
# *Stratigraphic Distribution of Vertebrate Localities in The Upper Cretaceous (?Santonian-Campanian) Menefee Formation in The Southeastern San Juan Basin*

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# STRATIGRAPHIC DISTRIBUTION OF VERTEBRATE LOCALITIES IN THE UPPER CRETACEOUS (?SANTONIAN–CAMPANIAN) MENEFEE FORMATION IN THE SOUTHEASTERN SAN JUAN BASIN

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**Abstract**—Upper Cretaceous strata in the San Juan Basin yield abundant nonmarine vertebrate fossils of late Campanian–Maastrichtian (Judithian, Kirtlandian, Lancian) age from the Fruitland and Kirtland formations. Much less well known are older assemblages from the Menefee Formation, which is of early Campanian age based on the age of over- and underlying marine units. Here we document an especially fossiliferous interval stratigraphically high in the Allison Member of the Menefee Formation. The Allison Member yields a nonmarine assemblage of rays, osteichthyans, turtles, and dinosaurs, but other fossils include marine chondrichthyans and trace fossils of *Teredolites*, associated with marine bivalves. This suggests that the upper Allison Member was sufficiently close to the shoreline of the Western Interior Seaway for the latter to exert influence on its biota. Relatively few Menefee Formation fossils are identifiable to the genus level, but the herpetofauna, particularly the turtles and dinosaurs, are taxonomically similar to those elements in younger Late Cretaceous vertebrate faunas across Laramidia.

## INTRODUCTION

Nonmarine Upper Cretaceous strata in the San Juan Basin are extremely fossiliferous, and vertebrate fossils from the Fruitland and Kirtland formations are world-famous, with a history of collecting dinosaurs and other taxa that dates back more than a hundred years (see reviews by Lucas et al., 2000; Sullivan and Lucas, 2015). Much less studied are the fossils from the stratigraphically lower rocks that make up the Menefee Formation. Despite an enormous outcrop belt (Fig. 1), to date there are relatively few vertebrate localities in the Menefee, in part because of unfavorable facies and other taphonomic factors, and in part due to outcrop accessibility issues. Almost all vertebrates in the Menefee Formation are from the medial Allison Member. The lower Cleary Coal Member and unnamed upper coal member generally lack identifiable vertebrate body fossils. In recent decades, our knowledge of Menefee Formation vertebrates has improved, but the stratigraphic distribution of these localities remains poorly constrained.

In this paper we provide a stratigraphic overview of several vertebrate localities on the southeastern edge of the Menefee Formation outcrop belt (Fig. 1). These include the type localities of the ceratopsian dinosaur *Menefeeceratops sealeyi* Dalman et al. (2021), and the alligatorid *Brachychampsa sealeyi* Williamson (1996; = *B. montana*, see Sullivan and Lucas, 2003), as well as many of the turtles described by Lichtig and Lucas (2015), and multiple new localities with as-yet-undescribed assemblages of fish (both chondrichthyans and osteichthyans), amphibians, reptiles, and mammals (Lewis et al., 2008; Fig. 1). These localities are stratigraphically superposed within the Allison Member, and therefore indicate the potential for the Allison Member to yield additional biostratigraphically significant fossils. Unsurprisingly, the microvertebrate localites are particularly diverse. Although a full description of these assemblages is beyond the scope of this paper, the assemblages from the uppermost Allison Member contain diverse taxa typically interpreted as terrestrial, freshwater, and marine, suggesting that the Allison Member of the eastern San Juan Basin was deposited close enough to the Western Interior Seaway for the latter to exert marine influence. The chondrichthyans (sharks) support previous work that indicates an early Campanian age for the Allison Member (e.g., Lucas et al., 2005).

## PREVIOUS STUDIES

In contrast to the stratigraphically higher Fruitland and Kirtland formations, both of which crop out as extensive badlands to the north and west in the San Juan Basin, the vertebrate assemblage of the Menefee Formation has a relatively brief history of study. Lucas et al. (1988) and Hunt and Lucas (1993) were among the first to report fragmentary assemblages of Menefee tetrapods, followed by Williamson (1996, 1997; Williamson and Brusatte, 2014). Lucas and Sullivan (2006) identified a specimen of the turtle they named *Denazinemys* from the Menefee Formation. Lucas and Hunt (2006) also reported dinosaur tracks from the Menefee Formation. At this

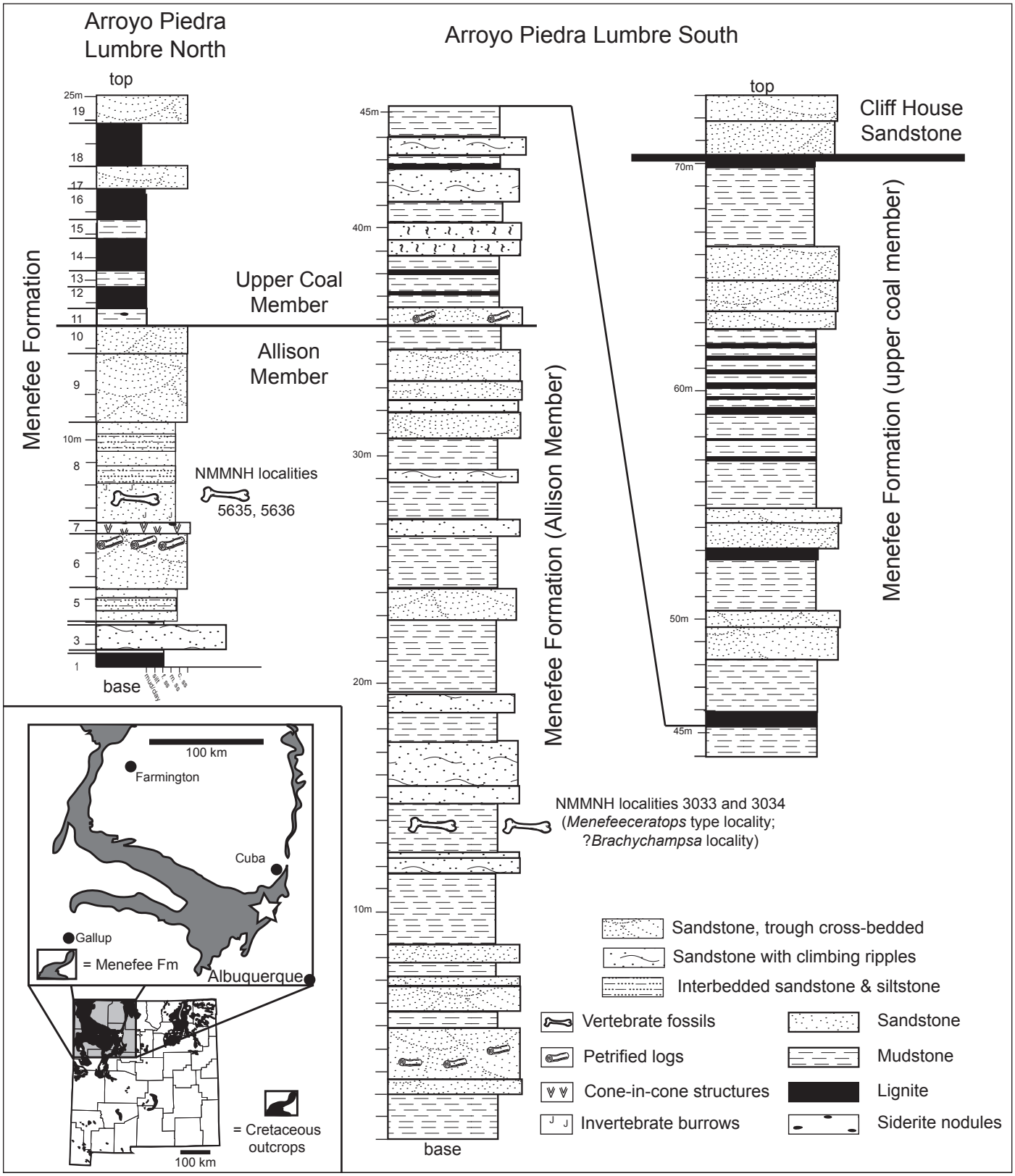


Figure 1. Measured stratigraphic sections of the Upper Cretaceous Menefee Formation east of Torreon Wash, eastern San Juan Basin. The Arroyo Piedra Lumbre South section is modified from Dalman et al. (2001, fig. 2). Inset map shows approximate location of Arroyo Piedra Lumbre within New Mexico and the San Juan Basin.

time, the documented assemblage consisted of fragmentary records dominated by turtles and dinosaurs, albeit most were not identifiable to the genus level. Lichtig and Lucas (2015) updated this record with numerous, albeit fragmentary, records of turtles. Among the taxa Lichtig and Lucas (2015) identified are the stem turtle *Naomichelys* sp., the adocid *Adocus* sp., the baenid *Denazinemys* sp., indeterminate trionychids, and bothremydids tentatively assigned to *Elochelys* cf. *E. perfecta*. These come from a variety of Menefee Formation localities, but some were collected in the outcrops associated with the Arroyo Piedra Lumbre drainage.

Farther to the north and west in the central portion of the San Juan Basin, recent work has identified several new dinosaurs, including indeterminate tyrannosaurid remains (Dalman and Lucas, 2018) from north of Arroyo Piedra Lumbre, and the tyrannosaurid *Dynamoterror dynastes* McDonald et al. (2018), the nodosaurid *Invictarx zephyri* McDonald and Wolfe (2018), and the hadrosaur *Ornatops incantus* McDonald et al. (2021) from Allison Member outcrops near La Vida Mission. That outcrop belt also yielded fossils assigned to the giant crocodilian *Deinosuchus* by Mohler et al. (2021).

In the eastern San Juan Basin, the centrosaurine ceratopsian first described by Williamson (1996) was named *Menefeeceratops sealeyi* by Dalman et al. (2021). Lichtig and Lucas (2015) identified *Adocus* sp., *Denazinemys*, and indeterminate trionychids from the near that locality. These turtles, *Menefeeceratops*, and the brachychampsid (Williamson, 1996; Sullivan and Lucas, 2003) come from strata in the same general area as the microvertebrate sites discussed here, but are stratigraphically older based on their position in the Allison Member relative to the overlying unnamed coal member (Fig. 1).

In their review of the Cretaceous turtles of New Mexico, Lichtig and Lucas (2015) recognized fragmentary shell material of turtles from several localities north of Arroyo Piedra Lumbre, several of which can be tied into the stratigraphic sections we present here (Fig. 1). Specifically, strata in Arroyo Piedra Lumbre north yield fossils that Lichtig and Lucas (2015) assigned to *Adocus* sp. and *Denazinemys*.

## GEOLOGIC SETTING

Collier (1919) named the Menefee Formation as part of the Mesaverde Group, which he identified as consisting of extensive exposures of coal-bearing nonmarine strata in southwestern Colorado that extended into northwestern New Mexico and represented the nonmarine (Menefee) and nearshore (Cliff House) strata that predated the transgression that deposited the Lewis Shale. Throughout its broad outcrop belt (Fig. 1), the Menefee Formation overlies the Point Lookout Sandstone and is overlain by the Cliff House Sandstone (e.g., Pike, 1947). Beaumont et al. (1956) formally defined a lower member, the Cleary Coal Member, and Mannhard (1976) formalized the middle Allison Member, so that the Menefee Formation consists of, in ascending order, the Cleary Coal, Allison, and informal upper coal members. Historically most geologic study of the unit was economically driven, focusing on the identification of coal and petroleum resources (e.g., Siemers and Wadell, 1977; Campbell and Roybal, 1987; Beaumont and Hoffman, 1992).

Because it is relatively thick (~140–500 m) and consists of interbedded resistant sandstones and less resistant mudstones and coals, the Menefee crops out across a broad swath of the southern San Juan Basin (Fig. 1 inset map). However, in some regions, including parts of the study area, some compilations map strata of the Menefee Formation with overlying units (e.g., Cliff House Sandstone or Lewis Shale) (e.g., the U.S. Geological Survey interactive geologic map [USGS, 2025]). As these compilations often underlie major databases (e.g., Macrostrat) and popular web-based applications such as Rockd® and Mancos®, there is potential for confusion regarding the stratigraphic position of fossil localities, as the microvertebrate localities described here occur in outcrops mapped as Lewis Shale on the USGS compilation map. Tabet and Frost (1979; sheets 2 and 3, geology credited to Tabet, Frost, and M.R. Whyte) mapped the area under study here, principally in townships 17–18N and ranges 3–4W at 1:24,000 scale, documenting all three members of the Menefee Formation. These authors reported approximate thicknesses of ~60–90 m of Cleary Coal Member, ~120–170 m of Allison Member, and as much as 200 m of the upper coal member. The thickness data are presented as isopach maps, not measured sections (Tabet and Frost, 1979). North of the study area, in the vicinity of La Ventana, Siemers and Wadell (1977) reported total Menefee Formation thicknesses of 140–275 m. All of the fossils reported here, as well as those in previous publications on the region (e.g., Williamson, 1996, 1997; Williamson and Brusatte, 2014; Lichtig and Lucas, 2015; Dalman and Lucas, 2018; Dalman et al., 2021) were recovered from outcrops that Tabet and Frost (1979) identified as in the Allison Member.

Mannhard (1976) and most subsequent authors have considered Menefee Formation strata to represent a combination of channel, floodplain, lagoonal, swamp, and estuarine depositional environments in relatively close proximity to the shoreline of the Western Interior Seaway. Beaumont and Hoffman (1992) documented the intertonguing relationship of the upper Menefee and the La Ventana Tongue of the Cliff House Sandstone and the eventual transgression marked by the Chacra Mesa Tongue of the Cliff House before deposition of the Lewis Shale locally. We follow Tabet and Frost (1979) and identify Menefee Formation strata that crop out on both sides of Arroyo Piedra Lumbre, a tributary of Torreon Wash, and provide measured stratigraphic sections of the upper portion of the Menefee Formation from both sides of Arroyo Piedra Lumbre (Fig. 1). These sections demonstrate the presence of nonmarine strata, including numerous carbonaceous to coaly beds, best correlated with the Menefee Formation as mapped by Tabet and Frost (1979) and thus stratigraphically below the transgression represented by the Cliff House Sandstone and Lewis Shale.

Strata of the Menefee Formation in this region consist predominantly of sandstones (Allison Member) or sandy mudstones and siltstones with interbedded coals (Cleary Coal and unnamed upper coal members; Fig. 1). Many sandstones of the Allison Member are heterolithic (muddy) and relatively poorly indurated, thus forming localized badlands exposures (Fig. 2A), while others are more resistant and form persistent

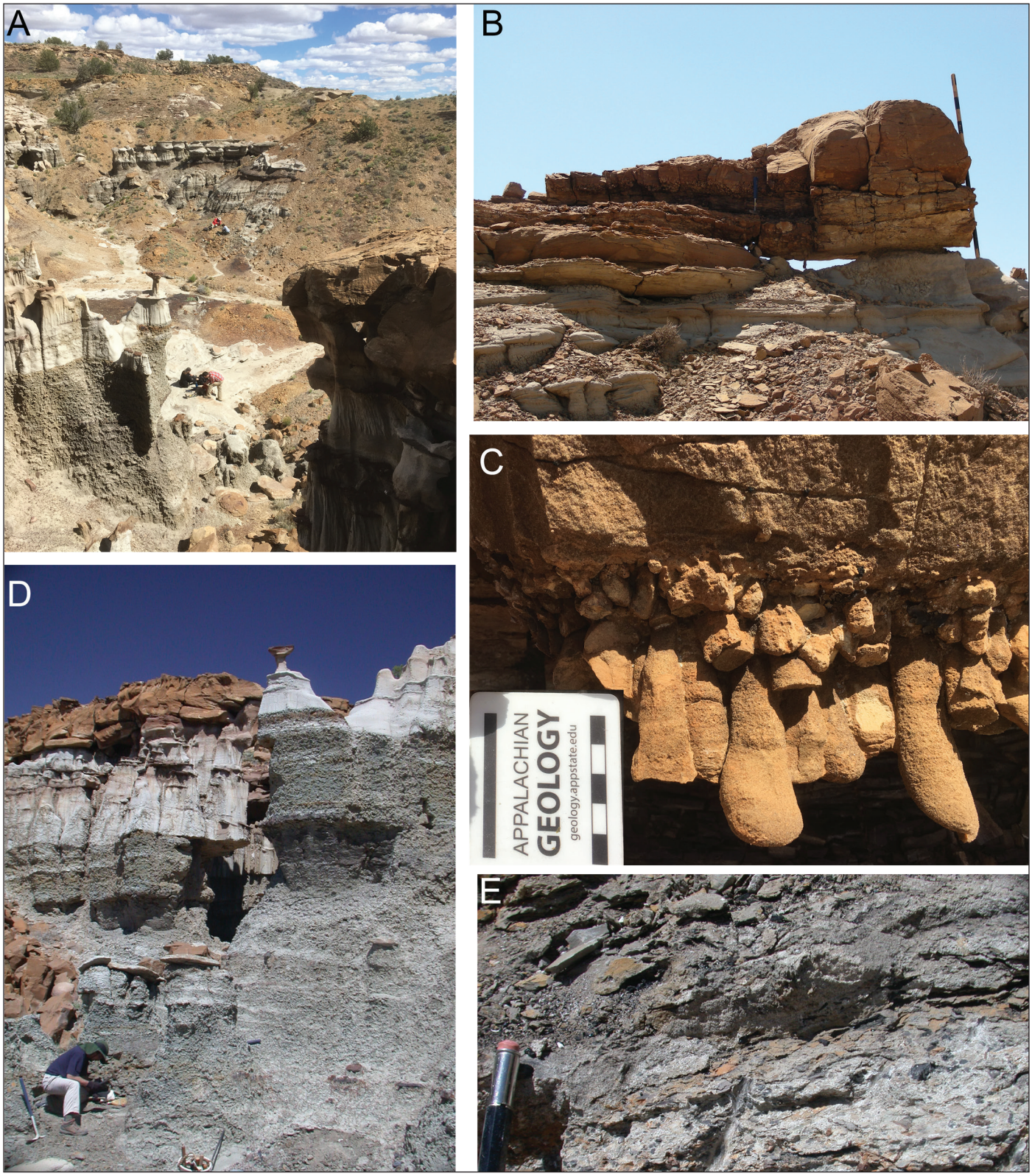


Figure 2. Field photographs of fossiliferous portions of the Allison Member of the Upper Cretaceous Menefee Formation north of Arroyo Piedra Lumbre. A: Overview of the primary fossiliferous horizon; B: a large petrified log oriented roughly N60˚E (base to SW); C: close-up of *Teredolites* fossils riddling the lower portion of the petrified log in B, scale bar in cm; D: view of the excavation of NMMNH locality 5636; E: in situ close-up view of the microvertebrate-bearing lag of NMMNH locality 5636.

ledges. The presence of persistent, if not especially thick, coal beds defines the Cleary and upper coal members. The intermediate Allison Member has some carbonaceous beds and thin lignites, but lacks significant bedded coal seams (Fig. 1). Thin beds of siderite nodules are present throughout the Allison Member and have been interpreted to represent stagnant water in an otherwise well-drained paleoenvironment (Tabet et al., 1985; Beaumont and Hoffman, 1992). Work elsewhere in the Menefee (e.g., Iacoboni, 2005) determined that siderite nodules from the Menefee are composed of >90% mol $FeCO_3$, which indicates freshwater deposition, as opposed to siderite forming in marine environments, in which there is extensive substitution of Mg and Ca (e.g., Mozley, 1989). Samples analyzed by one of us for an undergraduate thesis (Lewis, 2007) recovered 89.6% mol $FeCO_3$ from siderite nodules at the fossiliferous horizons of the Allison Member.

## SITE DESCRIPTION

The localities we document here are located on the north side of Arroyo Piedra Lumbre and were collected under permits issued to the New Mexico Museum of Natural History and Science (NMMNH) by the U.S. Bureau of Land Management. Detailed locality information is on file at NMMNH and is available to qualified researchers. Locally, there are petrified logs, some of which preserve indications of *Teredolites*, a trace fossil commonly ascribed to bivalves colloquially identified as "shipworms" (Figs. 2B and 2C), in strata immediately underlying the fossiliferous interval. The richest locality, NMMNH locality 5636, was the subject of a senior thesis at the University of New Mexico by one of us (Lewis, 2007) as well as several published abstracts on aspects of the assemblage (e.g., Lewis et al., 2008; Deans et al., 2017, 2018; Hendrix et al., 2017, 2018).

The localities are stratigraphically high in the Allison Member (Fig. 1). The primary sandstone layer yielding vertebrates is typically 4–5 m thick and is 4–8 m below the base of the upper coal member, separated from the latter by cliff-forming sandstones (Fig. 2). Both NMMNH localities 5635 and 5636 occur in a heterolithic sandstone bed that forms rounded hummocks except where it is protected by overlying ridge-forming sandstones (Figs. 2A and 2D). We interpret these sandstones, which are locally cross-bedded, as channel and proximal channel (crevasse splay) deposits. Cone-in-cone structures are locally present below this sandstone, and siderite nodules are present in discrete horizons throughout this interval.

Locality 5635 yields a sparse assemblage dominated by bone fragments of larger vertebrates, principally turtles and dinosaurs, although relatively few of these bones are identifiable even to the family level. Lichtig and Lucas (2015) identified some of the turtle material as *Denazinemys*. The assemblage was surface collected and was apparently weathering out of a muddy litharenite with abundant carbonaceous debris. Microvertebrates are present, and include teeth of rays and other sharks, lepisosteid (gar) scales, and other small teeth of osteichthyan fish.

Locality 5636 was discovered in 2004 and originally excavated with the intention of collecting a single limb bone that probably pertained to a dinosaur. The bone-bearing strata turned out to be an intraformational mud-pebble conglomerate and lithic sandstone that clearly represented a lag rich in small (<1 cm diameter) bones and teeth (Fig. 2E). Intraformational conglomeratic lags such as this often yield abundant microvertebrates, especially in the Upper Cretaceous of western North America (e.g., Brinkman et al., 2005; Rogers and Brady, 2010). Approximately 45 kg (100 lb) of this sediment was collected, washed through nested sieves, sorted, and the resulting fossils picked. A small selection of the thousands of recovered bones, teeth, and scales we recovered are illustrated in Figure 3.

We interpret several features at locality 5636 as consistent with a crevasse splay deposit, including fine-grained to very fine-grained sandstone; thin-bedded, randomly occurring, intraformational, thin pebble conglomerate lenses; and interlaminated mud sublamina (e.g., Stonecipher, 2000). We further consider it a splay into a standing body of water based on abundant organic debris, the high organic content of the mud sublamina, and diagenetic authigenic siderite nodules (Stonecipher, 2000).

## CHONDRICHTHYANS

The thousands of fossils collected from NMMNH locality 5635 will be described in greater detail elsewhere. Here we focus on a representative sample of the chondrichthyans (sharks), including both batoids (rays; Figs. 3A–3L) and other sharks (Figs. 3M–3R).

Rays are a common component of small vertebrate assemblages from Upper Cretaceous and lower Cenozoic strata, especially in western North America. This includes both nonmarine (e.g., Kirkland et al., 2013; Cook et al., 2014) and marine assemblages in New Mexico and elsewhere (e.g., Williamson et al., 1989, 1993; Becker et al., 2010; Bourdon et al., 2011; Maisch et al., 2021) from localities stratigraphically older and younger than the Menefee Formation. The teeth we illustrate here are representative of just part of the batoid diversity recovered from NMMNH locality 5636.

Key features used in ray taxonomy include the shape and proportions of the crown and these features relative to the root. Some of the teeth we recovered have flat to weakly convex crowns that lack a transverse ridge (Figs. 3A–3H). Some are quite large (e.g., NMMNH P-50093, Figs. 3E–3H). The vertical faces of the crowns typically meet both the occlusal and ventral surfaces at a right angle. In almost all cases the crowns and the roots are relatively tall. The teeth we illustrate here are generally hexagonal in occlusal view, although some are somewhat rounded with only weak facets developed on the sides of the crowns (e.g., Figs. 3A–3D). None of the teeth we recovered have the striated faces of the crown that typify *Myledaphus* (e.g., Kirkland et al., 2013). Similar teeth, but with a more pronounced occlusal crest (Fig. 3I–L), possess an otherwise similar combination of features that is diagnostic of the rhinobatoid ray *Pseudomyledaphus madseni* Kirkland et al. (2013), to which we tentatively refer teeth such as these.

Some small teeth from NMMNH locality 5635 have low roots and crowns, the latter are subtriangular in occlusal view, with a transverse ridge or crest (Figs. 3O–3R) superficially similar to that of many hybodonts such as *Lonchidion*. A secondary ridge extends down the labial face. The root is weakly bifurcated, and roughly the same size as the crown. In these features, teeth such as this one match both *Ptychotrygon* (e.g., Bourdon et al., 2011, figs. 20a–20f) and *Texatrygon* (Bourdon et al., 2011, figs. 21a–21f) well. Both taxa are common Cretaceous sharks known from diverse marine localities, and in particular *Ptychotrygon* is known from Campanian strata across the modern North American continent (Bourdon et al., 2011).

In addition to teeth, spines and dermal denticles of chondrichthyans can be common components of microvertebrate assemblages. Here we illustrate a typical sawfish rostral spine (NMMNH P-50185; Fig. 3M–3N). The cap is elongate and recurved, and slightly shorter than the peduncle. The base of the cap has small protuberances. The peduncle broadens considerably and appears to bifurcate. In these features, it well matches spines of *Ischyrhiza* illustrated by Bourdon et al. (2011, figs. 22g–22h), although it also closely resembles specimens of *Texatrygon* as illustrated by Bourdon et al. (2011, figs. 21g–21h) and Kirkland et al. (2013, figs. 9.21a–21d).

## DISCUSSION

One consequence of the relative paucity of fossil vertebrates from the Menefee Formation relative to younger units is that new localities such as those documented here can provide insight into numerous poorly constrained issues, including the age, paleoenvironment, and evolutionary relationships of the fossils.

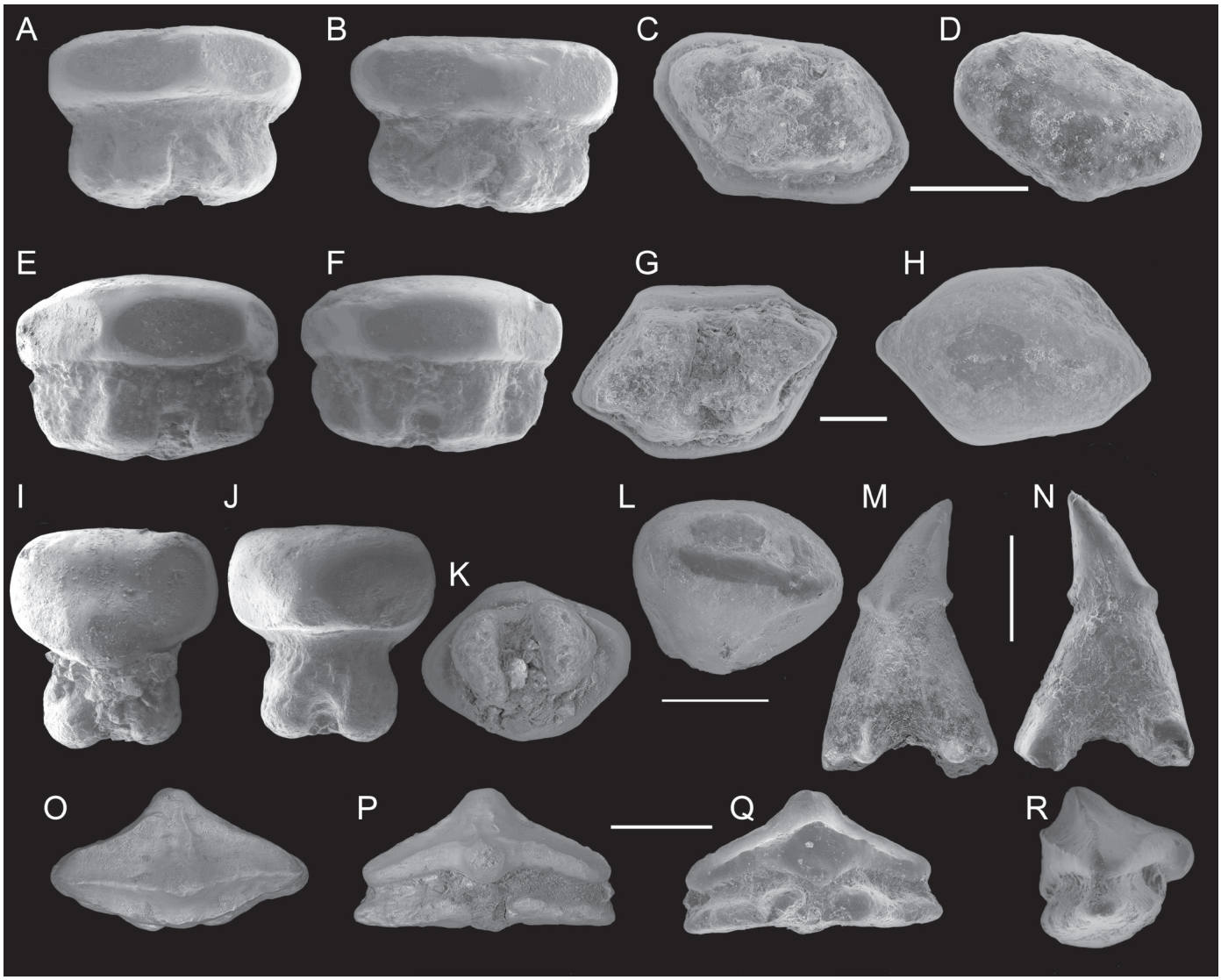


Figure 3. Scanning electron micrographs of selected chondrichthyans from NMMNH locality 5636 in the Allison Member of the Menefee Formation. A–L: rhinobatid teeth tentatively assigned to *Cristomylus* (A–H) and *Pseudomyledaphus* sp. (I–L); A–D: NMMNH P-50076 in lingual (A), labial (B), basal (C), and occlusal (D) views; E–H: NMMNH P-50090 in lingual (E), labial (F), basal (G), and occlusal (H) views; I–L: NMMNH P-50093 in lingual (I), labial (J), basal (K), and occlusal (L) views; M–N: sawfish rostral spine tentatively assigned to *Ischyrhiza* or *Texatrygon* (NMMNH P-50185) in labial (M) and lingual (N) views; O–R: tooth of the shark *Texatrygon* or *Ptychotrygon* sp. (NMMNH P-50092) in occlusal (O), labial (P), lingual (Q), and distal (R) views. All scale bars = 1 mm.

### Age

The Menefee Formation yields few biostratigraphically significant fossils. The underlying Point Lookout Sandstone, overlying Cliff House Sandstone, and related units, however, yield abundant ammonites and other fossils that constrain the age of the Menefee Formation to early Campanian (e.g., Lucas et al., 2005; Sealey and Lucas, 2019) and thus stratigraphically lower than most well-studied Upper Cretaceous nonmarine vertebrate-bearing units in the western interior of North America (see Fowler, 2017). At present, the most direct numerical constraint on the age of the fossils described here is from $^{40}Ar/^{39}Ar$ geochronology on an ash bed from the eastern edge of the San Juan Basin at the Gallina hogback. However, this middle Campanian age (78.22 ± 0.26 Ma) is not in complete agreement with the available biostratigraphic evidence, which is also radiometrically calibrated, and indicates an approximate age of early–middle Campanian for the Menefee Formation (Lucas et al., 2005). Lucas et al. (2005) also reported that palynomorphs from the Menefee Formation indicated a latest Santonian–early Campanian age, similar to that of the Milk River Formation of southern Alberta, Canada (Braman, 2001).

Given their widespread distribution and relative abundance, fossil ray teeth could be excellent biostratigraphic indicators in the Upper Cretaceous strata of Laramidia. Unfortunately, issues of intraspecific variation and their disarticulated nature complicate identification, especially as sites such as NMMNH locality 5636 clearly preserve multiple taxa exhibiting a wide, if not continuous, range of morphotypes. While our identifications of the ray teeth illustrated here are tentative, none of the teeth from locality 5636 (Figs. 3A–3L) have the strongly crenulated crowns typical of *Myledaphus*. *Myledaphus bipartitus* is presently understood to be restricted to the middle-upper Campanian (Kirkland et al., 2013; see also Freedman-Fowler and Horner, 2015). Like Freedman-Fowler and Horner (2015), we find that the teeth derived from older, lower Campanian strata, more closely resemble *Pseudomyledaphus*. The absence of ray teeth assignable to *Myledaphus* (sensu Kirkland et al., 2013) supports an early Campanian age, as *Myledaphus* appears to be restricted to strata of middle Campanian–Maastrichtian age (Kirkland et al., 2013).

### Paleoenvironment

The Allison Member of the Menefee Formation has typically been interpreted as nonmarine, albeit with some possible estuarine environments. Beyond the lithology and bedforms associated with these sites, the trace fossils in the petrified logs and some of the microvertebrate fossils are informative. The largest log (Fig. 2B) preserves numerous tubular structures in the outer layer of wood that are expanded (more bulbous) on the external surface (Fig. 2C). This is consistent with the trace fossil *Teredolites*, which is commonly associated with traces made by teredinid molluscs, known as shipworms, and associated with brackish to marine waters (Bromley et al., 1984; Srivastava et al., 2024).

The vertebrate fossils recovered here are dominated by freshwater and terrestrial taxa, but also record some marine influence. The microvertebrates of localities 5635 and 5636 preserve evidence of marine influence. Although rays are a common component of Upper Cretaceous nonmarine assemblages (e.g., Estes, 1964; see review by Kirkland et al., 2013), other chondrichthyans from these Menefee localities (e.g., *Ischyrhyza*, *Ptychotrygon*) are generally considered to be marine taxa, and thus demonstrate at least some marine influence in these eastern exposures of the Allison Member of the Menefee Formation. Time-averaged lag deposits, especially at formation-level contacts, are a relatively common feature in Upper Cretaceous strata of the western interior (Maisch et al., 2021). We suspect that similar processes, albeit acting at a more localized scale, may be responsible for the accumulation of abundant teeth of marine taxa. Modern sharks are known to penetrate many kilometers upstream in major river systems, and single sharks (including rays) can produce hundreds of fossil teeth. We thus suspect that the fossiliferous interval in the upper Allison Member reflects a relatively nearshore environment, with fluvial systems that may have cannibalized estuarine or other deposits with the remains of marine taxa.

Similarly, the presence of the trace fossil *Teredolites* at multiple localities in the study area suggests that the afflicted logs were exposed to brackish to marine salinities. Given the intertonguing nature of the upper coal member with the La Ventana Tongue of the Cliff House Sandstone, this is not surprising, but has not previously been documented using fossils from the Allison Member.

## CONCLUSIONS

The fossil vertebrates from the Menefee Formation are relatively understudied compared with those from the younger Fruitland and Kirtland formations in the San Juan Basin. Collecting efforts over the past two decades reveal a vertebrate assemblage from the Allison Member that is of early Campanian age and whose reptiles, principally the turtles and dinosaurs, strongly resemble the assemblages of other Campanian–Maastrichtian units. In particular, Menefee turtles include records of the adocid *Adocus*, the baenid *Denazinemys*, and abundant trionychids, and the dinosaur record includes tyrannosaurids, ceratopsians, and hadrosaurs, all of which are typical representatives of younger (Judithian, Kirtlandian, Lancian) assemblages in Laramidia. While the overwhelming majority of the fossils recovered are of nonmarine taxa, the trace fossil *Teredolites* and many of the sharks recovered from microvertebrate sites point to significant marine influence.

## ACKNOWLEDGMENTS

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Quaking aspen (Ts'iisbéíí, *Populus tremuloides*) leaf on the San Miguel Gneiss near San Gregorio Reservoir after an October rain.