m-long staff, tape measure and Brunton compass. Colors are those of Goddard et al. (1979).

Section A—Tollgate Canyon

Measured in the NW1/4 SW1/4 NE1/4, sec. 8, T31N, R29E, Union County, New Mexico in the W-facing cut of NM Highway 551 (Fig. 8B).

unit	lithology	thickness (m)
	Graneros Shale:	
16	Sandy limestone; medium dark gray (N 4) to grayish black (N 2) unweathered; weathers to yellowish gray (5 Y 8/1) and grayish yellow (5 Y 8/4); sand is fine grained, well rounded, well sorted and quartzose; very calcareous; massive.	not measured
15	Silty shale; light gray (N 7) unweathered; weathers to grayish orange (10 YR 7/4) and moderate yellowish brown (10 YR 5/4); non-calcareous; fissile.	7.6
14	Bentonitic shale; medium gray (N 5) to dark gray (N 3) unweathered; weathered splotches are dark yellowish orange (10 YR 6/6); non-calcareous; fissile.	0.8
	Romeroville Sandstone (Dakota Group):	
13	Sandstone; very pale orange (10 YR 8/2) unweathered; weathers to dark yellowish orange (10 YR 6/6) and moderate brown (5 YR 4/4); quartzose; fine-grained; well sorted; subangular to subrounded; hematite stains; non-calcareous; massive.	0.3
12	Siltstone; medium dark gray (N 4) to dark gray (N 3) unweathered; weathers to grayish yellow (5 Y 8/4); non-calcareous; massive; well indurated.	0.2
11	Sandstone; yellowish gray (5 Y 7/2) unweathered; weathers to grayish orange (10 YR 7/4); very fine and fine grained; quartzose; poorly sorted; subangular to subrounded; hematite stains; very calcareous; massive.	0.3
10	Silty sandstone; light gray (N 7) and medium gray (N 5); quartzose; very fine grained; well sorted; subrounded; non-calcareous; laminar.	0.1
9	Sandstone; very pale orange (10 YR 8/2) and grayish yellow (5 Y 8/4) unweathered; weathers to yellowish gray (5 Y 7/2) and dark yellowish orange (10 YR 6/6); quartzose; fine and medium grained; poorly sorted; subangular-subrounded; hematite stains; non-calcareous; massive.	0.1
8	Sandstone; very pale orange (10 YR 8/2) unweathered; weathers to grayish orange (10 YR 7/4) and dark yellowish orange (10 YR 6/6); quartzose; medium grained; subrounded-rounded; moderately well sorted; hematite stains; very calcareous; lower 0.3 m bioturbated; upper 0.6 m has low angle planar crossbeds.	1.5
	Pajarito Formation (Dakota Group):	
7	Shale; dark gray (N 3) unweathered; weathers to medium gray (N 5); slightly calcareous.	0.5
6	Silty sandstone; light gray (N 7) and medium dark gray (N 4); sand is quartzose, very fine grained, rounded and well sorted; carbonaceous; non-calcareous; laminar.	0.3
5	Sandstone; grayish orange (10 YR 7/4) unweathered; weathers to dark yellowish orange (10 YR 6/6) and moderate brown (5 YR 3/4); quartzose; fine-medium grained; poorly sorted; subangular-subrounded; calcareous; hematite stains; bioturbated.	0.6
4	Sandstone; light gray (N 8) and grayish black (N 2); quartzose; very fine and fine grained; well rounded; moderately sorted; non-calcareous; carbonaceous; laminar.	0.1
3	Sandstone; very pale orange (10 YR 8/2) and grayish orange (10 YR 7/4) unweathered; weathers to dusky yellowish brown (10 YR 2/2) and grayish orange (10 YR 7/4); quartzose; medium grained; rounded; well sorted, hematite stains, non-calcareous; laminar.	0.4
2	Interbedded sandstone and siltstone; siltstone is medium dark gray (N 4) and dark gray (N 3), non-calcareous and carbonaceous; sandstone is very light gray (N 8) and light gray (N 7), quartzose, fine grained, well rounded, well sorted, non-calcareous and laminar.	2.0
1	Sandstone; yellowish gray (5 Y 7/2) unweathered; weathers grayish yellow (5 Y 8/4) and grayish orange (10 YR 7/4); quartzose; very fine-fine grained; poorly sorted; angular-subangular; hematite stains; non-calcareous; very well indurated; massive.	0.6+

Section B—Long Canyon

Measured in the SW1/4 SE1/4 SW1/4, sec. 35, T32N, R29E, Union County, New Mexico on the northern wall of Long Canyon (Fig. 6A).

unit	lithology	thickness (m)
	Mesa Rica Sandstone:	
12	Sandstone; pale yellowish orange (10 YR 8/6) and dark yellowish orange (10 YR 6/6) unweathered; weathers to dark yellowish brown (10 YR 4/2) and dusky yellowish brown (10 YR 2/2); quartzose; medium-coarse grained; rounded-subrounded; well sorted; hematitic; non-calcareous; planar crossbeds; forms a cliff.	6.0+
	Disconformity	
	Glencairn Formation:	
11	Mudstone; medium dark gray (N 4) and dark gray (N 3) unweathered; weathers to grayish yellow (5 Y 8/4); calcareous.	2.9
10	Silty sandstone; dark yellowish orange (10 YR 6/6) with streaks of moderate yellowish brown (10 YR 5/4) and dusky yellowish brown (10 YR 2/2); quartzose; very fine grained;	

unit	lithology	thickness (m)
	well sorted; well rounded; hematitic; slightly calcareous; bioturbated.	0.9
9	Sandy siltstone; light gray (N 7) unweathered; weathers yellowish gray (5 Y 7/2); sand is quartzose, very fine grained, subrounded-subangular and well sorted; calcareous; massive.	1.8
	Long Canyon Sandstone Bed (type section):	
8	Fossiliferous sandstone; matrix is very pale orange (10 YR 8/2) unweathered and weathers to dark yellowish orange (10 YR 6/6) and moderate yellowish brown (10 YR 5/4); fossil shells are dark yellowish orange (10 YR 6/6); quartzose; coarse and very coarse grained; rounded-subrounded; poorly sorted; some chert pebbles; hematitic; non-calcareous except for fossil shells; massive; UNM locality 1342 (Fig. 6C–D).	0.5
7	Sandstone; same color and lithology as unit 8 but unfossiliferous.	0.6
6	Sandstone; very pale orange (10 YR 8/2) and grayish orange (10 YR 7/4) unweathered; weathers to pale yellowish brown (10 YR 6/2) and dusky yellowish brown (10 YR 2/2); quartzose; medium-coarse grained; poorly sorted; subangular-subrounded; hematitic; non-calcareous; bioturbated (*Ophiomorpha* present).	0.4
5	Sandstone; mottled pale yellowish orange (10 YR 8/6) and moderate reddish brown (10 YR 4/6) unweathered; weathers to yellowish gray (5 Y 7/2) and dusky yellowish brown (10 YR 2/2); quartzose; fine-medium grained; subrounded-subangular; moderately sorted; hematitic; non-calcareous; some liesegang banding; massive (Fig. 6B).	1.2
4	Silty sandstone; very light gray (N 8) and medium light gray (N 6) unweathered; weathers to grayish orange (10 YR 7/4) and very pale orange (10 YR 8/2); sand is quartzose, fine grained, well sorted and subangular-angular; slightly calcareous; laminar; carbonaceous (Fig. 6B).	0.3
	Disconformity	
	Lytle Sandstone:	
3	Sandstone; very pale orange (10 YR 8/2) and white (N 9) unweathered; weathers to dark yellowish orange (10 YR 6/6) and pale yellowish brown (10 YR 6/2); quartzose; very fine-fine grained; rounded; poorly sorted; locally hematitic; non-calcareous; planar crossbeds except top which is bioturbated (Fig. 6B).	3.9
2	Siltstone; very light gray (N 8) to bluish white (5 B 9/1) unweathered; weathered splotches are dark yellowish orange (10 YR 6/6); non-calcareous; massive.	1.2
1	Sandstone; very pale orange (10 YR 8/2) and pale yellowish orange (10 YR 8/6) unweathered; weathers to pale yellowish brown (10 YR 6/2) and moderate yellowish brown (10 YR 5/4); localized "liesegang rings" are moderate reddish brown (10 R 4/6) and dark reddish brown (10 R 3/4); quartzose; fine grained; rounded-subrounded; moderately sorted; locally hematitic; non-calcareous; planar crossbeds; forms a cliff.	12.8

Section C—Travesser Park

Measured in the S1/2 NW1/4 SW1/4, sec. 12, T31N, R32E, Union County, New Mexico.

unit	lithology	thickness (m)
	Mesa Rica Sandstone:	
13	Sandstone; very pale orange (10 YR 8/2) with dark yellowish orange (10 YR 6/6) hematized specks unweathered; weathers to grayish orange (10 YR 7/4) and pale yellowish brown (10 YR 6/2); quartzose; fine-medium grained; poorly sorted; subangular-subrounded; slightly calcareous; planar and trough crossbeds; caps the mesa.	not measured
	Glencairn Formation:	
12	Mudstone and silty sandstone; mudstone is light gray (N 7) unweathered, weathers to yellowish gray (5 Y 8/1) and is calcareous; silty sandstone is grayish orange (10 YR 7/4) and yellowish gray (5 Y 8/1) unweathered, weathers to dark yellowish orange (10 YR 6/6) and moderate brown (5 Y 4/4), quartzose, very fine grained, subangular, well sorted, hematitic, non-calcareous and massive; mostly covered.	2.6
11	Silty sandstone; grayish orange (10 YR 7/4) and dark yellowish orange (10 YR 6/6) unweathered; weathers to pale yellowish brown (10 YR 6/2) and grayish orange (10 YR 7/4); quartzose; very fine-fine grained; subrounded-subangular; poorly sorted; hematitic; slightly calcareous; bioturbated.	0.6
10	Mudstone and silty sandstone; same lithologies and colors as unit 12; 1.5 m above base is UNM locality 1341; mostly covered.	7.3
	Long Canyon Sandstone Bed:	
9	Sandstone; dark yellowish orange (10 YR 6/6) and moderate yellowish brown (10 YR 5/4) unweathered; weathers to yellowish gray (5 Y 7/2) and dark yellowish brown (10 YR 4/2); quartzose; fine and medium grained; subangular; moderately sorted; very calcareous; bioturbated.	0.6
	Disconformity	
	Lytle Sandstone:	
8	Sandstone; very pale orange (10 YR 8/2) with dark yellowish orange (10 YR 6/6) hematitic spots unweathered; weathers to grayish orange (10 YR 7/4) and dusky yellowish brown (10 YR 2/2); quartzose; very fine-fine grained; subrounded; poorly sorted; slightly calcareous; has calcareous siltstone pellets in some beds (pellets up to 1.5 cm in diameter); massive.	1.2
7	Sandstone; dark reddish brown (10 R 3/4) and grayish red (10 R 4/2) unweathered; weathers to very dusky red (10 R 2/2); quartzose; very fine grained; rounded; well sorted; hematitic; non-calcareous; massive.	0.1
6	Silty sandstone; very light gray (N 8) with dark yellowish orange (10 YR 6/6) hematitic specks unweathered; weathers to very pale orange (10 YR 8/2) and yellowish gray (5 Y 7/2); quartzose; fine grained; rounded; well sorted; hematitic; slightly calcareous; massive.	0.4
5	Sandstone; very pale orange (10 YR 8/2) and white (N 9) with pale yellowish orange (10 YR 8/6) streaks unweathered; weathers to yellowish gray (5 Y 7/2) and pale reddish purple (5 RP 6/2); quartzose; fine grained; subangular; well sorted; non-calcareous; bioturbated.	2.3
4	Sandstone; very pale orange (10 YR 8/2) with dark yellowish orange (10 YR 6/6) hematitic spots unweathered; weathers to grayish orange (10 YR 7/4); quartzose; very fine-fine grained; rounded-subrounded; moderately sorted; non-calcareous; planar crossbeds.	2.1
3	Sandstone; very pale orange (10 YR 8/2) with dark yellowish orange (10 YR 6/6) hematitic spots unweathered; weathers to grayish orange (10 YR 7/4); quartzose; medium-coarse grained; subangular; poorly sorted; contains clay pellet beds that are light greenish gray (5 GY 8/1), yellowish gray (5 Y 8/1) and pale red (5 R 6/2); non-calcareous; massive.	2.6
2	Sandstone; white (N 9) to very light gray (N 8) with hematitic spots of grayish orange (10 YR 7/4) unweathered; weathers to dark yellowish orange (10 YR 6/6); quartzose; medium-coarse grained; subangular-subrounded; poorly sorted; non-calcareous; hematitic; planar crossbeds.	3.5
	Disconformity	
	Morrison Formation:	
1	Sandy siltstone and silty sandstone; siltstones are dusky yellow (5 Y 6/4) and grayish yellow (5 Y 8/4) with quartzose, fine grained, rounded, well sorted sandstone and non-calcareous; sandstone is light gray (N 7) unweathered, weathers light brown (5 YR 5/6), quartzose, very fine-fine grained, subangular, moderately sorted, non-calcareous and massive.	1.5+

Section D—Reference section of Lytle Sandstone and Glencairn Formation

Measured in the NE¼ SW¼ SW¼, sec. 18, T5N, R2E, Cimarron County, Oklahoma (Fig. 5A).

unit	lithology	thickness (m)
	Mesa Rica Sandstone:	
18	Sandstone; grayish orange (10 YR 7/4) unweathered; weathers to moderate yellowish brown (10 YR 5/4) and dusky yellowish brown (10 YR 2/2); quartzose; medium grained; rounded; well sorted; some hematitic stains; non-calcareous; planar crossbeds, forms cliffs capping ridge (Fig. 5H).	not measured
	Disconformity	
	Glencairn Formation (reference section):	
17	Interbedded siltstone and sandstone; siltstone is medium gray (N 5) to light olive gray (5 Y 6/1), non-calcareous and massive; sandstone is dark yellowish orange (10 YR 6/6) and moderate brown (5 YR 4/4) unweathered, weathers to grayish orange (10 YR 7/4) and moderate brown (5 YR 4/4), quartzose, very fine grained, subrounded, well sorted, clayey, hematitic, non-calcareous and intensively bioturbated (Fig. 5H).	5.7
16	Sandstone; yellowish gray (5 Y 8/1) and pale red (5 R 6/2) unweathered; weathers to dusky yellowish brown (10 YR 2/2) and grayish red (5 R 4/2); quartzose; fine grained; subrounded; well sorted; clayey; hematitic; intensively bioturbated; non-calcareous; forms a bench.	2.4
15	Siltstone; medium dark gray (N 4) unweathered; weathers yellowish gray (5 Y 8/1); slightly calcareous; massive; mostly covered.	4.9
14	Fossiliferous sandstone; matrix is grayish orange (10 YR 7/4) and moderate yellowish brown (10 YR 5/4); fossil shells are dark yellowish orange (10 YR 6/6) and moderate brown (5 YR 3/4); quartzose; fine grained; subangular; well sorted; locally clayey; non-calcareous except for fossil shells; massive; UNM locality 1330B (Fig. 5G).	0.4
13	Shale, medium dark gray (N 4) unweathered; weathers to yellowish gray (5 Y 8/1); slightly calcareous.	4.1
	Long Canyon Sandstone Bed:	
12	Sandstone; grayish orange (10 YR 7/4) and dark yellowish orange (10 YR 6/6); quartzose; fine grained, subrounded-rounded; well sorted; hematitic, clayey; fossiliferous; calcareous; bioturbated; UNM locality 1330A (Fig. 5F).	0.9
11	Sandstone; light brown (5 YR 5/6) and moderate brown (5 YR 4/4) unweathered; weathers to dark yellowish orange (10 YR 6/6) in spots; quartzose; fine grained; subrounded; well sorted; hematitic; slightly calcareous; bioturbated.	1.5
10	Sandstone; very pale orange (10 YR 8/2) with dark yellowish orange (10 YR 6/6) hematitic spots unweathered; weathers to dark yellowish brown (10 YR 4/2) and dusky yellowish brown (10 YR 22/2); quartzose; very fine-medium grained; poorly sorted; subrounded-subangular; clayey; hematitic; slightly calcareous; intensively bioturbated.	0.3
	Disconformity	
	Lytle Sandstone (reference section):	
9	Sandstone; very pale orange (10 YR 8/2) and pale yellowish orange (10 YR 8/6) unweathered; weathers to pale yellowish orange (10 YR 8/6) and dark yellowish orange (10 YR 6/6); quartzose; medium-coarse grained; poorly sorted; rounded; some very coarse quartz and chert grains; hematitic; friable; planar crossbeds (Fig. 5E).	9.7
8	Sandstone and sedimentary breccia; sandstone is very pale orange (10 YR 8/2) unweathered, weathers to yellowish gray (5 Y 7/2), quartzose, fine grained, rounded, well sorted, clayey, non-calcareous and massive to low-angle planar crossbedded; sedimentary breccia is pale yellowish orange (10 YR 7/6) and dark yellowish orange (10 YR 6/6) unweathered, weathers dark yellowish brown (10 YR 4/2); contains grayish orange (10 YR 7/4) and very light gray (N 8) siltstone clasts that are up to 2.5 cm in diameter; matrix is quartzose, medium- and coarse-grained, poorly sorted, subangular, hematitic, non-calcareous sandstone rudely trough crossbedded; and breccia is matrix supported.	0.4
7	Sandstone; very pale orange (10 YR 8/2) with dark yellowish orange (10 YR 6/6) hematitic spots unweathered; weathers to dusky yellowish brown (10 YR 2/2); quartzose; fine-medium grained; rounded; moderately sorted; laminar and low angle planar crossbedded.	0.6
6	Conglomeratic sandstone; yellowish gray (5 Y 7/2) and grayish orange (10 YR 7/4) unweathered; weathers to same colors and dark yellowish orange (10 YR 6/6); matrix is quartzose, medium-coarse-grained, subrounded, poorly sorted and non-calcareous sandstone; clasts are dominantly chert, up to 6 cm diameter; matrix supported.	1.5
5	Conglomerate; same lithology and color as unit 3 (Fig. 5D).	0.3
4	Sandstone; yellowish gray (5 Y 7/2) and grayish orange (10 YR 7/4) unweathered; weathers to same colors and spots of dark yellowish orange (10 YR 6/6); quartzose; coarse-very coarse grained; well rounded; poorly sorted; non-calcareous; some chert fragments as much as 5 mm in diameter; planar crossbeds.	0.6
3	Conglomerate; dominantly very pale orange (10 YR 8/2) and yellowish gray (5 Y 7/2) but some clasts are dark gray (N 3); clast supported; largest clasts are 4 cm in diameter; matrix is quartzose, very coarse-grained, poorly sorted, subangular sandstone; clasts are dominantly chert but also include quartzite; non-calcareous; unstratified to rudely trough cross stratified.	2.0
2	Clayey sandstone; very pale orange (10 YR 8/2), pale yellowish orange (10 YR 8/6) and dark yellowish orange (10 YR 6/6) unweathered; weathers to moderate brown (5 YR 4/4); quartzose; very fine-fine grained; poorly sorted; subangular; hematitic; non-calcareous; bioturbated and rudely trough crossbedded.	0.2
	Disconformity	
	Morrison Formation:	
1	Siltstone; variegated grayish orange (10 YR 7/4) to pale yellowish orange (10 YR 8/6), grayish purple (5 RP 4/2) to grayish red purple (5 RP 4/2) and light gray (N 7); slightly calcareous in weathered spots (Fig. 5B).	1.0+

Section E—Stock pond

Measured in the SE¼ SE¼ NW¼, sec. 19, T5N, R2E, Cimarron County, Oklahoma along the western bank of a stock pond just W of the road to Lake Carl Etling.

unit	lithology	thickness (m)
	Mesa Rica Sandstone:	
5	Sandstone; dark yellowish orange (10 YR 6/6) and grayish orange (10 YR 7/4); quartzose; fine grained; well sorted; rounded; clayey; non-calcareous; bioturbated; planar crossbedded.	3.0+
	Disconformity	
	Glencairn Formation:	
4	Sandstone; yellowish gray (5 Y 7/2) and very light gray (N 8) unweathered; weathers to dark yellowish orange (10 YR 6/6) and moderate yellowish brown (10 YR 5/4); quartzose; fine-medium grained; well rounded; moderately sorted; non-calcareous; intensively bioturbated.	4.1
3	Interbedded sandy shale and clayey sandstone; sandy shale is medium dark gray (N 4) with quartzose, very fine-fine grained, subangular, poorly sorted sand; clayey sandstone is yellowish gray (5 Y 7/2) unweathered, dark yellowish orange (10 YR 6/6) weathered, quartzose, very fine grained, subrounded, well sorted, and massive to platey; non-calcareous.	5.5
2	Fossiliferous sandstone; matrix is grayish orange (10 YR 7/4) and pale yellowish brown (10 YR 6/2); fossil shells	

unit	lithology	thickness (m)
	are dark yellowish orange (10 YR 6/6); quartzose; fine-medium grained; poorly sorted; subangular-subrounded; non-calcareous except fossil shells; massive; UNM locality 1335 in this unit and lower 0.3 m of unit 3.	0.3
1	Sandy shale; dark gray (N 3) to olive black (5 Y 2/1); sand is quartzose, fine grained, poorly sorted and subangular-subrounded; non-calcareous.	1.5+

Section F—South Carrizo Creek

Measured in the NE¼ NE¼ NW¼, sec. 7, T4N, R2E in the western bank of South Carrizo Creek just south of Black Mesa State Park, Cimarron County, Oklahoma.

unit	lithology	thickness (m)
	Pajarito Formation:	
15	Clayey sandstone; grayish orange (10 YR 7/4) and dark yellowish orange (10 YR 6/6); weathers to moderate brown (5 YR 3/4); quartzose; very fine-fine grained; subangular, poorly sorted; slightly calcareous; ripple laminar to bioturbated.	0.5
14	Interbedded clayey sandstone and shale; same lithologies and colors as unit 12.	1.5
13	Clayey sandstone; very pale orange (10 YR 8/2) and moderate yellowish brown (10 YR 5/4) unweathered; weathers to dark yellowish brown (10 YR 4/2) and dusky yellowish brown (10 YR 2/2); quartzose; medium grained; well sorted; well rounded; slightly calcareous; laminar; UNM locality 1480 (dinosaur footprints) at top of unit.	0.6
12	Interbedded clayey sandstone and shale; sandstone is yellowish gray (5 Y 8/1), quartzose, very fine grained, well rounded, moderately sorted, non-calcareous and laminar to bioturbated; shale is yellowish gray (5 Y 8/1) and medium dark gray (N 4); non-calcareous.	1.4
11	Clayey sandstone; very pale orange (10 YR 8/2) and yellowish gray (5 Y 8/1); hematized burrows are moderate brown (5 YR 4/4); quartzose; fine grained, well sorted; well rounded, non-calcareous; bioturbated.	0.7
10	Clayey sandstone; very pale orange (10 YR 8/2) and pale yellowish brown (10 YR 6/2); quartzose; fine grained; well sorted; well rounded; slightly calcareous; bioturbated to ripple laminar.	0.8
9	Interbedded shale and sandstone; same lithologies and colors as unit 5.	2.6
8	Sandstone; grayish orange (10 YR 7/4); weathers to moderate reddish brown (10 YR 5/4) and moderate brown (5 YR 4/4); quartzose; very fine-fine grained; rounded-subrounded; well sorted; non-calcareous; hematitic; massive.	0.8
7	Interbedded shale and sandstone; same lithologies and colors as unit 5.	0.3
6	Sandstone; grayish orange (10 YR 7/4); weathers to dark yellowish orange (10 YR 6/6) and moderate brown (5 YR 4/4); quartzose; fine-medium grained; well sorted; subrounded-rounded; non-calcareous; hematitic; massive.	0.4
5	Interbedded shale and clayey sandstone; shale is medium gray (N 5) and light olive gray (5 Y 6/1), contains some lignite that is dark gray (N 3) and is non-calcareous; sandstone is moderate brown (5 YR 4/4), weathers grayish orange (10 YR 7/4), quartzose; fine-coarse grained, very poorly sorted, subrounded, carbonaceous in places and intensively bioturbated.	1.2
4	Sandstone; very pale orange (10 YR 8/2) with moderate brown (5 YR 3/4) and dark yellowish orange (10 YR 6/6) hematitic streaks; quartzose; very fine-medium grained; poorly sorted; subrounded-rounded; some hematized plant stems; non-calcareous; intensively bioturbated.	0.3
3	Interbedded siltstone and silty shale; siltstone is medium gray (N 5) and dark gray (N 4) and non-calcareous; shale is pale yellowish orange (10 YR 8/6) and moderate brown (5 YR 4/4) and non-calcareous.	0.8

unit	lithology	thickness (m)
2	Sandstone; very pale orange (10 YR 8/2); weathers to moderate yellowish brown (10 YR 5/4); quartzose; fine-medium grained; rounded-subrounded; moderately sorted; non-calcareous; massive with some trough crossbeds.	0.8
1	Sandstone; medium gray (N 5) and grayish orange (10 YR 7/4); quartzose, very fine-medium grained; poorly sorted; subrounded; carbonaceous; calcareous; ripple laminar.	0.6+

Section G—UNM locality 1332

Measured in the SE¼ SE¼ NE¼, sec. 20, T5N, R2E, Cimarron County, Oklahoma

unit	lithology	thickness (m)
	Mesa Rica Sandstone:	
13	Sandstone; yellowish gray (5 Y 7/2) and grayish yellow (5 Y 8/4) unweathered; weathers to pale yellowish brown (10 YR 6/2) and dusky yellowish brown (10 YR 2/2); quartzose; very fine-fine grained; subrounded; poorly sorted; calcareous; laminar and bioturbated.	not measured
	Disconformity	
	Glencairn Formation:	
12	Sandstone(?) and shale; partly covered; shale is similar to unit 11 in lithology and color.	5.3
11	Shale; medium dark gray (N 4); weathers light olive gray (5 Y 5/2); slightly silty; non-calcareous; UNM locality 1332C at top of unit.	4.3
10	Silty sandstone; medium gray (N 5) to light gray (N 7) unweathered; weathers to pale yellowish brown (10 YR 6/2) and grayish orange (10 YR 7/4); quartzose; very fine grained; rounded; well sorted; non-calcareous; massive; fossiliferous (UNM locality 1332B).	1.2
9	Silty mudstone; medium gray (N 5); weathers to yellowish gray (5 Y 7/2); slightly calcareous.	2.7
	Long Canyon Sandstone Bed:	
8	Sandstone; grayish orange (10 YR 7/4) and dark yellowish orange (10 YR 6/6); quartzose; fine grained; rounded-subrounded; well sorted; hematitic; calcareous; intensively bioturbated; contains a few *Texigryphaea* molds and shell fragments at top (UNM locality 1332A).	1.5
7	Sandstone; very pale orange (10 YR 8/2) with hematitic streaks of pale yellowish orange (10 YR 8/6) to dark yellowish orange (10 YR 6/6); weathers to dusky yellowish brown (10 YR 2/2) and moderate yellowish brown (10 YR 5/4); quartzose; medium grained; subrounded; well sorted; hematitic; non-calcareous; bioturbated.	0.1
	Disconformity	
	Lytle Sandstone:	
6	Sandstone; very pale orange (10 YR 8/2) and dark yellowish orange (10 YR 6/6); weathers light olive gray (5 Y 6/1) and dusky yellowish brown (10 YR 2/2); quartzose; fine grained; subrounded; well sorted; planar crossbeds.	2.4
5	Sandy siltstone; same lithology and color as unit 3; partly covered.	1.1
4	Sandstone; very pale orange (10 YR 8/2) with grayish orange (10 YR 7/4) hematitic mottles; weathers to pale yellowish brown (10 YR 6/2) and dark yellowish orange (10 YR 6/6); quartzose; fine-medium grained; subrounded; poorly sorted; hematitic; non-calcareous; bioturbated.	0.3
3	Sandy siltstone; variegated grayish pink (5 R 8/2), pale red (10 R 6/2) and pale olive (10 Y 6/2); sand is quartzose, fine grained, subrounded and well sorted; non-calcareous; mostly covered.	5.3
2	Sandstone; very pale orange (10 YR 8/2) with moderate reddish brown (10 R 4/6) burrow fillings; weathers to moderate brown (5 YR 4/4) and dusky yellowish brown (10 YR 2/2); quartzose; very fine grained; well sorted, rounded; hematitic; calcareous; intensively bioturbated.	0.4

unit	lithology	thickness (m)
1	Sandstone; very pale orange (10 YR 8/2) with dark yellowish orange (10 YR 6/6) hematitic spots; weathers to grayish orange (10 YR 7/4) and very pale orange (10 YR 8/2); quartzose; coarse-very coarse grained; subrounded; poorly sorted; some quartzite and chert pebbles as much as 0.5 cm in diameter; fines upward; non-calcareous; trough and planar crossbeds.	5.6+

Section H—Boise City railroad cut

Measured in the S1/2 SW1/4 NW1/4, sec. 34, T5N, R5E, Cimarron County, Oklahoma in the N-facing cut of the Santa Fe Railroad.

unit	lithology	thickness (m)
	Mesa Rica Sandstone:	
6	Sandstone; pale yellowish orange (10 YR 8/6) and grayish orange (10 YR 7/4); weathers to moderate brown (5 YR 4/4) and dusky brown (5 YR 2/2); quartzose; very fine-medium grained; poorly sorted; subrounded-rounded; hematitic; non-calcareous; massive.	1.5+
	Disconformity	
	Glencairn Formation:	
5	Clayey sandstone; grayish orange (10 YR 7/4); weathers to very pale orange (10 YR 8/2) and yellowish gray (5 Y 7/2); quartzose; very fine-fine grained; moderately sorted; rounded-subrounded; non-calcareous; bioturbated.	3.3
4	Clayey sandstone; light gray (N 7); weathers to very pale orange (10 YR 8/2) and grayish orange (10 YR 7/4); quartzose; very fine grained; well sorted; angular; non-calcareous; massive, platey and bioturbated.	2.3
3	Clayey sandstone; grayish orange (10 YR 7/4) and pale yellowish orange (10 YR 8/6); burrows are yellowish gray (5 Y 8/1); quartzose; very fine grained; subrounded; well sorted; slightly calcareous; intensively bioturbated; some scour surfaces.	4.3
2	Fossiliferous sandstone; matrix is dark yellowish orange (10 YR 6/6); fossil shells are dark yellowish orange (10 YR 6/6) and dark yellowish brown (10 YR 2/2); quartzose; very fine grained; well sorted; subangular; hematitic; massive; non-calcareous except fossil shells (UNM locality 1336).	0.4
1	Sandy shale; medium gray (N 5); weathering splotches are grayish yellow (5 Y 8/4); sand is quartzose, very fine grained, well sorted and rounded; slightly calcareous.	1.2+