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Spencer G. Lucas, Gary Weadock, Kenneth K. Kietzke, Adrian P. Hunt, and Barry S. Kues

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GEOLOGY OF THE IMA NW QUADRANGLE, EAST-CENTRAL NEW MEXICO

SPENCER G. LUCAS[1], GARY WEADOCK[1], KENNETH K. KIETZKE[1], ADRIAN P. HUNT[2] AND BARRY S. KUES[3]
[1]New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, NM 87104; [2]Mesa Technical College, Tucumcari, NM 88401;
[3]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Abstract.—The Ima NW quadrangle, located along part of the eastern border of Guadalupe County with Quay County, straddles the edge of the Southern High Plains (Llano Estacado) and the drainage divide between the Canadian and Pecos Rivers. No substantial geologic structures are exposed on the quadrangle, which is underlain by an essentially flat-lying section of Upper Triassic, Middle-Upper Jurassic, Lower Cretaceous and Neogene sedimentary rocks ~330 m thick. About half of that section (~170 m) is Upper Triassic nonmarine red beds of the Trujillo, Bull Canyon and Redonda formations of the Chinle Group. A much thinner (~63 m thick) section of overlying Jurassic strata belongs to the Entrada (Slick Rock and Exeter members), Todilto (Luciano Mesa Member), Summerville and Morrison formations. The Lower Cretaceous section is also thin (~30 m) and assigned to the upper Albian Tucumcari and Mesa Rica formations. Fossils from the Bull Canyon, Todilto, Tucumcari and Mesa Rica formations on the Ima NW quadrangle are abundant and of biostratigraphic significance. Neogene strata on the quadrangle belong to the Ogallala Formation, which underlies the Llano Estacado, and alluvial, eolian and colluvial units of Pleistocene age that are mostly exposed along Bull Canyon and Alamogordo Creeks.

INTRODUCTION

The Ima NW quadrangle is a U. S. Geological Survey 7.5-minute topographic map located along part of the border of Guadalupe and Quay Counties about 37 km east of Santa Rosa (Fig. 1). In 1983, we began studying the stratigraphy and paleontology of the Mesozoic rocks exposed on the quadrangle. This resulted in geologic mapping of the quadrangle (Lucas et al., 1994). Here, we present a review of the geology of the Ima NW quadrangle. NMMNH = New Mexico Museum of Natural History, Albuquerque and UNM = University of New Mexico, Albuquerque.

PREVIOUS STUDIES

The majority of previous work in the Ima NW area has been related either to the paleontology of the Upper Triassic Bull Canyon Formation, the Middle Jurassic Todilto Formation or to Mesozoic stratigraphy in general. Mehl (1922) first described a Triassic fossil from Guadalupe County. This phytosaur skull had imprecise published provenience, but all recent workers agree that it derives from Bull Canyon (e.g., Hunt and Lucas, 1989). In 1947, J. T. Gregory of Yale University collected fossils from Triassic strata in Bull Canyon and conducted limited stratigraphic studies (Gregory, 1972; Hunt, 1997). In 1983, another phytosaur skull was discovered, and a field party from the University of New Mexico subsequently collected this specimen. This ushered in a period of extensive Triassic fossil collecting in Bull Canyon by field crews from Albuquerque in the early-mid 1980s (e.g., Kues, 1985; Lucas et al., 1984,1985a, b, c, d; Hunt, 1994).

Koerner (1930) was the first to collect Jurassic fish from the Todilto Formation on the Ima NW quadrangle. The rich fossil fish localities near Bull Canyon were later referred to as Bull Canyon, Merrill Ranch and Hornsby Ranch. Fossil fish were later collected by Sternberg, Dunkle, Pierce and Gregory in 1947, Henderson (date unknown), Ash in 1958 and Schaeffer in 1964 (Dunkle, 1942; Schaeffer and Patterson, 1984; Lucas et al., 1985c; Lucas and Kietzke, 1986). In 1983 and 1984, the University of New Mexico made extensive collections of Todilto fish (Lucas et al., 1985c). Subsequently, some fish were collected on the Ima NW quadrangle for NMMNH and by commercial collectors. The intensive paleontological studies of the University of New Mexico in the early-mid 1980s included detailed stratigraphic studies and mapping (e.g., Lucas et al., 1985b, c, 1994) that provide much of the basis of this article.

The geologic map of Dobrovolny et al. (1946) at a scale of 1:62,500 encompassed the eastern edge of the Ima NW quadrangle. Lucas et al. (1994) mapped the geology of the quadrangle at a 1:24,000 scale. That map, somewhat simplified, is reproduced here (Fig. 2).

OVERVIEW

The Ima NW quadrangle is located at a significant physiographic junction--it straddles the boundary between the Southern High Plains (Llano Estacado) and the drainage divide between the Canadian and Pecos Rivers (Fig. 2). Thus, most of the northern third of the quadrangle is Bull Canyon, a 128-152 m deep canyon developed in Mesozoic bedrock by Bull Canyon Creek, a tributary of the Canadian River. The northeastern part of the quadrangle is Luciano Mesa, the westernmost edge of the Llano Estacado, whereas the western third of the quadrangle is a Quaternary upland surface.

The southern two-thirds of the Ima NW quadrangle are dominated by the broad, shallow drainage of Alamogordo Creek, a tributary of the Pecos River. Triassic and Jurassic strata are locally exposed here, particularly along the western escarpment of the Alamogordo Valley. However, most of the rocks exposed in the southern two-thirds of the quadrangle are Quaternary alluvial units.

STRUCTURE

The Ima NW quadrangle mostly exposes flat-lying Mesozoic and Neogene sedimentary rocks. The only geologic structure recognized on the surface of the quadrangle is a down-to-the-northwest normal fault in the Upper Triassic strata near the head of

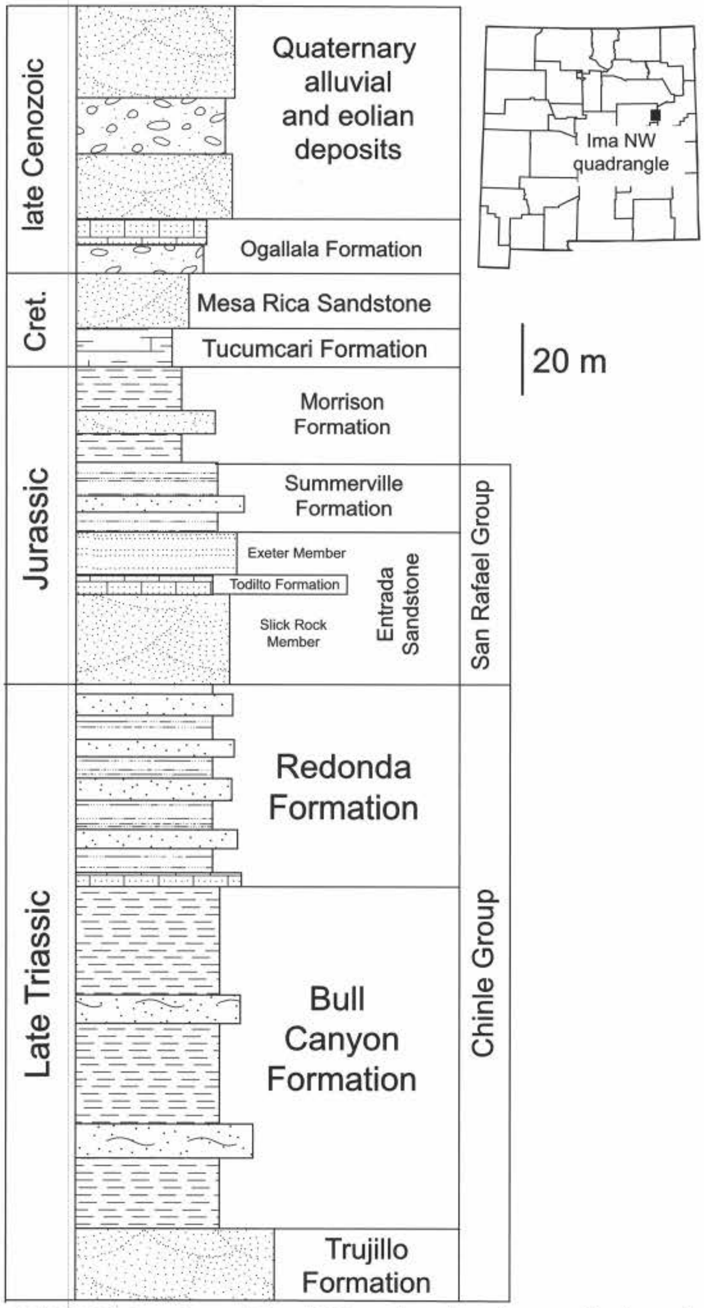


FIGURE 1. Location of Ima NW quadrangle and generalized stratigraphic section of strata exposed on the quadrangle.

Bull Canyon (Fig. 2). We interpret this as a Laramide (Late Cretaceous-Paleogene) structure because it is parallel to the SW-NE trending Laramide structures found elsewhere in east-central New Mexico (Hunt and Lucas, 2001).

MESOZOIC STRATIGRAPHY

Triassic Strata

The oldest rocks exposed on the Ima NW quadrangle are Upper Triassic strata of the Trujillo, Bull Canyon and Redonda formations of the Chinle Group.

Trujillo Formation

The Trujillo Formation of Gould (1907) (=Cuervo Sandstone Member of Chinle Formation of Kelley, 1972b) is only exposed in the southwestern portion of the Ima NW quadrangle along Alamogordo Creek and its tributaries. Here, approximately 6-20 m of the upper part of the formation crop out and are yellowish-gray, trough-crossbedded micaceous litharenites.

In east-central New Mexico, the Trujillo Formation is the medial sandstone complex of the Chinle Group, and is as much as 68 m thick (Kelley, 1972a, b; Broadhead, 1984; Lucas and Hunt, 1989; Lucas et al., 2001). Sandstones like those exposed on the Ima NW quadrangle are the dominant lithotype, although thin reddish brown mudstones and intrabasinal (mostly calcrete-pebble) conglomerates are common. Tetrapod fossils from the Trujillo Formation in eastern Quay County indicate it is of Revueltian (early-middle Norian) age (Lucas and Hunt, 1993; Hunt and Lucas, 1993; Hunt, 1994, 2001), but we collected no fossils from the Trujillo Formation on the Ima NW quadrangle.

Bull Canyon Formation

The Bull Canyon Formation of Lucas and Hunt (1989) (= upper shale member of the Chinle Formation of Kelley, 1972a, b) is the most extensively exposed Upper Triassic unit on the Ima NW quadrangle. Badlands developed in the Bull Canyon Formation form the floor of Bull Canyon in the northern part of the quadrangle. Most of the Bull Canyon Formation crops out here; on the Ima NW quadrangle, the unit has a maximum thickness of 82 m without its base exposed. At the type section of the Bull Canyon Formation, a few km north of the Ima NW quadrangle (sec. 4, T12N, R24E), the entire formation, between the Trujillo and Redonda Formations, is 95 m thick (Lucas and Hunt, 1989).

On the Ima NW quadrangle, as elsewhere in east-central New Mexico, the Bull Canyon Formation is mostly grayish-red and moderate reddish-brown mudstone, minor sandstones that are typically yellowish-gray to grayish-red laminar and crossbedded litharenites, and a few beds of intraformational conglomerates (Fig. 3A). The Trujillo-Bull Canyon contact is picked at the base of the first thick, mudstone interval above the highest Trujillo Formation sandstone. A persistent, bench-forming sandstone as much as 10 m thick and about 25 m below the top of the formation supports an areally extensive Quaternary floodplain terrace in upper Bull Canyon.

This sandstone bench and strata just below it are extremely fossiliferous, and the NMMNH records list more than 50 discrete fossil localities from these strata (Lucas et al., 1985d). Fossils are of plants, especially pith casts of the calamitalean *Neocalamites* (Fig. 3B; Lucas et al., 1985a), invertebrates, especially unionid bivalves and gastropods (Fig. 4; Kues, 1985), and of vertebrates, especially phytosaurs and other tetrapods (e.g., Lucas et al., 1985d; Hunt and Lucas, 1989, 1997; Hunt, 1994, 2001). The tetrapods indicate a Revueltian (early-middle Norian) age for the Bull Canyon Formation on the Ima NW quadrangle.

Redonda Formation

The youngest Triassic strata on the Ima NW quadrangle are assigned to the Redonda Formation of Dobrovolny et al. (1946).

About 55 m of Redonda strata are present, mostly interbedded moderate orange, fine-grained sandstones and moderate reddish-brown mudstones with lesser beds of pale red calcareous siltstone, pebbly mudstone and light greenish gray silty micrite. Redonda beds are laterally continuous and cyclically bedded (Fig. 3C-D), reflecting their deposition in an extensive (minimum area 5000 km^2) lacustrine system (Hester, 1988; Hester and Lucas, 2001). The basal bed of the Redonda is a distinctive bluish gray to purple silty limestone above reddish brown mudstone at the top of the Bull Canyon Formation.

The Redonda Formation is well exposed on the Ima NW quadrangle, especially along the flanks of Bull Canyon (Figs. 2, 3C-D). We collected no biostratigraphically significant fossils from the Redonda Formation on the Ima NW quadrangle. However, in Quay County it yields the type vertebrate-fossil assemblage of the Apachean (late Norian-Rhaetian?) land-vertebrate faunachron (Lucas and Hunt, 1993; Hunt, 1994).

Jurassic Strata

Jurassic rocks exposed on the Ima NW quadrangle are assigned to the Entrada, Todilto, Summerville and Morrison Formations. The Entrada, Todilto and Summerville Formations comprise the San Rafael Group in east-central New Mexico (Lucas and Anderson, 1998). They are best exposed around Bull Canyon and on the flanks of Luciano Mesa in the northern part of the quadrangle.

Entrada Sandstone

The Entrada Sandstone forms the bold, light-colored cliffs that ring Bull Canyon (Fig. 3C-D) and also defends part of the escarpment west of Alamogordo Creek. The Slick Rock and Exeter members of the Entrada sandstone are present.

The bulk of the Entrada Sandstone is the Slick Rock Member, as much as 26 m of yellowish-orange and pale orange subarkosic sandstone that typically displays large-scale trough crossbedding and laminar bedding (Fig. 3E). The Slick Rock Member rests with profound disconformity on the Upper Triassic Redonda Formation. This is the J-2 unconformity of Pipiringos and O'Sullivan (1978) that encompasses a hiatus of approximately 40 million years from the latest Triassic (age of the Redonda Formation) to the Callovian (Middle Jurassic), which is the age of the Slick Rock Member.

The Todilto Formation or the Exeter Member of the Entrada Formation disconformably overlies the Slick Rock Member. The Exeter Member is up to 10 m thick and is lithologically similar to the Slick Rock Member (Fig. 3G). Like Lucas et al. (1985c, 1987) and Lucas and Anderson (1998), we regard the Exeter as an upper tongue of the Entrada Sandstone that post-dates deposition of the Todilto Formation. No fossils are known from the Entrada Sandstone on the Ima NW quadrangle, so its age is based on regional stratigraphic relationships (Lucas et al., 1985c).

Todilto Formation

The Todilto Formation is well exposed along the walls of Bull Canyon, where it is up to 3 m of dark gray, kerogenic limestone with minor interbeds of sandstone and shale at its base (Fig. 3E-F). Lucas et al. (1985c) and Lucas and Kietzke (1986) provided a detailed description of the Todilto Formation on the Ima NW quadrangle. Large numbers of fossil fishes come from the Todilto Formation here, especially along the southwestern edge of Bull Canyon (Koerner, 1930; Dunkle, 1942; Schaeffer and Patterson, 1984; Lucas et al., 1985c). Furthermore, pinchouts of the Todilto Formation into the Entrada eolianites are evident along the southern edge of Bull Canyon (Figs. 3G, 5).

Across northern New Mexico, the Todilto Formation consists of two members, the Luciano Mesa (lower limestone) and Tonque Arroyo (upper gypsum) members (Lucas et al., 1995; Lucas and Anderson, 1998). The type section of the Luciano Mesa Member is on the Ima NW quadrangle (Lucas et al., 1995).

Summerville and Morrison Formations

Jurassic strata above the Exeter Member of the Entrada Sandstone are poorly exposed along the flanks of Luciano Mesa, where they are mostly covered by soil and colluvium (Figs. 2, 3H). Because of their poor exposure, we have mapped the Summerville and Morrison formations together as a single unit (Fig. 2).

However, the two units are easily discriminated in measured sections (Fig. 6). Thus, Summerville strata are red-bed mudstones, siltstones and fine (gypsiferous?) sandstones that directly overlie sandstone of the Exeter Member. A few thin, prominent beds of red chalcedony ("agate beds") are present (Fig. 6). Maximum Summerville thickness is approximately 20 m.

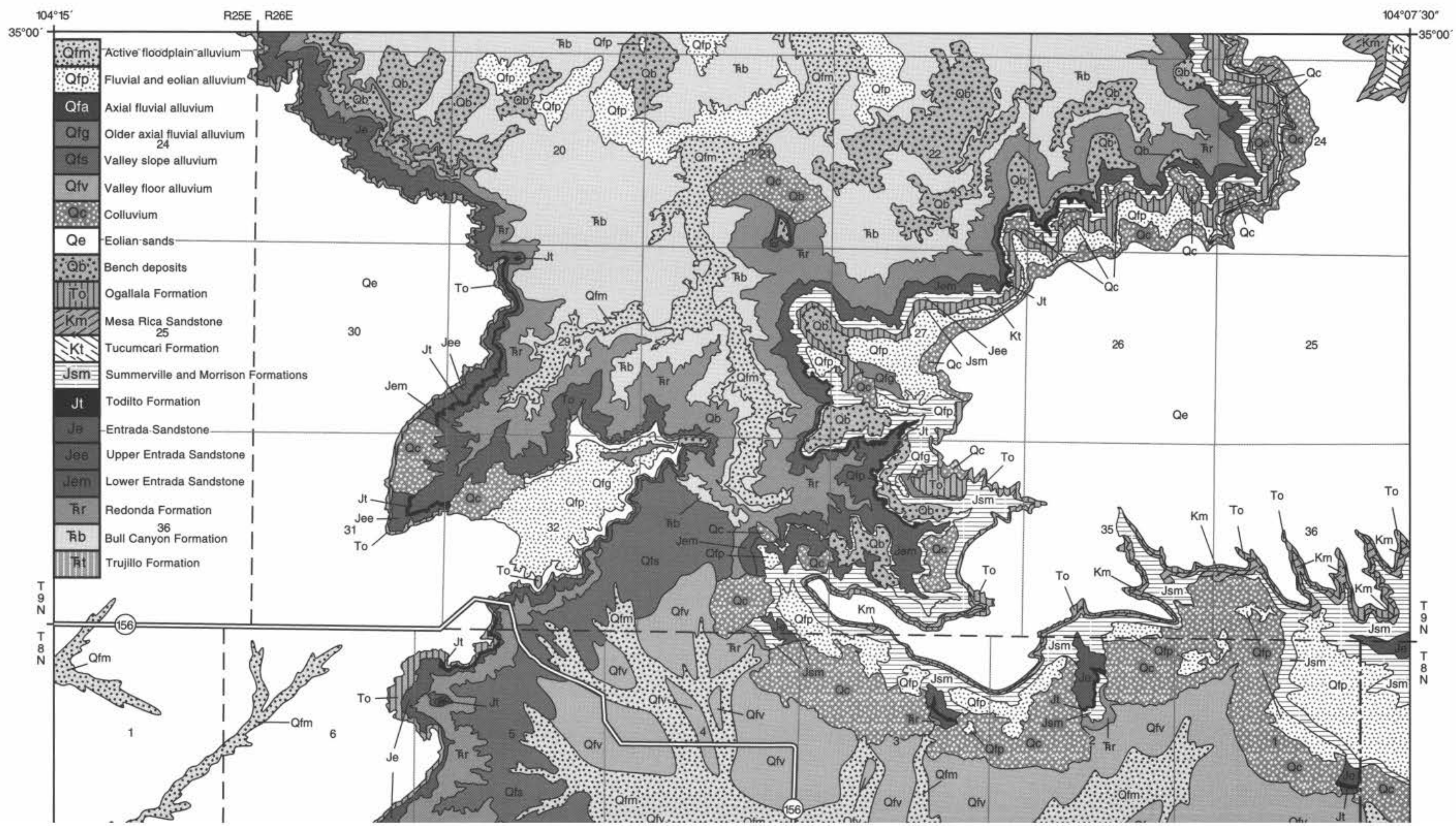
The Morrison Formation on the Ima NW quadrangle is as much as 30 m thick and consists of green smectitic claystone and trough-crossbedded subarkosic sandstone. The Morrison-Summerville contact is placed at the base of the first bed of green smectitic mudstone above Summerville red beds. Regional correlations indicate the Morrison Formation outcrops at the Ima NW quadrangle are part of the Brushy Basin Member (Lucas and Anderson, 1998). Fragmentary bones of sauropods and *Stegosaurus* are present in Jurassic strata on the Ima NW quadrangle (Fig. 6; Lucas et al., 1985c, fig. 25).

Cretaceous Strata

Two Lower Cretaceous units are exposed on the Ima NW quadrangle along the flanks of Luciano Mesa, the Tucumcari and Mesa Rica Formations.

Tucumcari Formation

The Tucumcari Formation is pale green, yellow, purple and gray, slope-forming shale up to 13 m thick that rests directly on trough-crossbedded sandstone or green smectitic mudstone of the Morrison Formation. It represents shoreface to offshore marine environments and has a diverse molluscan fauna dominated by large valves of the gryphaeid oyster *Texigryphaea pitcheri* (Fig. 7). At a locality in the SW1/4 NE1/4 SW1/4 sec. 23, T9N, R6E, the Tucumcari Formation yields hundreds of valves of *T. pitcheri* from a biostrome in the upper part of the formation (Fig. 5). Ammonites and bivalves from the Tucumcari Formation in Quay County indicate it is of late Albian age (Kues et al., 1985; Kues, 1997; Kues and Lucas, 2001).


104°15′
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Qfm Active floodplain alluvium
Qfp Fluvial and eolian alluvium
Qfa Axial fluvial alluvium
Qfg Older axial fluvial alluvium
Qfs Valley slope alluvium
Qfv Valley floor alluvium
Qc Colluvium
Qe Eolian sands
Qb Bench deposits
To Ogallala Formation
Km Mesa Rica Sandstone
Kt Tucumcari Formation
Jsm Summerville and Morrison Formations
Jt Todilto Formation
Je Entrada Sandstone
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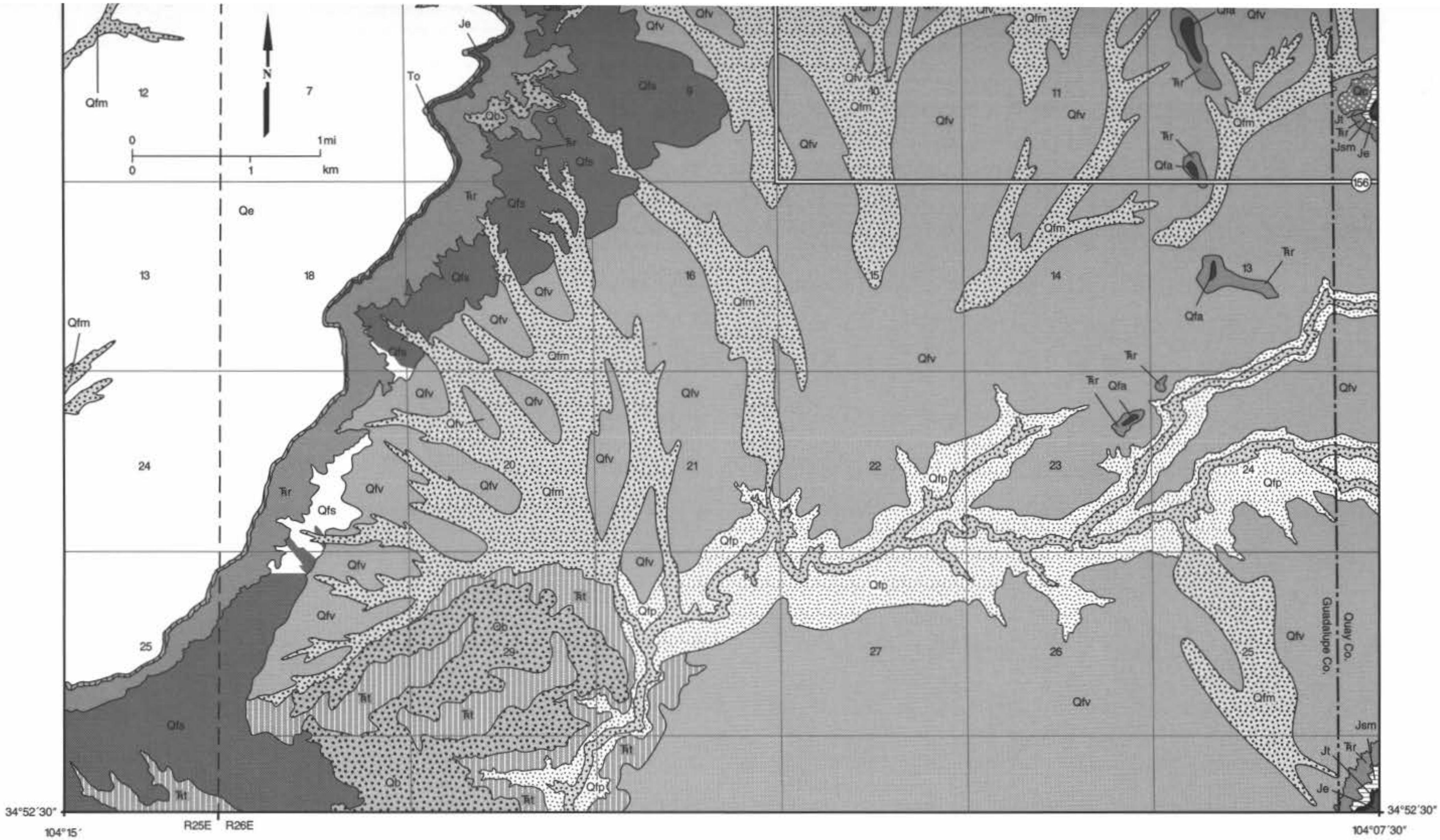
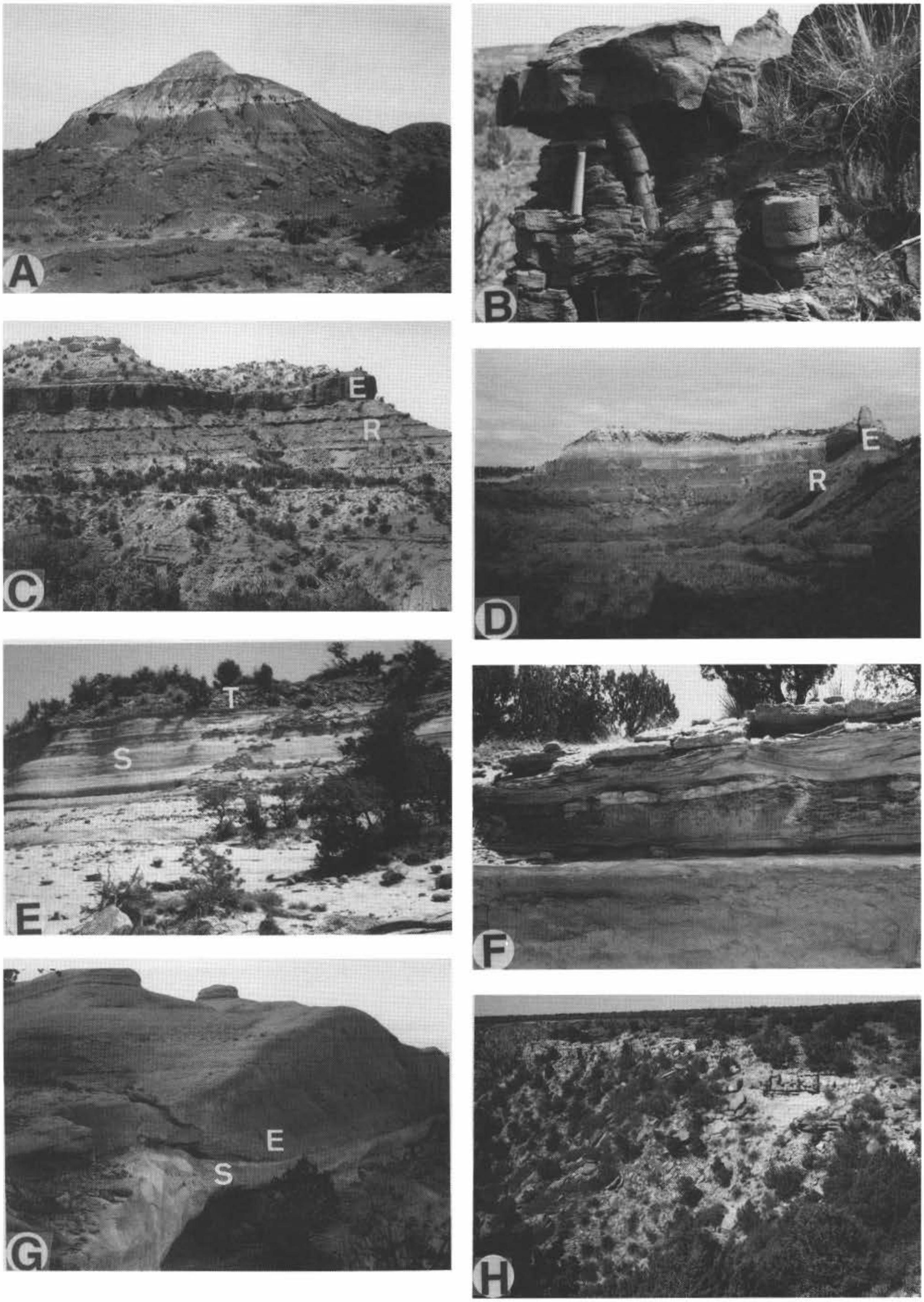


FIGURE 2. Geologic map of the Ima NW quadrangle. Simplified from Lucas et al. (1994).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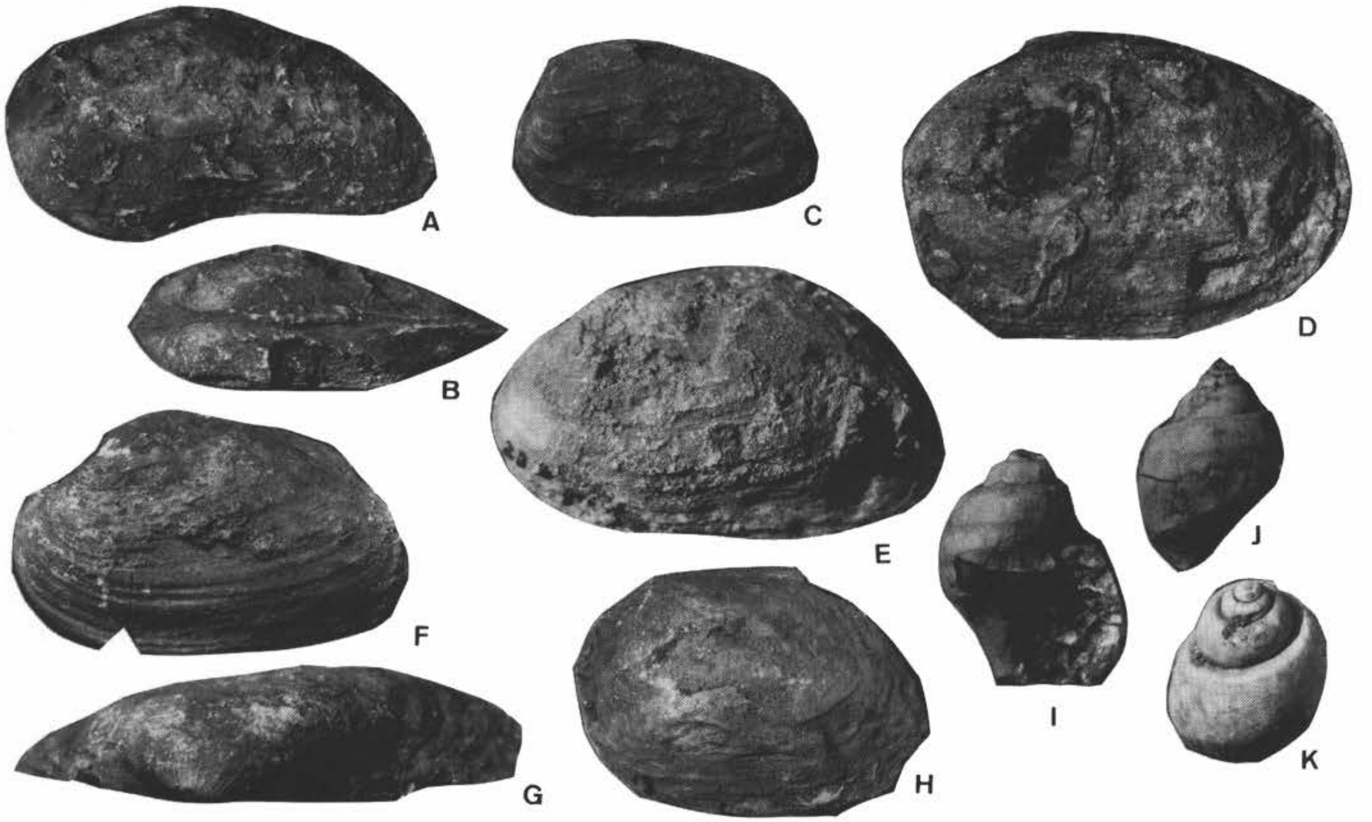

FIGURE 4. Selected nonmarine bivalves (A-H) and gastropods (I-K) from the upper part of the Bull Canyon Formation on the Ima NW quadrangle. All figures x 1 unless otherwise indicated. A-B. "*Unio*" *arizonensis* Henderson, left valve, UNM 8403. C. "*Unio*" sp. 1, left valve, UNM 8450. D. "*Unio*" sp. 5, left valve, showing possible phytosaur tooth mark, UNM 8393. E. "*Unio*" sp. 3, left valve, UNM 8371. F-G. *Antediplodon dockumensis* (Simpson), left valve with incomplete posterior margin, UNM 8356 (F), and dorsal view of right valve, showing beak lirae, UNM 8352 (G). H. "*Unio*" sp. 6, left valve, UNM 8402. I-K. *Triasamnicola pilsbryi* Yen and Reeside (all x 2), apertural view, UNM 8469 (I), adapertural view, UNM 8465 (J), and oblique apical view, UNM 8468 (K).

Mesa Rica Sandstone

The Mesa Rica Sandstone is up to 17 m thick and consists chiefly of yellowish-brown to pale orange, trough-crossbedded sandstone that rests sharply on shale of the Tucumcari Formation. This is a minimum thickness, as the top of the unit is eroded off on the quadrangle. The Mesa Rica Sandstone is the basal unit of the Dakota Group in east-central New Mexico, and typically is approximately 30-40 m thick (Lucas and Kisucky, 1988). At Luciano Mesa, a specimen of the late Albian index ammonite *Mortoniceras equidistans* (Kues et al., 1985, fig. 9I) was collected from the basal Mesa Rica Sandstone just above the *Texigryphaea* biostrome mentioned above (Fig. 6).

FIGURE 3. Photographs of selected outcrops on the Ima NW quadrangle. A. Typical mudstone-dominated strata of the Upper Triassic Bull Canyon Formation. B. Upright, *in situ* pith casts of the calamitalean *Neocalamites* in the Bull Canyon Formation (see Lucas et al., 1985a). C. Cyclically-bedded strata of the Redonda Formation (R) overlain by the Entrada Sandstone (E). D. Cyclically-bedded strata of the Redonda Formation (R) overlain by the Entrada Sandstone (E). E. Slick Rock Member of Entrada Sandstone (S) overlain by Todilto Formation (T). F. Todilto Formation. G. Pinchout surface of Todilto Formation between Slick Rock (S) and Exeter members (E) of Entrada Sandstone. H. Slope-forming Morrison Formation.

CENOZOIC STRATA AND GEOMORPHOLOGY

Cenozoic strata on the Ima NW quadrangle are of Neogene (including Quaternary) age. The Ima NW quadrangle is located on the northwestern border of the Llano Estacado. Quaternary evolution of the Bull Canyon and Alamogordo Valley drainage basins has been characterized by several episodes of entrenchment, partial backfilling and valley floor stability. Evidence of Quaternary processes is recorded in a stepped sequence of graded valley-margin geomorphic surfaces of both constructional and erosional origin that are inset against the Ogallala Formation and older strata. In Bull Canyon, geomorphic surfaces take the form of large bedrock benches overlain by thin alluvium. Conversely, Alamogordo Valley has few bedrock benches, but numerous alluvial deposits and transport-limited slopes. Neogene strata recognized in the area include five Pleistocene valley-fill units, two eolian units, a colluvial unit and the Miocene Ogallala Formation. Thus, there are two principal kinds of Neogene deposits on the Ima NW quadrangle: (1) remnants of the formerly extensive Ogallala Formation; and (2) a suite of younger valley border and valley floor alluvial and stream deposits and associated geomorphic surfaces.

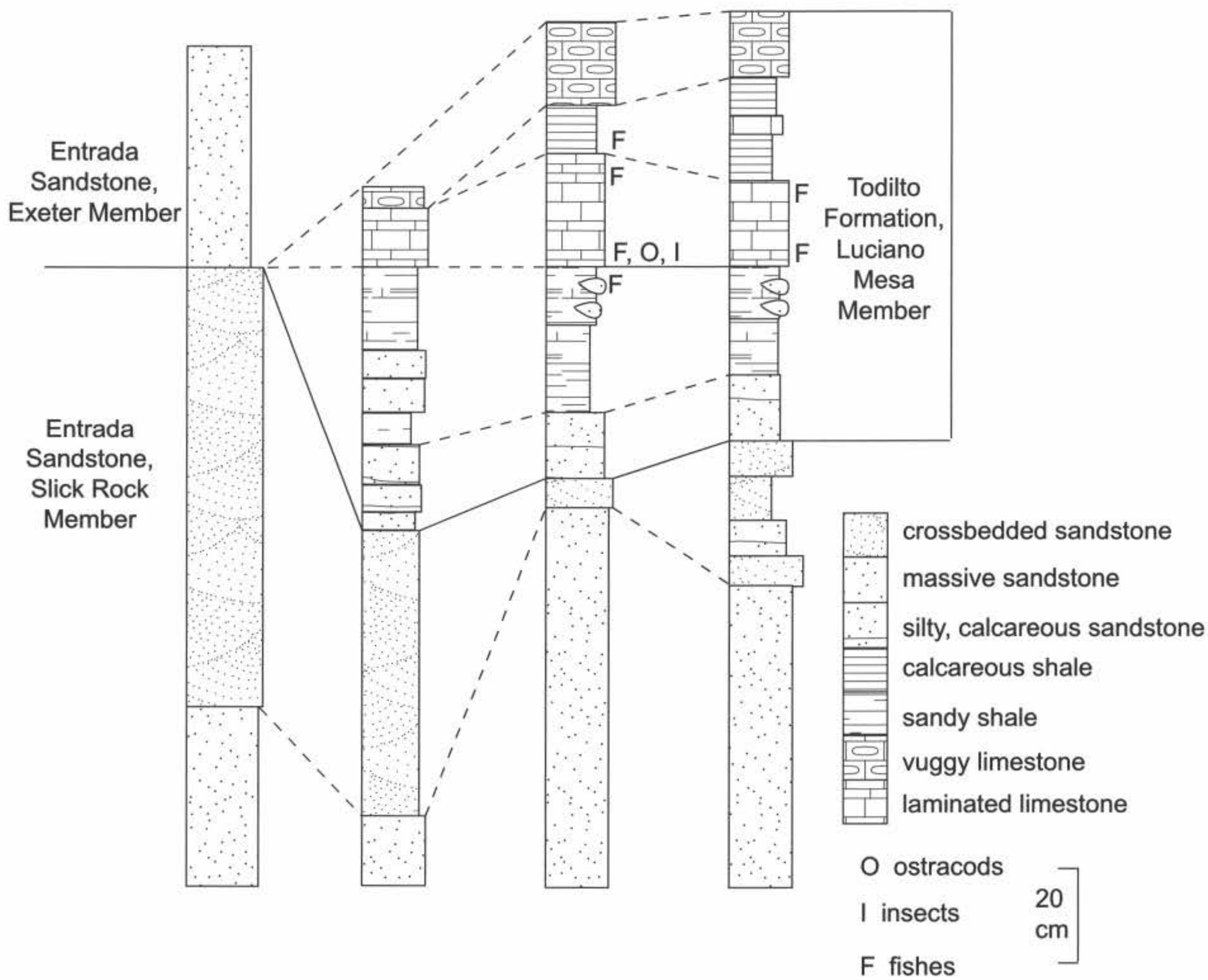

FIGURE 5. Jurassic stratigraphic sections showing the pinchout of the Todilto Formation in SW ¼ SW ¼ sec. 28, T9N, R26E.

Ogallala Formation

On the Ima NW quadrangle, the escarpment of Luciano Mesa and the upland surface to the west of Bull Canyon are underlain by the Miocene Ogallala Formation (cf. Hawley, 1984). The Ogallala here is 9-14 m thick and consists of a lower interval of conglomerate and an upper interval of white to tan calcrete, the "Caprock caliche."

The basal conglomerate of the Ogallala Formation is massive, moderately sorted and dominated by pebbles and cobbles of metamorphic (quartzite, gneiss) and sedimentary (sandstone) rocks. It has a carbonate matrix and is weakly cemented. The overlying calcrete is light colored (white to tan), thick (up to 10 m), highly indurated and has lenses of sand and gravel. The top of the Ogallala Formation is a plain covered by a thin veneer of eolian sand.

Older Alluvium (Qfg, Qfp)

Older alluvium includes deposits associated with at least three Pleistocene episodes of valley incision and partial backfilling, prior to the formation of the present landscape. Ancestral floodplain positions that formed local base levels ranged from 20-100 m above the present active floodplain. Older valley-fill alluvium represents aggradational events or cycles culminated by long periods of base level stability and geomorphic surface formation.

Unit Qfg contains stream deposits laid down during dissection of the Ogallala plain. This sediment is composed of large, rounded gravel clasts (1-15 cm in diameter) in a matrix of medium-grained sand and calcium carbonate. The matrix is pale tan to white, whereas the gravels are of various colors and lithologies. Clasts include granite, gneiss, Jurassic and Cretaceous sandstone as well as clasts derived from the Ogallala Formation. On the margin of Luciano Mesa, this unit forms elongated terraces that overlie Morrison Formation sandstone and ranges from 2 to 25 m in thickness.

At its most complete outcrops, Qfg has three distinct units. The lower unit is clast-supported and imbricated gravel (1-10 cm diameter clasts) in a calcium carbonate-cemented sand matrix. The middle coarse sand has abundant calcium carbonate in the matrix, is not imbricated, but does have inclined bedding dipping to the northwest. The upper section is poorly sorted gravel (clasts 5-15 cm in diameter), sand and silt containing only small amounts of calcium carbonate. Generally, these three cycles of sedimenta-

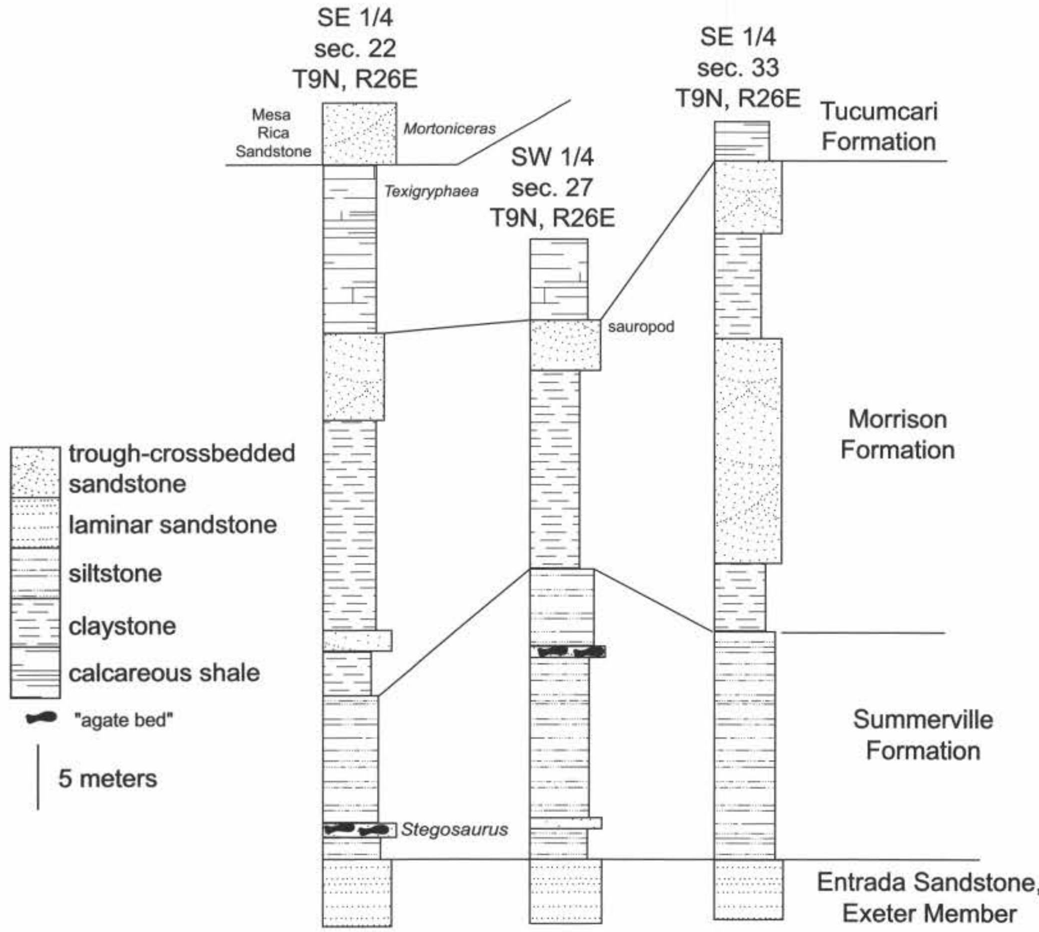

FIGURE 6. Sections of the Jurassic-Lower Cretaceous along the western edge of Luciano Mesa.

tion fine upward, although the uppermost unit is so poorly sorted that discrimintaing fluvial from eolian sands is difficult.

At the base of Qfg, recent gullying has exposed scour marks in the Morrison sandstone. These large scours (1 m deep) suggest a high-energy fluvial depositional environment for Qfg gravels. The orientation of scour marks as well as clast imbrication indicate a southerly flow for this early to middle Pleistocene river system.

Unit Qfp is primarily sandy fluvial and eolian deposits associated with graded surfaces formed during previous periods of Bull Canyon dissection and partial backfilling, with intermediate episodes of landscape stabilization and soil development. Many layers contain buried soils composed of fine-grained sediments, and, typically large amounts of pedogenic carbonate. Most of the buried soils are well developed and have stage II to stage III carbonate morphology (terminology of Gile et al., 1966). Unit Qfp contains fine- to coarse-grained river and floodplain sediments plus silty eolian material. Sediments contained in Qfp are interpreted to have been derived from local bedrock sources, including Chinle through Morrison strata in addition to some reworked Qe, Qrg and Ogallala sediments. Thickness of Qfp is variable and ranges from 2 to12 m.

Due to the discontinuous nature of these deposits, it is difficult to tell exactly how far local base level has dropped since the Pleistocene, although in central Bull Canyon 20 m of relief between Pleistocene and modern base levels are common. In central Bull Canyon, regional slope of the upper section of Qfp suggests a reversal in stream flow direction, from south flowing to north flowing.

Younger Alluvium (Qfs, Qfv, Qfm)

Younger valley-fill deposits are interpreted to be associated with episodes of valley incision and partial backfilling during late Pleistocene and Holocene time. Ancestral floodplain positions appear to have been 5 to 10 m above the modern channels. Soils are weakly developed. Younger valley-fill deposits represent aggradational events with few periods of base-level stability and/or soil formation.

Valley-slope alluvium (Qfs) is associated with alluvial aprons and graded surfaces formed during previous periods of aggradation of Alamogordo Valley. Sediments are generally coarse-grained sand and gravelly sand to silty clay.

On the western edge of Alamogordo Valley, Qfs is typically fine-grained sediments of arroyos and alluvial fans having a regional slope to the east, into central Alamogordo Valley. Sediments are locally derived from bedrock sources including Chinle through Morrison strata as well as reworked Ogallala Formation. Generally, Qfs sediments packages become finer upward locally,

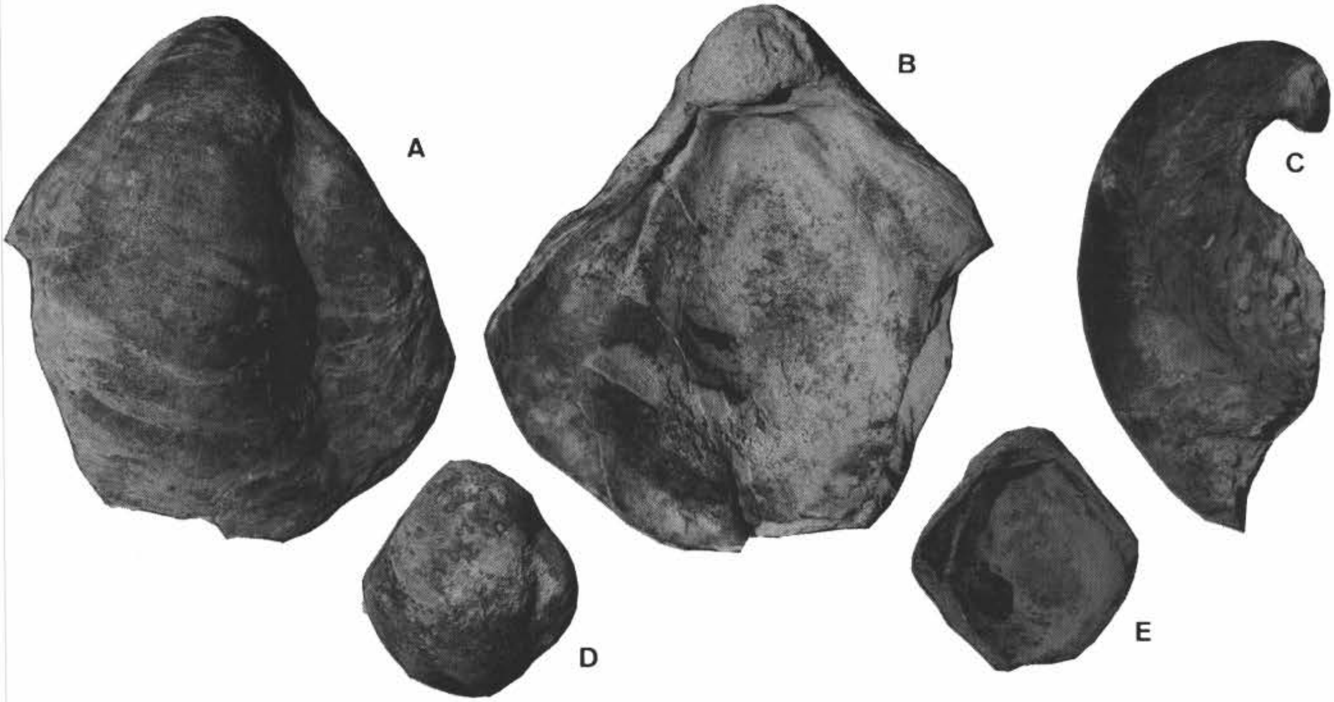

FIGURE 7. *Texigryphaea pitcheri* (Morton) from the Tucumcari Formation at Luciano Mesa, NE1/4 SW1/4 sec. 23, T9N, R26E. All figures x 1. A-C, external, internal and side views of large left valve, UNM 13137. D-E, external and internal views of small left valve, UNM 13138.

and they can contain laterally continuous buried soils with abundant disseminated calcium carbonate indicative of weak soil development. Ancestral local base level positions on the western slopes of Alamogordo Valley are approximately 5 to 10 m above the present floodplain. Thickness of these deposits at this location ranges from 3 to 10 m.

In contrast to Qfs on the western border of Alamogordo Valley, sediments preserved in the northeastern section are very coarse-grained sand and gravel. The sandy sediment was derived from local bedrock sources, including Chinle through Morrison strata; coarser gravels are primarily reworked Ogallala pebbles and cobbles. Thickness of the gravel deposits is approximately 3-4 m. As with Qfs on the western margin of the Alamogordo Valley, the base level position of Qfs in the east-central section of the Ima NW quadrangle is 15 m above the modern active channel and floodplain. Remnants of Qfs in the east-central part of Alamogordo Valley presently defend slopes and hilltops of less resistant material. These gravel-topped hills form an arcuate outcrop pattern near the eastern border of Alamogordo Valley.

Unit Qfv is confined to the floor of Alamogordo Valley and contains eolian and fluvial-arroyo sediments having surfaces graded to a Holocene, but not modern base level. Most of Qfv contains fine-grained sands and silts with discontinuous lenses of small gravel, and minor amounts of calcium carbonate. Material composing Qfv was derived from Chinle and reworked older Pleistocene sediments. Generally, Qfv sediment packages fine upward, although the poorly sorted alluvial fan and arroyo-distributary deposits may have an eolian component. In most sections of Alamogordo Valley, Qfv intertongues with Qfm, and overlaps basal sections of Qfs, making precise determination of contacts uncertain. Soils are typically immature and have only minor accumulations of calcium carbonate.

Modern floodplain alluvium, associated with surfaces graded to the present local base level, constitute Qfm. These sediments include fine-grained fluvial and floodplain deposits and coarse-grained alluvial fan/distributary channel sediments containing minor amounts of calcium carbonate. In both Alamogordo Valley and Bull Canyon, the composition of Qfm is largely reworked Triassic through Quaternary sediments. Generally, these sediments fine upwards from small gravels to medium sands. The thickness of unit Qfm is typically 0.5- 3 m.

In Alamogordo Valley, Qfm takes the form of partially channelized fans and distributary arroyos that are not integrated with the trunk stream of Alamogordo Creek. Instead, these distributaries terminate as large lobes of coarse-grained material and higher, abandoned floodplain surfaces. On the southwestern edge of Alamogordo Valley, the distance from the Llano Estacado escarpment to the axial drainage is short, and ephemeral streams connect to Alamogordo Creek. Throughout most of Alamogordo Valley, Qfm intertongues and overlaps with Qfv and locally overlaps and dissects lower sections of Qfs.

Unit Qfm in Bull Canyon is limited to small ephemeral streams (e.g., Bull Canyon Creek) and to arroyos originating on weathering limited bedrock slopes along valley margins. Compared to Alamogordo Valley, Bull Canyon has much less surface area covered by active channelized drainage. This is probably due to several factors, including greater canyon relief, well-developed Holocene channel patterns, and a lower local base level. These deposits overlap and dissect older Quaternary alluvium as Bull Canyon stream entrenchment migrates upstream.

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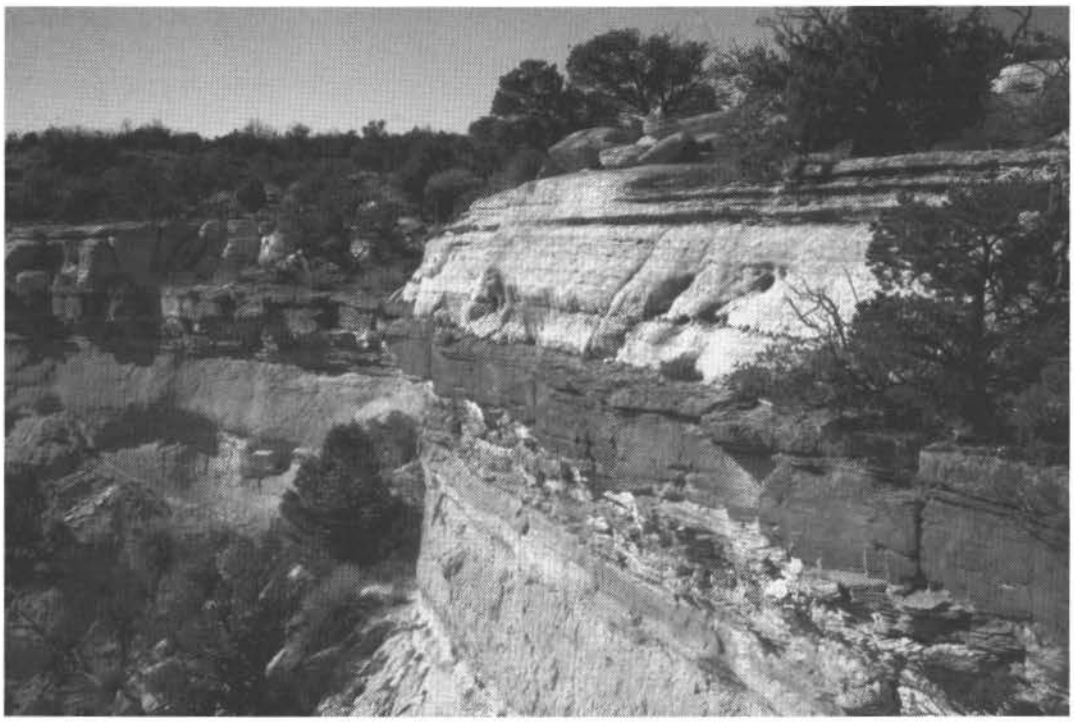

At Bull Canyon in eastern Guadalupe County, the Middle Jurassic Todilto Formation is a thin (up to 2 meters) bed of dark, kerogenic limestone between lower and upper eolian sandstone tongues of the Entrada Sandstone. Indeed, it is possible here to walk the Todilto to its pinchout into the eolianites, and thus examine the margin of the vast Todilto salina.