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Late Cretaceous (Lancian) dinosaurs from the McRae Formation, Sierra County, New Mexico

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Introduction

Identifiable skeletal elements of Late Cretaceous dinosaurs are known from three formations in New Mexico: the Fruitland Formation and Kirtland Shale of the San Juan Basin, and the McRae Formation in and around the Elephant Butte Reservoir area. This is the second published description of dinosaur remains from the McRae Formation. The first report was published by Lee (1905). Recent discoveries of McRae dinosaurs began in 1981 when Lozinsky observed the presence of dinosaur-bone fragments during geologic studies in the Elephant Butte area (Lozinsky, 1982). Subsequent fossil prospecting has yielded additional dinosaur-bearing localities (Fig. 1). In this paper we describe the dinosaur and fossil-plant occurrences, we review previous studies of the McRae Formation, and we discuss the age of the McRae and its possible correlation to stratigraphic units in the Western Interior.

McRae Formation

Although recognized as a discrete stratigraphic unit since the early twentieth century (e.g., Lee, 1905, 1907), the McRae Formation was first named by Kelley and Silver (1952). This unit consists of a thick sequence of nonmarine clastic rocks exposed in the Cutter sag and Jornada del Muerto (Fig. 2). Bushnell (1953, 1955) recognized two McRae members, the lower Jose Creek and the upper Hall Lake, and he suggested that the McRae Formation may approach 1,000 m in thickness (Fig. 3). Because part of the section is submerged beneath the waters of Elephant Butte Reservoir and because of pronounced faulting, measurement of a complete section is not possible.

The Jose Creek Member rests unconformably upon rocks of the Mesaverde Group and consists of a sequence of sandstone, shale, conglomerate, and an unusual breccia conglomerate (Bushnell, 1953; Lozinsky, 1982, 1984). This member is 120 m thick at its type locality.

The Hall Lake Member conformably overlies the Jose Creek and is distinguished by its abundance of purple and maroon shales. The boundary between the two members is marked by a basal conglomerate. When the conglomerate is absent, the boundary is marked by the first purple or maroon shale. The top of the Hall Lake Member is absent in all areas and is unconformably overlain by various Cenozoic units.

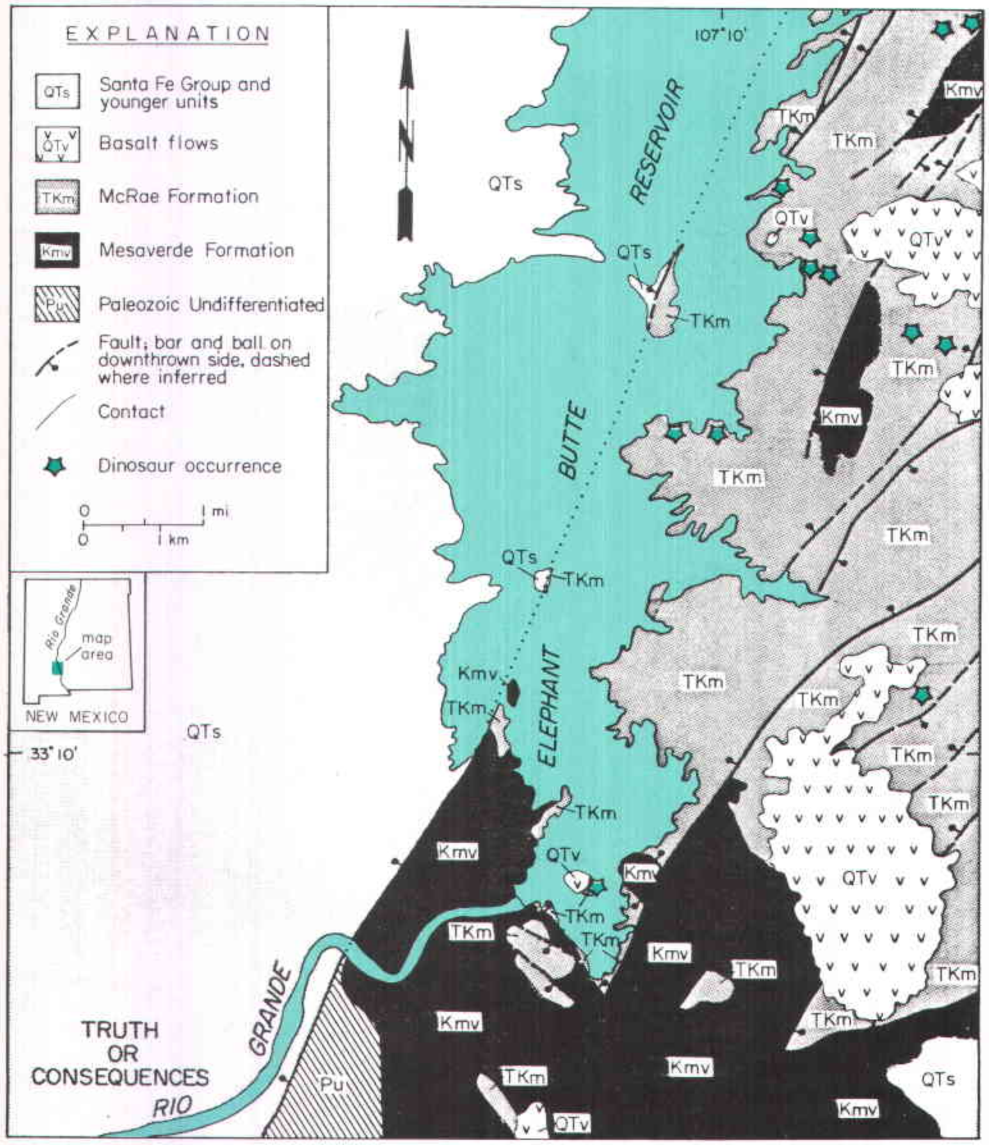

FIGURE 1—Generalized geologic map of the Elephant Butte Reservoir area; dinosaur-bearing localities are highlighted in blue.

Paleobotany

Megascopic plant remains appear to be restricted to the Jose Creek Member and are most common in the finer grained sandstones and siltstones. Fossil leaves also have been reported from the underlying upper Crevasse Canyon Formation (Table 1; Lozinsky, 1982; Wallin, 1983). Despite difficulties that arise from comparing Crevasse Canyon and Jose Creek fossil floras to floras elsewhere, the assignment of a Late Cretaceous age to the Crevasse Canyon and McRae is consistent with available data as indicated below.

In addition to fossil leaves, abundant petrified wood fragments and occasional fragmentary logs and in situ stumps occur in the Jose Creek Member. Some of the stumps are of substantial size (± 1 m in diameter) and appear to be in growth position.

Vertebrate paleontology

Lee (1905) reported dinosaur bones in rocks at or near Elephant Butte. Two additional collections were made in the area during the next eight years (Kelley and Silver, 1952), and these fossils were referred to the ceratopsian genus *Triceratops* by J. W. Gidley (Lee, 1907; Lull, 1933). The fossil material collected during the 1905–1913 period was included in the collections of the U.S. National Museum. Today, this material consists of two dinosaur vertebral centra and other bone

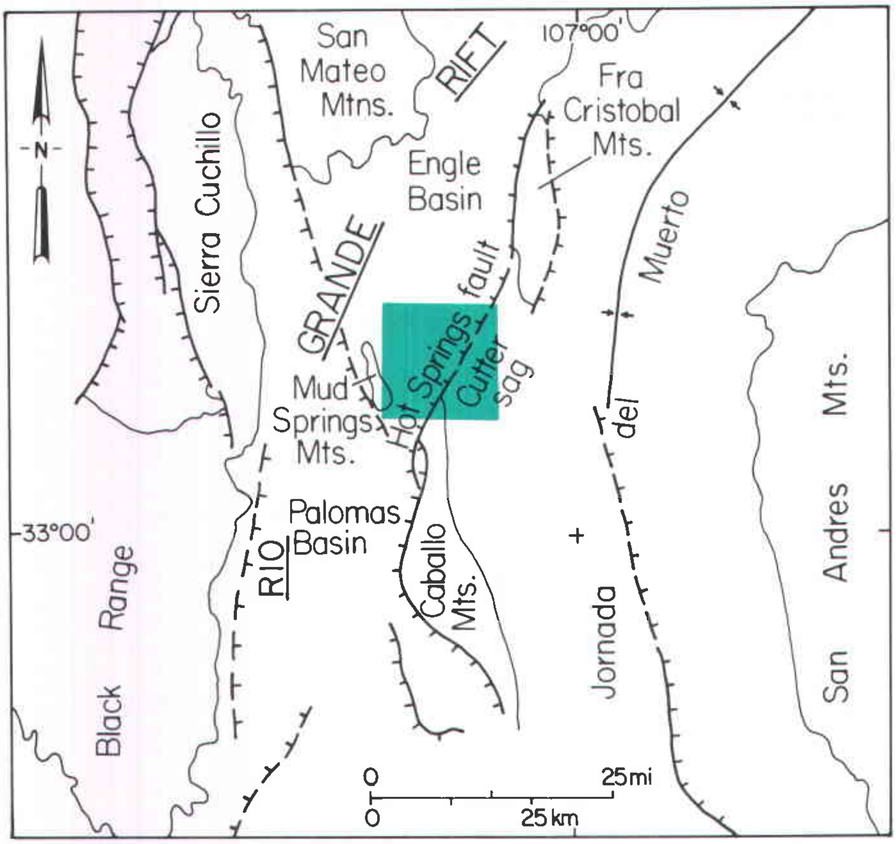

FIGURE 2—Tectonic setting of the Elephant Butte area. Hatched lines are normal faults with hatchures on the downthrown side; the lines are dashed where faults are buried or inferred. Solid lines delineate major uplifts (after Woodward and others, 1978). Shaded portion is the area covered by Lozinsky (1982, 1984).

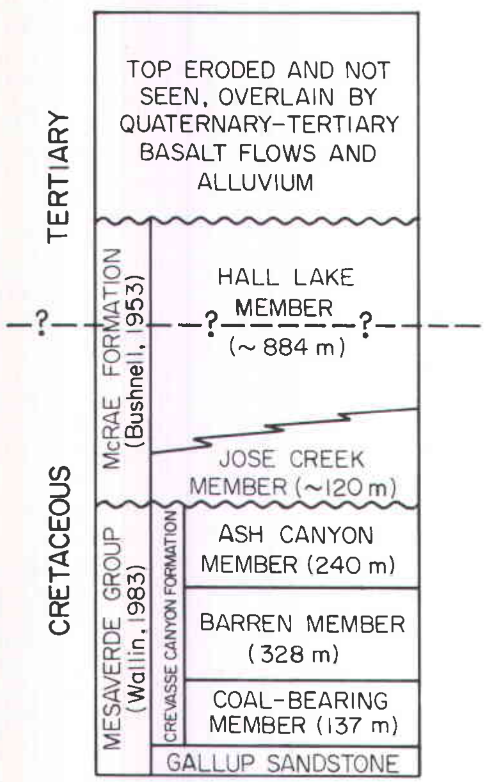

FIGURE 3—Generalized stratigraphic column for the Elephant Butte area based on Lozinsky (1982, 1984) and Wallin (1983).

TABLE 1—CREVASSE CANYON AND JOSE CREEK FLORAS.

Rock unit	Taxa
Jose Creek Member of McRae Formation (Bushnell, 1953; Kottlowski, et al., 1956; Lozinsky, 1982)	*Geinitzia* cf. *formosa* ?*Canna magnifolia* *Sabal montana* *Phyllites* cf. *ratonensis* *Salix* sp. *Cinnamomum* sp. *Sequoia* sp. *Sequoia reichenbach:* *Sabalites* sp. *Sabalites montana* *Ficus planicostata* *Ficus trinerius* *Viburnum marginatum* *Araucarites longifolia*
Crevasse Canyon Formation (Lozinsky, 1982; Wallin, 1983)	*Sequoia montana* *Ficus planiostata* cf. *Dryophyllum* sp. cf. *Laurophyllum wardiana* cf. *Dillenites cleburn:* *Cercidiphyllum* sp. cf. *Quercus viburnifolia*

fragments, all catalogued as USNM 2437. It is likely that these specimens are all that remain of the 1905–1913 collections. Figure 4 shows the two centra that have been referred to *Triceratops*.

Current criteria for defining ceratopsian taxa are based mainly on skull characteristics. The

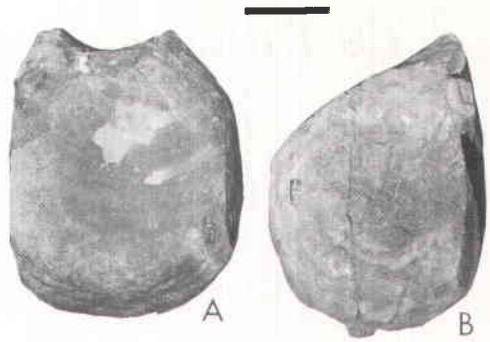

FIGURE 4—Anterior views of USNM 2437 (× 1/3), dorsal centra referred to *Triceratops*, possibly by J. W. Gidley (Lee, 1907; Lull, 1933; bar is 10 cm long).

USNM 2437 collection contains no cranial material and cannot provide a realistic basis for generic identification. However, the two centra of USNM 2437 are large and within the size range of *Triceratops* (Hatcher and others, 1907, pl. 8). *Torosaurus*, a Late Cretaceous ceratopsian as large as *Triceratops*, is known only from cranial remains (Colbert and Bump, 1947). It is not possible to determine whether USNM 2437 represents *Triceratops*, *Torosaurus*, or a new ceratopsian taxon.

Between 1913 and 1981 no dinosaur fossils were collected from the McRae Formation, although no less than seven geologic mapping projects included the McRae (Doyle, 1951; Kelley and Silver, 1952; Bushnell, 1953; McCleary, 1960; Thompson, 1961; Melvin, 1963; Warren, 1978). However, in 1968, John Hawley and William Seager (now at the New Mexico Bureau of Mines and Mineral Resources and New Mexico State University, respectively) were notified of a partial ceratopsian skull discovered at a time of a very low water level in the Elephant Butte Reservoir. Unfortunately, this locality has not been exposed since then.

The studies initiated by Lozinsky in 1981 have resulted in the discovery of 12 localities (Fig. 1) that have yielded fossil material representing four dinosaur taxa (another locality lies just outside the map area to the north). Additionally, in 1983 a yachtsman discovered a locality on the east bank of the reservoir that yielded an incomplete jaw of *Tyrannosaurus rex*. This very significant specimen is in the collections of the New Mexico Museum of Natural History and has been made available to us through the courtesy of David Gillette, who first recognized its significance. A detailed description of this specimen will be undertaken by the New Mexico Museum of Natural History and the New Mexico Bureau of Mines and Mineral Resources in a separate paper.

THE USNM fossils probably came from low in the Hall Lake Member. Localities discovered recently occur at or near the boundary between the Hall Lake and Jose Creek Members. Fossil bone is often associated with conglomeratic or shaly beds. Discussion of the most significant specimens found by us follows.

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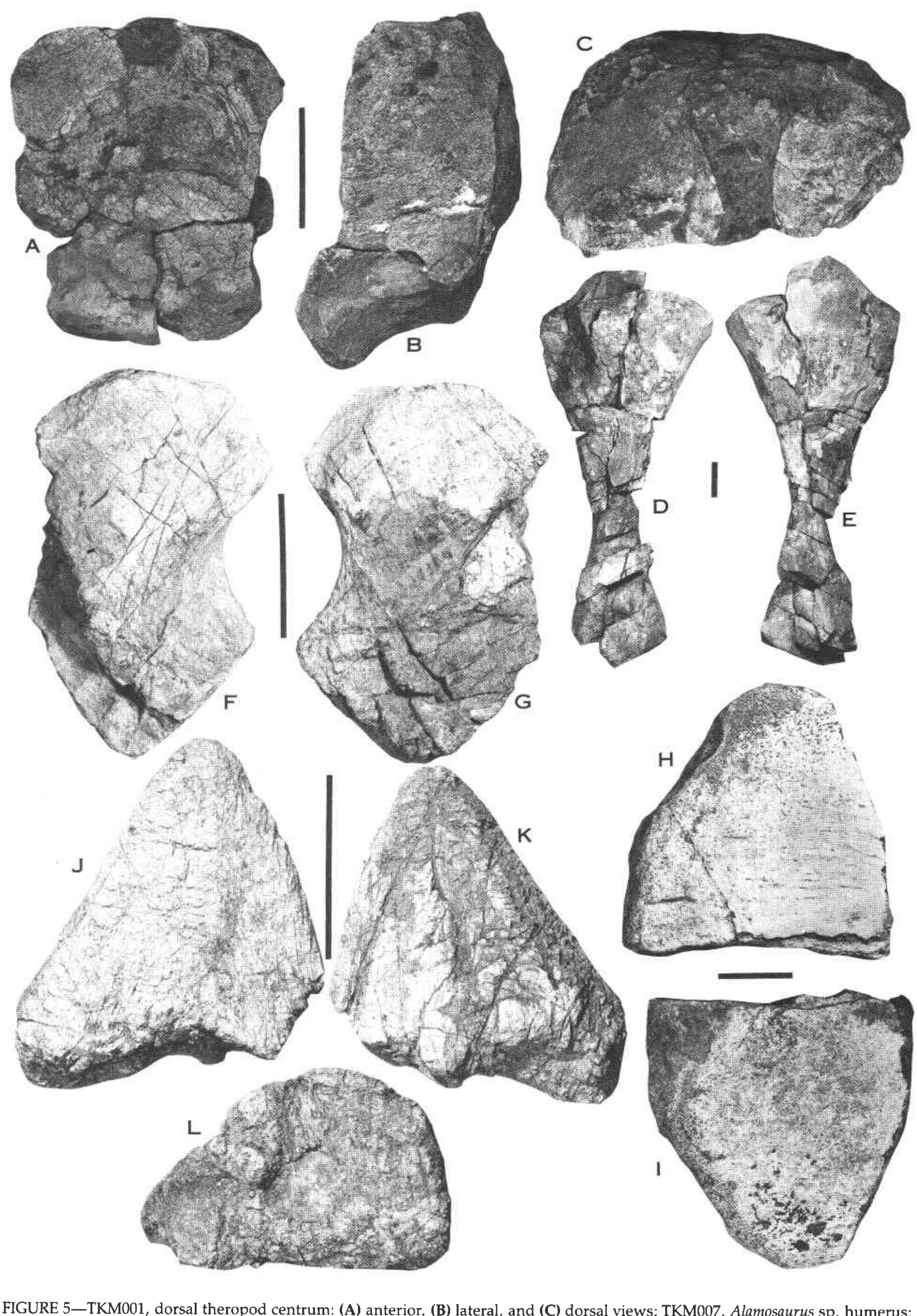

FIGURE 5—TKM001, dorsal theropod centrum: **(A)** anterior, **(B)** lateral, and **(C)** dorsal views; TKM007, *Alamosaurus* sp. humerus: **(D)** anterior and **(E)** posterior views; TKM002, ceratopsian coronoid process: **(F–G)** lateral views; TKM020, ceratopsian crest fragment: **(H)** dorsal and **(I)** ventral views; TKM011, ankylosaur armor fragment: **(J–K)** lateral and **(L)** basal views. The solid bars are all 5 cm in length except **D–E,** which is 10 cm.

Centrum

TKM001 (Fig. 5, A–C) is an incomplete, but relatively well preserved, dorsal centrum. It is strongly opisthocoelous and ovoid in outline, and it is higher than wide and broader dorsally than ventrally (height 150 mm, width 130 mm, length 75 mm). The neural canal is filled by a natural cast and intrudes the body of the centrum. It is roughly oval in cross section and hour-glass shaped longitudinally. Remnants of the pedicels of the neural arch are transversely broader than long. A moderately large excavation low on the left lateral surface of the centrum (length 25 m, height 20 mm) is interpreted to represent the remnant of a pleurocoel. A prominent overhanging lip is evident at the posteroventral margin of the centrum. This feature is not preserved anteroventrally, but it is likely to have been similarly developed and to have formed a deep concavity between the two lip-like structures.

The strongly opisthocoelous character, relatively large size, presence of a pleurocoel and secondary foramina on the pedicels of the neural arch, and the excavated nature between anterior and posterior overhanging lips lead us to believe that TKM001 represents a large theropod, possibly a tyrannosaurid.

Humerus

TKM007 is an incomplete right humerus (length 96 cm, dorsal width 45 cm) and is estimated to be 75–80% complete (Fig. 5, D–E). When discovered, the specimen was very fragmented and has been pieced together.

The deltopectoral crest is massive. It arises at the humeral head and extends in an arc downward, roughly parallel to the external margin of the humeral shaft. Although eroded anteriorly, the crest was probably deflected somewhat medially. Externally, the margin of the humerus is relatively straight and contrasts strongly to the concavity formed by the sharply sloping internal margin.

As can be seen in TKM007, the relatively straight external margin and the well developed deltopectoral crest recall *Alamosaurus sanjuanensis*, known from the Naashoibito Member of the Kirtland Shale in the San Juan Basin (Gilmore, 1922), the Javelina Formation of Texas (Lawson, 1976), and the lower part of the North Horn Formation of Utah (Gilmore, 1946). The deltopectoral crest of TKM007 is less massive than that of *Alamosaurus* and is not as medially deflected. However, Gilmore (1946) notes that the extent of the medial deflection seen in the North Horn specimen has been exaggerated by lateral crushing. This specimen is tentatively referred to *Alamosaurus* sp.

Femur

TKM009 is a massive left sauropod femur (Fig. 6) that is at least 168 cm long and 46 cm wide proximally. The specimen was found in a thoroughly silicified pebble conglomerate and is still in the field.

The shaft is straight and the proximal head, still partially encased in matrix, extends directly laterally to the greater trochanter. There is little, if any, evidence for a neck. Distally, the internal and external condyles are indicated as rounded swellings.

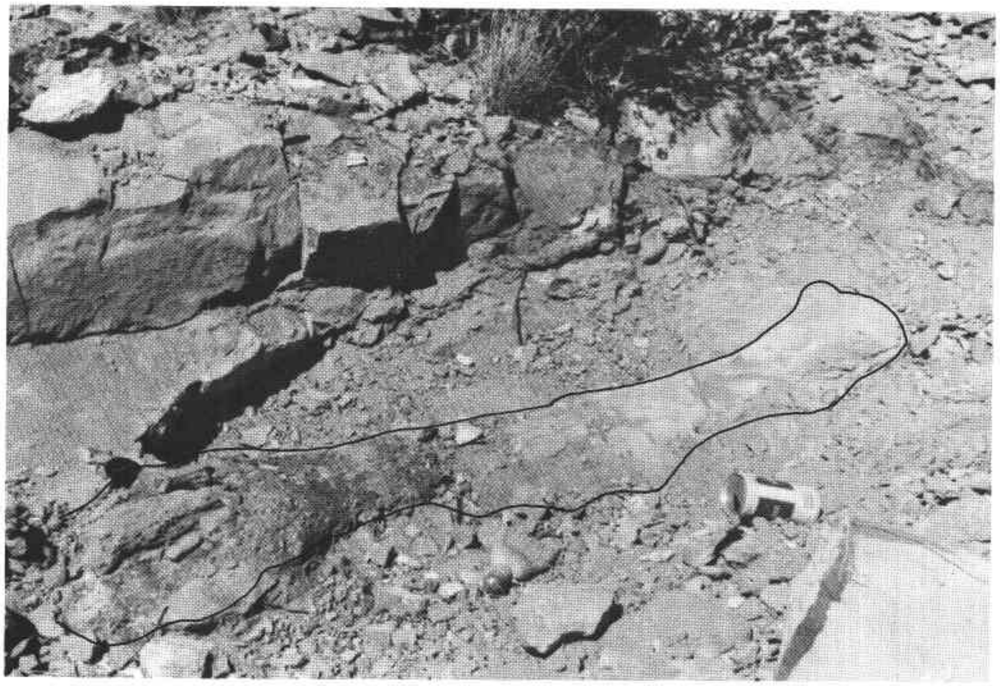

FIGURE 6—Sauropod femur (TKM009), still partially encased in sandstone of the Jose Creek Member matrix, is more than 168 cm long.

Based on the morphology of this specimen and the enormous size it is clear that TKM009 represents a sauropod. The most reasonable hypothesis is that this specimen be referred to *Alamosaurus*. However, there is a strong tendency to refer records of Late Cretaceous North American sauropods to *Alamosaurus* without real justification. Apart from the forelimb described by Gilmore (1946), little is known of the apendicular skeleton of *Alamosaurus*. Therefore, we only note that the estimated femur/humerus length ratio of TKM009 and TKM007 is 1.3, which agrees well with the ratio expected in a titanosaurid (Van Valen, 1969).

Ceratopsian coronoid

TKM002 is a 13.0-cm-long fragment of left mandible that preserves a portion of the dentary and the coronoid process (Fig. 5, F–G). The coronoid process is heavy and anteroposteriorly compressed. It is expanded dorsally with maximum antero-posterior width of approximately 10 cm two-thirds up the summit. The surface of the arcuate coronoid summit is rugose and the anterior coronoid margin curves up and forward into an anteriorly directed, hook-like process. A deep cavity for the reception of the surangular is present at the posterior of the coronoid. These features are sufficient to demonstrate the ceratopsian nature of TKM002. Although it is not possible to differentiate between *Triceratops* and *Torosaurus* based on the material available, the coronoid is much more massive and not as high as the coronoid in *Pentaceratops*.

Ceratopsian crest fragment

TKM020 (Fig. 5, H–I) is a bone fragment 125 mm × 115 mm that varies in thickness from 34 mm at its broken edge to 8 mm at an almost intact margin. The cortex is cancellous and bounded above and below by dense, laminar bone. The surfaces of the fragment are slightly concave and slightly convex, respectively. Both surfaces exhibit narrow linear and arcuate grooves, interpreted as impressions of blood vessels. Based on these features and comparison with material available to us, TKM020 represents a fragment from a ceratopsian crest. Given the thickness of this fragment it is likely that it came from a large individual.

Ankylosaur armor

TKM011 is a pyramidal, laterally compressed bone fragment 75 mm long, 45 mm wide, and approximately 70 mm high (Fig. 5, J–L). A central and roughly circular medial foramen is present in its base.

This specimen, although poorly preserved, almost certainly is a fragment of ankylosaur armor, more specifically a compressed conical plate (Coombs, 1978). It is virtually identical to an ankylosaur plate in the University of New Mexico collections (UNM–FKK–001P) from the Lancian Naashoibito Member of the Kirtland Shale.

Our current interpretation of the composition of the McRae fauna is shown in Table 2.

Age of the McRae Formation

Controversy and misconception have surrounded the question of the age of the McRae Formation and of its relationships to other formations in the Western Interior. Table 3 summarizes the changing concepts.

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TABLE 2—Composition of the McRae fauna.

Class Reptilia
- Subclass Archosauria
  - Order Saurischia
    - Suborder Theropoda
      - Infraorder Carnosauria (TKM001)
        - Family Tyrannosauridae
          - *Tyrannosaurus rex* (New Mexico Museum of Natural History jaw)
      - Infraorder Sauropoda (TKM009)
        - Family Titanosauridae
          - Genus *Alamosaurus* (TKM007)
  - Order Ornithischia
    - Suborder Ankylosauria (TKM011)
    - Suborder Ceratopsia
      - Family Ceratopsidae (USNM 2437, TKM002, TKM020, Hawley specimen)

The youngest diagnostic fossil that occurs below the McRae is *Lopha sannionis*, found in the Gallup Sandstone (Wallin, 1983). *L. sannionis* ranges from late Turonian to early Coniacian (Hook and Cobban, 1981). However, the Gallup strata are separated from the McRae by at least 700 m of intervening strata of the Crevasse Canyon Formation (Wallin, 1983). In the San Juan Basin, the Crevasse Canyon contains early Coniacian pollen (Tschudy, 1976) and may extend up to the mid-Santonian (Molenaar, 1983). Marine deposits associated with Molenaar's T-4 transgression terminated Crevasse Canyon deposition in the San Juan Basin, but this transgression did not reach Sierra County, New Mexico (Molenaar, 1983, fig. 2). Therefore, no upper age limit can be placed on the Crevasse Canyon Formation in the Elephant Butte area based on regional correlations. An age substantially younger than mid-Santonian is quite possible.

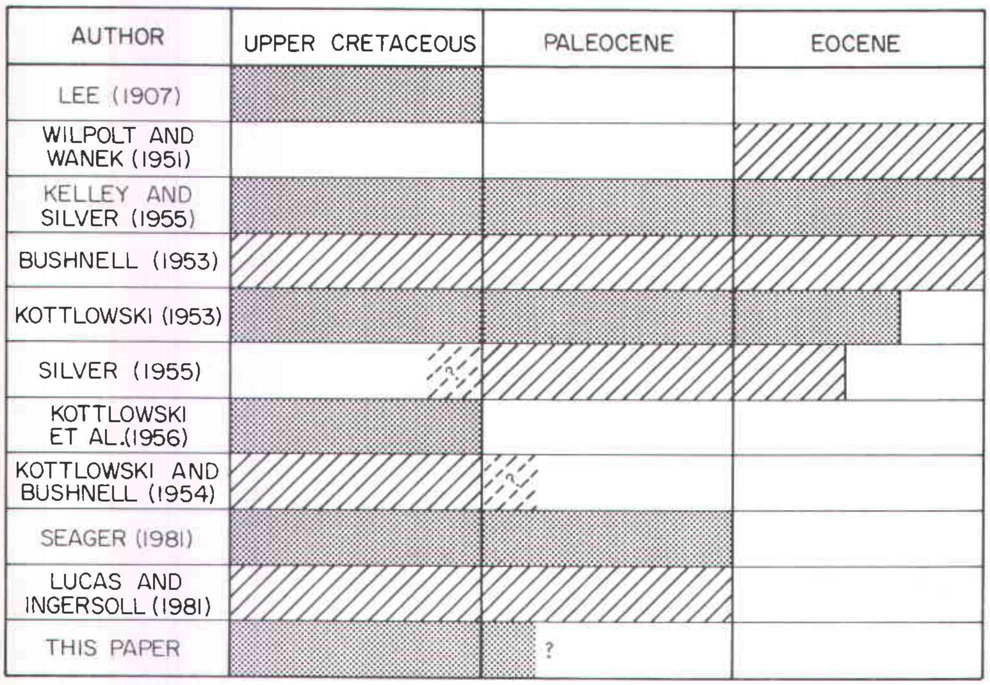
At present, paleontological evidence offers the only means for narrowing the minimum age for the McRae Formation. The presence of *Tyrannosaurus rex* (the NMMNH specimen), a large theropod (possibly a tyrannosaurid), several large ceratopsian specimens (early reports, the Hawley skull, our collections), and a titanosaurid referred by us to *Alamosaurus* is strongly, if not conclusively, in favor of a Lancian age for the McRae Formation.

The Lancian dinosaur fauna from the North Horn Formation described by Gilmore (1946) contains *Torosaurus, Alamosaurus*, and *Tyrannosaurus* (Lawson, 1976). The Naashoibito Member of the Kirtland Shale also contains these three genera (Gilmore, 1922; Lehman, 1981; Lucas et al. (pers. comm. 1983). Although Lancian in age, these faunas do not contain *Triceratops*. As we have shown, it is not possible to determine whether the McRae ceratopsian is *Triceratops* or *Torosaurus*.

Sloan (1970) proposed the concept of a biogeographical dichotomy of Maestrichtian terrestrial communities in the Western Interior of North America. The "*Triceratops* community" of Sloan was dominated by *Triceratops, Anatosaurus, Torosaurus*, and *Tyrannosaurus*. This community extended as far south as north-central Colorado (Fig. 7). A southern "*Alamosaurus* community" was characterized by the presence of *Alamosaurus* and *Torosaurus* in addition to the persistence of more archaic hadrosaurs (Sloan, 1970). Based on recent discoveries, it now appears that the *Tyrannosaurus* is present in the *Alamosaurus* community as well.

The presence of the *Alamosaurus* community in the McRae Formation of south-central New Mexico ties together the other reported occurrences of this community: the Javelina Formation of west Texas, the Naashoibito Formation of the San Juan Basin, and the North Horn Formation of Utah. The presence of the *Alamosaurus* community in the McRae leads to the conclusion that at least the upper part of the Jose Creek Member and the lower portion of the Hall Lake Member are Lancian in age. Because approximately 850 m of the Hall Lake Member overlies the dinosaur-bearing rocks, it seems reasonable to infer that the upper portion of the Hall Lake Member is at least early Paleocene in age.

TABLE 3—Synopsis of changing concepts of the age of the McRae Formation.



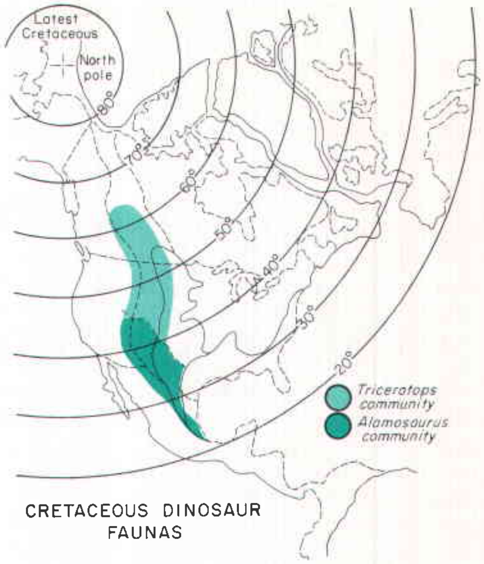


FIGURE 7—Geographic distribution of the latest Cretaceous dinosaur communities in North America (after Sloan, 1970).

Based on extant collections, the presence of *Triceratops* in the McRae Formation cannot be demonstrated, and we cannot exclude the possibility that the ceratopsian present is *Torosaurus*. Indeed, given the known distribution of these ceratopsians and Sloan's community concept, it is more likely that *Torosaurus* is the ceratopsian present in the McRae. If future collecting demonstrates that *Triceratops* is present in the McRae, Sloan's community concept would have to be modified, but the probable age relationships of the McRae to other stratigraphic units would remain unchanged. Fig. 8 shows our proposed correlation with units elsewhere.

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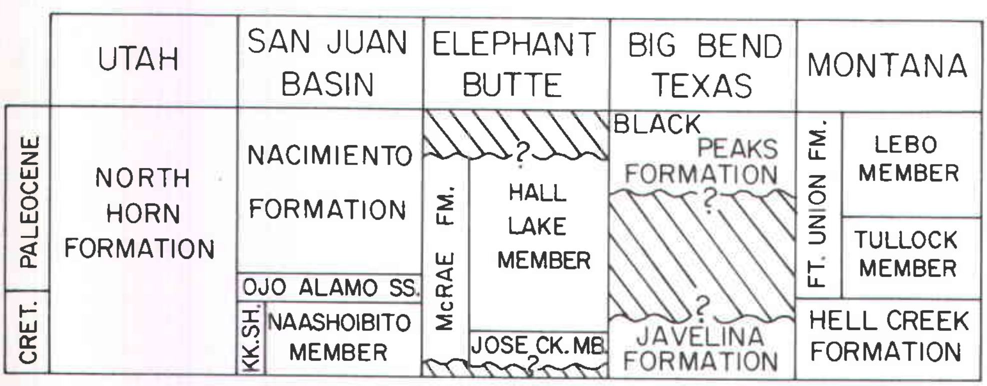

FIGURE 8—Proposed correlation of the McRae Formation with rocks found elsewhere in the Western Interior.

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