Geology of Anthony quadrangle, Doña Ana County, New Mexico

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Abstract

The northernmost extension of the Franklin Mountains, a tilted block of Paleozoic (Ordovician–Permian) carbonates and shales, is the dominant topographic feature of the Anthony 7½-min quadrangle in southeast Doña Ana County, New Mexico. Rocks of the northern Franklin Mountains have been subjected to early Tertiary (?) folding, possibly related to the Laramide orogeny, and late Tertiary to Quaternary faulting associated with the Rio Grande rift. The most unusual structures in the quadrangle are north-trending, low-angle, normal faults. Apparently, these low-angle fault planes originally were steep fractures that rotated to low-angle attitudes as the Franklin Mountains block tilted west. As rotation continued, movement along the low-angle faults became inefficient; consequently, high-angle, normal faults developed in the Hueco Bolson, east of the Franklin Mountains. The Camp Rice Formation (late Tertiary to early Quaternary) and middle to late Quaternary fan and eolian deposits cover large portions of the map area. Three distinct facies of the Camp Rice Formation are present in the Anthony quadrangle: 1) a fluvial facies composed of channel sand and floodplain clay, 2) an eolian facies consisting of loamy sand, and 3) a piedmont-slope facies composed of fan material from the adjacent mountains. These Quaternary deposits indicate that during the Pleistocene a substantial amount of water from the ancestral Rio Grande flowed east through Fillmore Pass into the Hueco Bolson. Less water flowing west of the mountains into the Mesilla Valley led to the development of a relatively stagnant, deltaic environment, southwest of Fillmore Pass. During the Pleistocene, the prevailing westerly wind blew across the broad floodplain in the Mesilla Valley and piled fluvial sand into eolian dunes against alluvial fans that were forming adjacent to the rising Franklin Mountains.

INTRODUCTION

1 The Anthony 7½-min quadrangle is in southeast Doña Ana County, New Mexico, just north of the New Mexico–Texas state line (fig. 1). A tilted block of folded and faulted Paleozoic carbonates and shales forms a low mountain ridge in the central portion of the map area. This block, which is the northernmost extension of the Franklin Mountains, is part of the continuous, north-trending San Andres–Organ–Franklin fault block of south-central New Mexico and west Texas. The mountains are flanked on the east by the Hueco Bolson and on the west by the Mesilla Valley. Although large portions of the valley are covered by recent eolian and alluvial-colluvial sediments, entrenchment of the Mesilla Valley by the Rio Grande and Quaternary movement along the Artillery Range fault in the Hueco Bolson have provided good exposures of Pleistocene to Holocene deposits in the area.

2 Previous workers in this quadrangle were concerned with either bedrock geology or ground water and geomorphic studies. A geologic map of the southern third of the Anthony quadrangle was published by Harbour (1972) as part of his map of the northern Franklin Mountains in Texas and New Mexico. Several minor modifications of his map are made in this report. The stratigraphy and microfacies of the Pennsylvanian formations exposed south and west of Anthony Gap have been described by Allouani (1976), El Foul (1976), and Hair (1976, 1977). Figuers (personal communication, 1979) is currently analyzing the structural geology of the "pipeline complex" southeast of Anthony Gap. Knowles and Kennedy (1958), Leggat and others (1962), and King and others (1971) discussed the lithology and groundwater conditions surrounding several wells located in or near the map area. In addition, Hawley (unpublished data, 1969) has done detailed work on the soils and geomorphic surfaces near Anthony Gap in the southern part of the area. In this report, we have combined the results of previous efforts with our own observations in describing the geology of the Anthony 7½-min quadrangle.

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DESCRIPTION OF ROCK UNITS

3 A composite section of the Paleozoic rocks exposed in the Anthony quadrangle is presented on the back of this sheet. Harbour's (1972) measured sections of the Ordovician, Silurian, and upper Mississippian rocks at North Anthony's Nose have been incorporated into this section. Hair's (1977) section of the Panther Seep and Harbour's (1972) section of the Hueco, measured at the southern boundary of the map area, have also been included in the composite section. The remainder of the section is the result of work done during this study.

4 PALEOZOIC ROCKS—The *El Paso Limestone* (Lower Ordovician) is the oldest rock unit exposed in the northern Franklin Mountains. This formation, originally named by Richardson (1904) from exposures in the Franklin and Hueco Mountains, has been divided into three unnamed members by Harbour (1972). Only a portion of Harbour's upper dolomite and sandy limestone member is found in the Anthony quadrangle in a poorly-exposed outcrop just east of North Anthony's Nose. The outcrop consists of approximately 30 m (98 ft) of gray, cherty dolomite that weathers to light tan. The most common fossils in the El Paso Limestone (Lower Ordovician) are snails, brachiopods, trilobites, and conodonts (Harbour, 1972). Because the El Paso thins northward due to post-depositional, pre-Montoya erosion (Harbour, 1972), the outcrop exposed in the Anthony quadrangle is far below the depositional top of the El Paso section. The El Paso is approximately 369 m (1,210 ft) thick farther south in the Franklin Mountains (Harbour, 1972).

5 The El Paso Limestone unconformably underlies the *Montoya Dolomite,* which was differentiated from the El Paso by Richardson (1908). Although many workers in southern New Mexico (Kelley and Silver, 1952; Pray, 1958; Kottlowski, 1975) divide the Montoya into the Upham, Aleman, and Cutter Formations, Harbour (1972) considers the Upham, Aleman, and Cutter to be members within the Montoya Dolomite. For mapping purposes, we have chosen to follow Harbour's definition of the Montoya Dolomite. A fourth member of the Montoya, the *Cable Canyon Sandstone Member,* is absent in the Franklin Mountains, but is present at the base of the formation in the mountains farther north.

6 The Montoya weathers to a gray to light-gray, ledgy slope along the east front of the northern Franklin Mountains. The lowermost unit of the Montoya, the *Upham Dolomite Member,* is a medium-grained, gray dolomite that weathers gray to dark gray. Above the Upham is the *Aleman Dolomite Member,* a fine-grained, dark-gray dolomite with conspicuous, abundant lenses and nodules of medium- to light-gray chert. Overlying the Aleman is the *Cutter Dolomite Member,* a fine-grained, dark-gray dolomite that weathers to light gray. The Upham Member (Middle Ordovician) and the Aleman and Cutter Members (Upper Ordovician) (Kottlowski and others, 1956; Howe, 1959) contain a few brachiopods, corals, and gastropods and abundant, dolomitized fossil debris. Thickness of the Montoya ranges from 116 m (380 ft), at a point 4.8 km (3.0 mi) south of the New Mexico–Texas state line (Harbour, 1972), to 130 m (426 ft) at Bishop Cap (Kramer, 1970). The Upham, Aleman, and Cutter Members of the Montoya are 27 m (89 ft), 44 m (144 ft), and 52 m (170 ft) thick, respectively (Harbour, 1972); total thickness of the Montoya Dolomite in this area is 123 m (403 ft).

7 The *Fusselman Dolomite* (Silurian), which was defined by Richardson (1908), disconformably overlies the Montoya Dolomite. Rugged, complexly jointed, light-gray cliffs formed by the Fusselman crop out along the entire east side of the northern Franklin Mountains, except at the extreme northern end. The Fusselman is a pure, thick-bedded, light-gray dolomite with minor amounts of chert and limestone. Richardson (1909) and Pray (1958) both assigned a Middle Silurian age to the Fusselman on the basis of brachiopods, corals, and gastropods found within the formation. Erosion prior to the Middle Devonian caused the formation to thin from 185 m (607 ft) in the southern part of the area to 150 m (492 ft) at the north end of the Franklin Mountains (Harbour, 1972). Silicified zones containing barite, fluorite, and limonite mineralization are common in the Fusselman near its unconformable upper contact with the Canutillo Formation. Mineralizing fluids probably migrated upward through extensive fractures in the Fusselman and spread laterally along the unconformity upon encountering the impermeable Canutillo Formation and Percha Shale.

8 The *Canutillo Formation* overlies the Fusselman with slight angular discordance caused by minor erosion following tilting of the Fusselman and older rocks. Nelson (1940) included all Devonian rocks in the Franklin Mountains in the Canutillo Formation; however, Laudon and Bowsher (1949) later realized that the upper part of Nelson's Canutillo Formation is actually correlative with the Percha Shale farther north. As a result, the name "Canutillo Formation" is applied to only the lower portion of Nelson's Canutillo Formation.

9 The Canutillo crops out in talus-covered slopes along the eastern escarpment of the range, except at the north end of the Franklin Mountains. The lower two-thirds of the formation is primarily lenses of chert and marl; the upper third consists of interbedded, dark-gray shale and siltstone. Because the Canutillo is composed of incompetent strata, small, local, disharmonic folds are common within the formation. The only significant fossils found in the Canutillo Formation (late Middle Devonian) are brachiopods and conodonts (Harbour, 1972). This formation thins northward from at least 30 m (97 ft) at North Anthony's Nose (Harbour, 1972) to approximately 15 m (49 ft) near Webb Gap.

10 Conformably overlying the Canutillo Formation is the *Percha Shale,* a fissile, black shale, distinguished mainly by its stratigraphic position between thick limestone or dolomite units. This shale was correlated by Laudon and Bowsher (1949) with the Percha Shale of southwest New Mexico. Like the Canutillo, the Percha forms a talus-covered slope on the east face of the northern Franklin Mountains. The Percha pinches out just north of North Anthony's Nose and appears to be absent between North Anthony's Nose and Anthony Gap. A relatively thin (12–15 m; 39–49 ft) Percha section crops out in the mountains south of Anthony Gap. The exact age and correlation of the Percha in this area are uncertain, because no fossils have been found in this shale. The average thickness of the Percha in the Franklin Mountains north of North Anthony's Nose is approximately 18–21 m (60–70 ft).

11 The *Las Cruces Limestone* (Mississippian), named by Laudon and Bowsher (1949) for exposures in Vinton Canyon, 3.5 km (2.1 mi) south of the New Mexico–Texas state line, unconformably overlies Devonian rocks. The Las Cruces forms distinctive, light-gray, evenly bedded (0.3–0.6-m-thick beds), ledgy cliffs along the east side of the Franklin Mountains. In general, the Las Cruces is a dense, brittle, primarily chert-free micrite. Small chert lenses and thin (0.5–1.0 cm), bioturbated, sandy layers are interbedded with limestone in the upper 4 m (13 ft) of the section, north of Webb Gap. Small chert lenses are more common throughout the Las Cruces section, south of Webb Gap. Although the Las Cruces contains very few fossils, Laudon and Bowsher (1949) considered the formation to be of Meramecian age on the basis of a few ostracod valves and lithologic resemblance to the overlying Rancheria Formation. Conodonts found in the Las Cruces at Vinton Canyon indicate that the formation is of late Osage to early Meramecian age (Lane, 1974). The Las Cruces is approximately 27 m (90 ft) thick throughout the area.

12 The *Rancheria Formation,* also named by Laudon and Bowsher (1949), apparently lies conformably on the Las Cruces. The Rancheria crops out in orange-brown to light-gray slopes with few cliffs or ledges along the east face of the range. This formation is divided into three unnamed members: a lower member composed of cherty, black micrite with some siltstone and shale; a middle member characterized by chert-free black micrite that weathers to a light-gray band; and an upper member composed of cherty, sandy, black micrite. The lower member includes a 3-m (10-ft) thick basal bed of crossbedded, crinoidal limestone. The Rancheria, which was assigned a Meramecian age by Laudon and Bowsher (1949), contains abundant crinoid debris, bryozoa, brachiopods, and gastropods. The crinoidal bed near the base of the Rancheria at Vinton Canyon yields a few conodonts that also indicate a Meramecian age (Lane, 1974). The lower, middle, and upper members of the Rancheria are 45, 11, and 61 m (150, 35, and 200 ft) thick, respectively.

13 The upper member of the Rancheria grades into the overlying *Helms Formation.* The Helms, named by Beede (1920) and more clearly defined by Laudon and Bowsher (1949), forms greenish-gray slopes below the Pennsylvanian limestone cliffs along most of the east flank of the Franklin Mountains. This formation is composed of calcareous, gray shale, fossiliferous, olive-green micrite, and some oolitic, olive-green micrite. A 6-m-thick red quartzite lens containing a *Lepidodendron* impression (Harbour, 1972) crops out at the top of the Helms, south of North Anthony's Nose. Fossils found in the Helms Formation (Chesterian) include brachiopods, gastropods, ostracods, crinoids, and bryozoa. The Helms is approximately 30 m (100 ft) thick in the Anthony quadrangle.

14 The *Magdalena Group* (Pennsylvanian) conformably overlies the Helms. Originally, Richardson (1904, 1908, 1909) described the Magdalena Group as part of the Hueco Formation, which at that time included all rocks between the Silurian and Cretaceous. Nelson (1940) restricted the term "Magdalena Group" to Pennsylvanian rocks in the Franklin Mountains. Harbour (1972) called the Magdalena a formation and divided the formation into four members: the La Tuna, Berino, Bishop Cap, and unnamed transitional members. Because many workers in New Mexico and Texas (Kelley and Silver, 1952; LeMone, 1976) consider the Magdalena to be a group, we have assigned formation status to Har-

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bour's four members. In order of decreasing age, the formations within the Magdalena Group are: the La Tuna, Berino, Bishop Cap, and Panther Seep Formations. Harbour's unnamed transitional members seem to be correlative with the Panther Seep Formation defined by Kottlowski and others (1956) in the San Andres Mountains. The Magdalena Group forms the crest and western dip slope of the northern Franklin Mountains.

15 The *La Tuna Formation,* which forms imposing, gray-weathering, (100–130 ft) high cliffs on the east side of the range, is a cherty, gray, crystalline limestone that is massively bedded at its base. Because the number of shale interbeds in the La Tuna increases upward in the stratigraphic sequence, the top of the formation is more thinly bedded. The La Tuna is equivalent to Morrowan rocks in the Midcontinent (Harbour, 1972; Lane, 1974) and contains abundant silicified corals, brachiopods, crinoids, mollusks, bryozoans, and some petrified wood. The La Tuna, which thins to the south, is approximately 107 m (350 ft) thick at the north end of the range and 85 m (280 ft) thick south of Anthony Gap. Because the La Tuna grades vertically into the Berino Formation, the contact between the two is somewhat arbitrary. We placed the contact at the base of the first major (3–5 m) shale break, which corresponds to the basal Berino contact defined by Allouani (1976) in Vinton Canyon.

16 The *Berino Formation,* which forms the yellowish-brown and gray, ledgy outcrops on the western dip slope of the Franklin Mountains, is composed of beds of gray limestone (0.5–6 m; 1.6–19 ft thick) alternating with layers of carbonaceous, brown shale (0.5–8 m; 1.6–26 ft thick). Both lithologies are present in approximately equal proportions. This formation is partially equivalent to both the Atoka and Desmoines Series of the Midcontinent (Harbour, 1972; Allouani, 1976). Dominant fossils in the Berino include mollusks, brachiopods, corals, bryozoa, and fusulinids. Thickness of the Berino in the map area is approximately 160 m (530 ft); however, the contact between the Berino and the overlying Bishop Cap Formation is arbitrary, so this thickness may be in error by ± 5 m (± 16 ft) compared to other sections of the Berino measured in the Franklin Mountains. Allouani (1976) measured 154 m (505 ft) of Berino Formation at Vinton Canyon. We could not positively identify the massive limestone unit used by Allouani to define the top of the Berino at Vinton Canyon in our measured sections north of Anthony Gap, so we chose a distinctive, algal limestone bed as the approximate contact between the Berino and the Bishop Cap. Beds found within 3 m (10 ft) above and below this marker were sufficiently different to suggest an important change in depositional environment. Specifically, strata above the algal bed contain thicker shale units, pseudomorphs of hematite after pyrite, and a fauna characterized by abundant algae, gastropods, and pelecypods.

17 The *Bishop Cap Formation* is exposed in a few small, talus-covered ridges along the west edge of the mountain front. This formation consists primarily of shale that weathers to a puffy, yellow clay and contains a few medium-bedded, fossiliferous, dark-gray micrite layers. Algae, gastropods, pelecypods, corals, brachiopods, and fusulinids within the formation indicate that the Bishop Cap is of middle Desmoinesian age (Harbour, 1972). A complete section of the Bishop Cap is not exposed in the quadrangle, but Harbour (1972), using the base of a shale unit as the basal contact of the Bishop Cap, measured 194 m (636 ft) of the formation at Vinton Canyon. El Foul (1976) measured 180 m (590 ft) of Bishop Cap at the same locality in Vinton Canyon. El Foul used the base of the massive limestone discussed by Allouani (1976) as the basal contact of the Bishop Cap.

18 Conformably overlying the Bishop Cap is the *Panther Seep Formation,* named by Kottlowski and others (1956) in the San Andres Mountains. Nelson (1940) and Harbour (1972) assigned the uppermost Pennsylvanian rocks in the quadrangle to an upper, unnamed transitional member of the Magdalena Formation; however, based on lithology and relative position in the section, these rocks appear to be correlative with the Panther Seep Formation in the Organ and San Andres Mountains (LeMone, 1976; Hair, 1976, 1977). The Panther Seep, which generally forms gentle, talus-covered slopes, is well exposed at quarries in a plunging syncline in the southern portion of the map area. This formation is composed of silty, argillaceous limestones, 2–12-m (6.5–39-ft) thick gypsum beds, and silty shale but lacks sufficient fossils to be dated accurately. Fossils in the San Andres Mountains suggest a Virgilian age for most of the formation, although the chert-pebble conglomerate exposed at the base of the Panther Seep in Vinton Canyon may be Missourian (Harbour, 1972), and the uppermost beds may be Wolfcampian (Hair, 1977). Harbour (1972) arbitrarily placed the upper contact of the Panther Seep halfway between the last occurrence of Pennsylvanian fauna and the first appearance of Permian fauna in the section. Hair (1977) redefined the upper contact on the basis of a facies change from basinal sedimentation to shelf sedimentation in this area. We chose to use the contact defined by Hair (1977), because it is easier to recognize in the field.

19 The *Hueco Limestone* conformably overlies the Panther Seep Formation in the Franklin Mountains. As defined by recent workers, the Hueco contains only the Permian rocks in Richardson's (1904, 1908, 1909) Hueco Formation. The Hueco is divided into three units (Harbour, 1972), but only the lower member and part of the middle member of the formation are present in the map area. This formation is characterized by limestone cliffs and ledges separated by talus-covered slopes of siltstone and shale and crops out in low, U-shaped hills formed by a plunging syncline west of the main range along the southern edge of the quadrangle. The Hueco consists of fossiliferous, cherty, gray limestone and marly, yellowish-gray siltstone. Although the lithology is not markedly different above or below the siltstone outcrops, the siltstone beds serve as markers between the three members because these beds are laterally continuous. Abundant brachiopods, crinoids, gastropods, corals, and fusulinids in the formation indicate that the lower and middle members of the Hueco are of Wolfcampian age. The lower unit is 200 m (656 ft) thick, and approximately 213 m (699 ft) of the middle member (Harbour, 1972) is exposed in the Anthony quadrangle.

20 QUATERNARY DEPOSITS—Overlying the Paleozoic rocks with pronounced angular unconformity is the *Camp Rice Formation* (late Tertiary (?) to early Quaternary). Although the Camp Rice was originally described by Strain (1966) in west Texas, Seager and others (1971) were the first to apply Camp Rice terminology to the older Quaternary and latest Tertiary river and piedmont-slope deposits adjacent to the Rio Grande valley in south-central New Mexico. The Camp Rice Formation is primarily a Quaternary unit, but fossil evidence and radiometric dating of interbedded basalt indicate that the basal conglomerate of the formation, at some locations in the Rio Grande valley, is of Pliocene age (John Hawley, personal communication, 1979).

21 Three distinctive facies of the Camp Rice Formation are present in the Anthony quadrangle: 1) a *fluvial facies* composed of channel sand and floodplain clay that intertongues with or is overlain by, 2) an *eolian facies* consisting of loamy sand that in turn intertongues with, 3) a *piedmont-slope facies* composed of alluvial-fan gravel and sand derived from the Franklin Mountains (fig. 2).

22 The fluvial facies crops out in arroyo cuts approximately 0.8 km (0.5 mi) west of the current western mountain front, and outcrops extend to the modern floodplain of the Rio Grande. This fluvial facies is also exposed in the Hueco Bolson along the Artillery Range fault scarp and is characterized by well-rounded gravel and gray to buff sand, interbedded with red, floodplain clay. The gravel includes abundant chert, quartz, granite, and basalt pebbles from distant upstream sources as well as rounded silicic volcanics from nearby ranges like the Organ Mountains. The fine- to coarse-grained, locally crossbedded sand is found in either well-defined channels or discontinuous sheets. Stacked paleosols with reddish-brown, slightly leached, root-mottled clay horizons that grade into lighter-colored, carbonate-enriched zones are common in the floodplain clay. The only fossils found so far in the fluvial facies in this area are silicified roots in the paleosols. On the west side of the Mesilla Valley, fossil remains of mastodons, horses (*Mammuthus, Equus*), and other vertebrates of Irvingtonian age (Hawley and others, 1969) are present in the fluvial facies. Although we were not able to determine the exact thickness of the fluvial unit because the base is not exposed in the Anthony quadrangle, lithologic logs from wells in or near the map area provided some idea of the thickness of the unit (table 1). The fluvial facies is approximately 235–271 m (770–890 ft) thick in Fillmore Pass, more than 218 m (715 ft) thick in the Mesilla Valley near Berino, and more than 331 m (1,085 ft) thick in the Hueco Bolson, just east of the Anthony quadrangle.

23 In the northernmost part of the map area and in the Hueco Bolson, very little floodplain clay is found in the fluvial facies. Approximately 1.6 km (1.0 mi) west of the northwest tip of the Franklin Mountains, floodplain clay forms more than 50% of the exposed fluvial section. At approximately the same latitude on the west side of the Mesilla Valley, between the villages of Chamberino and La Mesa, a similar type of transition in the fluvial facies is observed (S.A. Kelley, unpublished mapping for the southeast Las Cruces 1° x 2° sheet, 1979). Apparently, when the river flowed through Fillmore Gap (Hawley, 1975), a large amount of water flowed into the Hueco Bolson, while less water was transported into the southern Mesilla Bolson. Less water and the proximity of Lake Cabeza de Vaca (Strain, 1966; Hawley, 1975) led to the formation of a relatively stagnant, deltaic environment south and southwest of Fillmore Pass. The deltaic environment was characterized by the development of a meandering-river system (channel sand and gravel and sand sheets) on a broad alluvial flat or floodplain (red clays with paleosols).

24 The eolian facies crops out in a 90–915-m (300–3,000 ft) wide strip, 0.5–0.8 km west of the western edge of the mountain front. A few thin (0.1–1 m thick) layers of piedmont toeslope facies composed of reddish-brown, clayey to silty deposits that represent distal-fan and/or adjacent basin-floor sediments are lumped with the eolian facies for mapping purposes. The eolian facies includes reddish-brown, fine- to medium-grained sand and silt, and a minor amount of polished chert and quartz gravel. Both the eolian facies and the minor, piedmont toeslope facies complexly intertongue with the fluvial and piedmont-slope facies. The only fossils in this facies are silicified roots (root casts) in the paleosols developed on the sand. The eolian facies ranges from 0.3 m (1 ft) thick (sand stringers in the floodplain deposits) to approximately 30 m (100 ft) thick (ancient dunes near Anthony Gap).

25 The Camp Rice eolian dunes formed during the Pleistocene in much the same way that coppice dunes east of the Rio Grande floodplain are forming today. The prevailing westerly wind, after picking up sand from river sediments in the valley, deposited sand against alluvial fans forming next to the Franklin Mountains during the Pleistocene. Eolian sand was concentrated west of Webb Gap and Anthony Gap, where changes in wind direction and velocity caused deposition. Absence of the eolian facies west of a large, plunging syncline on the southern edge of the quadrangle suggests that the ancestral Rio Grande once flowed close to this structure and eroded away the windblown sand.

26 The piedmont-slope facies of the Camp Rice Formation, present on both the east and west flanks of the Franklin Mountains, is divided into two units; 1) a basal, well-lithified, calcium-carbonate-cemented, boulder-to-pebble fanglomerate (*Qcrc*) overlain by 2) a younger, less- consolidated, sandy and gravelly, alluvial-fan deposit (*Qcrp*). Gravel in the piedmont-slope facies includes mostly chert, limestone, and dolomite pebbles and boulders derived from the Franklin Mountains. A well-developed petrocalcic horizon averaging 0.3–0.9 m (1–3 ft) thick is generally present just below the constructional surface (Jornada I surface) of the *Qcrp* fan deposits. Because the contact between the upper and lower gravels is often difficult to locate, particularly in the Hueco Bolson, we mapped the piedmont-slope facies as a single unit (*Qcru*). The piedmont-slope facies is approximately 5–60 m (16–200 ft) thick.

27 In 1969, John Hawley discovered an ash bed 18 cm (7 inches) thick in the upper piedmont-slope (*Qcrp*) facies in the El Paso Natural Gas pipeline cut near Anthony Gap (SE¼ SW¼ NE¼ sec. 28, T. 26 S., R. 4 E.). The discontinuous bed of impure, white, rhyolitic ash occurs in a layer of light-brown sand containing root casts. Analysis of the ash indicates that its source probably was the Long Valley caldera near Bishop, California (Hawley, 1975), which implies an age of 0.7 m.y. for the upper piedmont-slope facies (*Qcrp*) in this area. The brown, sandy zone probably is a tongue of the eolian facies within the fan deposits (John Hawley, personal communication, 1979). K-Ar dates of 3–4 m.y. on basalts interbedded with the basal piedmont-slope facies (*Qcrc*) found elsewhere in the Rio Grande valley imply that, locally, the basal part of the Camp Rice Formation is of late Pliocene age.

28 Unconformably resting on the Camp Rice Formation are middle to late Quaternary valley-slope deposits associated with entrenchment of the Rio Grande on the west side of the mountains and continuing sedimentation in the Hueco Bolson on the east side. We have adopted the same terminology used by Seager and Hawley (1973) and Seager and others (1975) in other portions of the Rio Grande valley to describe units older than the Camp Rice in our area.

29 *Valley-slope deposits associated with river entrenchment*—Older, valley-slope deposits (*Qvo*) that form terraces along arroyos in the western part of the map area are silty to gravelly, locally derived fan deposits. These deposits are associated with geomorphic surfaces (Tortugas and Picacho, fig. 2) that are graded to late Pleistocene levels of the Rio Grande floodplain. The *Qvo* deposits and surfaces are inset below the Camp Rice fan deposits (Jornada I surface) but typically are graded to surfaces 15–30 m (49–98 ft) above the present floodplain. A well-developed, petrocalcic soil up to 1 m (3 ft) thick is developed on the surfaces, especially in the southern part of the map area. The *Qvo* fan deposits are as much as 15 m (49 ft) thick in some places; however, *Qvo* deposits generally are approximately 6 m (20 ft) thick.

30 The *older, valley-fill fluvial facies* (*Qvof*) that intertongues with the *Qvo* fan deposits is found in a low ridge near the modern floodplain. Other outcrops of this facies are present adjacent to the floodplain, but these outcrops were not included on the map because they are poorly exposed. The sandy to gravelly river deposit contains well-rounded, locally derived pebbles as well as rounded quartz, chert, granite, and basalt pebbles from upstream sources. The deposit is 6–9 m (20–30 ft) thick, and its constructional surface apparently is correlative with the Picacho geomorphic surface (fig. 2).

31 Holocene and latest Pleistocene (< 15,000 yrs) *arroyo-fan alluvium* (*Qvy*) is present in modern arroyo bottoms on the west side of the map area. Silty to gravelly, unconsolidated arroyo-channel fill and broad arroyo fans next to the modern Rio Grande floodplain are graded to either the floodplain or Fillmore geomorphic surface (fig. 2), which is 1.5–4.6 m (5–15 ft) above the floodplain. The arroyo alluvium in the northern part of the Anthony quadrangle contains abundant magnetite that was probably reworked from the Camp Rice fluvial facies. The young arroyo-fan alluvium is approximately 1.5–6 m (5–20 ft) thick.

32 The *younger* (Holocene and latest Pleistocene) *valley-fill fluvial facies* (*Qvyf*) that forms the modern floodplain of the Rio Grande is composed of sandy, gravelly, and loamy floodplain and channel deposits less than 15,000 yrs old that interfinger with the younger arroyo-fan alluvium. The unit is approximately 9–21 m (30–70 ft) thick.

33 Holocene, *windblown sand* (*Qs*) forms coppice dunes and relatively thin (0.9–4.5 m; 3–15 ft) veneers of unconsolidated sand on the Camp Rice fluvial facies, older valley-slope deposits, and younger valley-slope deposits (*Qcrf, Qvo,* and *Qvy*) adjacent to the modern floodplain. Recent eolian sand, also found in small, coppice dunes next to blowouts in the Hueco Bolson, is derived from reworking of Camp Rice fluvial deposits and/or erosion of modern floodplain sediments.

34 *Basin-fill deposits not affected by activity of the Rio Grande*—Most of the floor of the Hueco Bolson is covered by late Pleistocene *piedmont-slope deposits* (*Qpo*) and *younger* (Holocene) *piedmont-slope, arroyo alluvium* (*Qpy*). We had difficulty distinguishing between *Qpo* fans and *Qpy* fans in this area, so we lumped the two units together to form an undifferentiated upper Pleistocene to Holocene *piedmont-slope, arroyo-alluvium unit* (*Qpa*). The *Qpa* deposits are composed of reddish-brown silt and angular, locally derived gravel. Younger alluvium (*Qpy*) in the Hueco Bolson is found primarily in shallow arroyos and fans at modern arroyo mouths. Shallow drainageways occupied by younger piedmont-slope, arroyo alluvium are usually inset below the constructional surface (Jornada I surface) of the Camp Rice fans. Most of the thin (0.6–3 m; 2–10 ft), unconsolidated, loamy alluvium on Camp Rice fan surfaces east of the mountains probably is older piedmont-slope alluvium (*Qpo*).

35 The La Mesa geomorphic surface is the basinal extension of the Jornada I piedmont-slope constructional surface (fig. 2). This surface is well developed on the Camp Rice fluvial facies in Fillmore Pass, along the north edge of the quadrangle, and in the Hueco Bolson, just south of the Fort Bliss Military Reservation boundary. Large portions of the La Mesa surface in both Fillmore Pass and Hueco Bolson are covered by late Pleistocene and Holocene, brownish-red, silty *basin-floor and toeslope sediments* (*Qbf*). Basin-floor silt and clay also cover the floor of a large depression east of the Artillery Range fault in Hueco Bolson. Undissected basin-floor and toeslope deposits are lithologically similar to the minor toeslope facies of the Camp Rice Formation because both *Qbf* sediments and Camp Rice toeslope sediments were deposited in the transition zone between central-basin floors and piedmont slopes. The *Qbf* deposits locally include well-developed soil profiles, which indicates that much of the basin-floor and toeslope sediments probably are correlative with older piedmont-slope alluvium (*Qpo*). Basin-floor sediment are approximately 1–3 m (3–10 ft) thick.

Holocene ephemeral-lake sediments, brown silt, and clay deposits on floors of modern playa lakes in Hueco Bolson lie unconformably on basin-floor sediments in the northwest portion of the map area. Ephemeral-lake sediments are approximately 1–3 m (3–10 ft) thick.

STRUCTURE OF NORTHERN FRANKLIN MOUNTAINS

36 Early Tertiary (?) folds, possibly formed during the Laramide orogeny, and late Tertiary to Quaternary faults associated with the Rio Grande rift are the major tectonic features in the Anthony quadrangle. The only pre-Cenozoic structure in the area is a local, pre-Mississippian anticline (Harbour, 1972) or topographic high that lies roughly between Anthony Gap and North Anthony's Nose. The Percha Shale and the upper 1–5 m (3–16 ft) of the Canutillo Formation were eroded from the section across this topographic high. The Las Cruces Limestone (Mississippian) was deposited directly on irregular, eroded beds of the Canutillo Formation in this area.

37 Cenozoic structural features in the quadrangle are of four types: 1) plunging folds, 2) north-south-trending, low-angle, normal faults, 3) north-south-trending, high-angle faults, and 4) east-west-trending, high-angle, normal faults.

38 Major plunging folds in the area include the large, south-plunging syncline and anticline west of the main range along the southern boundary of the map area, the west-trending monocline north of Webb Gap, and the southwest-trending monocline southeast of North Anthony's Nose. Because the folds cannot be dated more precisely than post-Permian and pre-late Pliocene, the exact origin of these structures is uncertain.

39 The large, south-plunging syncline and anticline southwest of Anthony Gap may be related to the Laramide orogeny (early Tertiary) that affected much of southern New Mexico (Chapin and Seager, 1975). Alternatively, the folds could have formed as a result of resistance to rapid, westward tilting of the Franklin Mountains block (Lovejoy and Seager, 1978) during the late Tertiary. Lovejoy (1975) has suggested that these folds are part of a landslide block, but the coherence of the folds and the apparent continuity of the stratigraphic section between the main range of the Franklin Mountains and the large synclinal structure do not seem to support this theory. Two west-trending monoclines in the main part of the range may have formed by buckling related to movement on late Tertiary faults.

40 Several minor folds are present throughout the range; for example, in the saddle just southwest of the monocline near Webb Gap (S½ NE¼ sec. 5, T. 26 S., R. 4 E.), the dip of the beds flattens abruptly from 61° on the east side of a small, north-trending fold to 45° on the west side of the fold. This fold, like the large, plunging syncline and anticline in the southern part of the area, may be the result of resistance to westward tilting of the Franklin Mountains. Another small fold, a west-trending flexure that is probably related to late Tertiary faulting, occurs in the La Tuna Formation, just north of the small landslide block that is east of Webb Gap.

41 Three north-trending, low-angle, normal faults are perhaps the most interesting structural features in the quadrangle. The largest fault, which dips 30°–45° N.E., occurs in the southern portion of the quadrangle. The downthrown block is east of the fault. The fault has approximately 1,220 m (4,000 ft) of stratigraphic displacement in Hitt Canyon, which is 0.8 km (0.5 mi) south of the New Mexico–Texas state line (Harbour, 1972). Displacement across the fault decreases northward to only a few meters at a point 0.8 km north of North Anthony's Nose. A smaller, north-trending, low-angle, normal fault located at Webb Gap also has rotational motion about a fixed hinge or pole, with the eastern block on the downthrown side. This fault, which dips 38°–40° E., has approximately 90–120 m (300–400 ft) of stratigraphic displacement. The third small, north-trending fault is just below the radar antenna at the north end of the range. Although this fault has only approximately 3 m (10 ft) of offset, the fault is significant because it dips only 15° E.

42 These low-angle faults could be either low-angle, gravity-slide planes or high-angle fault planes that later rotated to low-angle attitudes. The landslide theory (Lovejoy, 1975) is credible if the northern Franklin Mountains were higher in the Tertiary than they are today (current maximum relief is only 300 m; 990 ft). High elevation, coupled with rapid tilting, may have led to sufficient instability on the east face of the mountains to cause landsliding toward the east (Lovejoy and Seager, 1978). Indeed, two small landslide blocks bounded by high-angle, east-dipping, normal faults occur on the east side of the range (NE¼ SW¼ sec. 9 and E½ sec. 27, T. 26 S., R. 4 E.). However, because of the relative coherence of huge blocks on the downthrown side of the large, low-angle faults, we believe that the fault planes originally were steep fractures that rotated to low-angle attitudes as the Franklin Mountains block tilted westward (Seager, 1981). Proffett (1977) and Morton and Black (1974) offer a similar explanation for the closely-spaced, low-angle faults in Nevada and the Afar region of Ethiopia. Fig. 3 (Seager, 1981) diagrammatically models the development of low-angle faults in the northern Franklin Mountains. According to this model, movement on steep, east-dipping, normal faults caused the early uplift and rotation of the Franklin Mountains (fig. 3a). As tilting progressed, the faults were rotated to some critical angle that made movement difficult and inefficient (fig. 3b). At this point, new, steep, normal faults, such as the Artillery Range fault, developed (fig. 3c) to allow continued uplift and westward tilting of the range (fig. 3d). Eventually, the Artillery Range fault may also be rotated to a low angle.

43 The two high-angle, normal faults that form the eastern boundary of the northern Franklin Mountains are the Artillery Range fault and the fault just east of North Anthony's Nose. Both faults were active during the Pleistocene. The Artillery Range fault, which can be traced from the Organ Mountains (Seager, 1981) to El Paso (Harbour, 1972), offsets the La Mesa surface by approximately 12 m (40 ft). This fault also offsets late Pleistocene piedmont-slope deposits (*Qpo*) that crop out approximately 0.8 km (0.5 mi) north of the northern map boundary. The north-trending, high-angle fault along the base of the mountains just east of North Anthony's Nose appears to be a major fault, perhaps one of the range-boundary faults. Using the base of the La Tuna Formation as a marker, maximum stratigraphic displacement of the fault is approximately 168 m (550 ft). Drag of basal Camp Rice conglomerate (upper Pliocene or lower Pleistocene) is associated with the North Anthony's Nose fault.

44 Two high-angle, normal faults on the western edge of the mountains are relatively minor features. A small, northwest-trending fault, 0.8 km north of the Webb Gap monocline, dips 75° E. The last motion on this fault, indicated by slickensides that rake 5° and trend northwest, was essentially along strike. Actual displacement along the fault is difficult to determine because Berino Formation is on both sides of the fault. Dip on the high-angle fault northwest of Anthony Gap is uncertain, because slickensides at one location suggest nearly vertical movement, while slickensides elsewhere along the fault indicate dip-slip movement along a plane that dips 60° W. This fault, characterized by a silicified zone up to 3 m (10 ft) wide, shows little displacement because lower Bishop Cap is present on both sides of the fault.

45 The east-trending, high-angle, normal faults north of Webb Gap and north of Anthony Gap probably formed by differential uplift along the strike of the northern Franklin Mountains during rapid westward rotation of the Franklin Mountains block. These high-angle, normal faults probably developed after the low-angle, normal faults, possibly after movement along the low-angle faults became ineffective (stage b or c in fig. 3). Evidence for this age relationship can be found at the northernmost end of the range where a low-angle fault near the radar antenna appears to be truncated by one of the high-angle, east-trending, normal faults.

MINERAL DEPOSITS

46 According to Dunham (1935), the small mine in the Bishop Cap member of the Magdalena Group on the low-angle fault at Webb Gap produced jarosite as well as goethite, limonite, aragonite, and gypsum. Dunham (1935) also discussed a lead-fluorite prospect tunnel, 1.6 km (1.0 mi) northeast of the mine at Webb Gap. This prospect is in a north-striking, silicified and brecciated zone that, in some places, cuts across the Fusselman Dolomite and, in other places, follows the Fusselman–Canutillo contact. Mineralizing fluids that formed the silicified zone traveled through fractures in the Fusselman Dolomite and spread laterally upon encountering relatively impermeable shale, marl, and chert of the Canutillo Formation. Both of the mines mentioned by Dunham (1935) are inactive now. Additionally, several shallow prospect pits were dug in silicified, brecciated zones 0.8 km south of Webb Gap near the Fusselman–Canutillo contact. A silicified breccia in the La Tuna member of the Magdalena Group, 0.8 km (0.5 mi) north of Anthony Gap (SE¼ NE¼ sec. 27, T. 26 S., R. 4 E.), contains limonite, and possibly jarosite.

47 Gypsum deposits with thin interbeds of chert, limestone, and dolomite crop out on the north side of a plunging syncline on the south edge of the map area. These deposits, which occur in the upper Panther Seep Formation and lower Hueco Limestone, were quarried for cement material by a company in El Paso (Dunham, 1935; Harbour, 1972). At the time of this report, the quarries were not in use. Another quarry, a currently inactive shale prospect in the Helms Formation, is south of Anthony Gap (SE¼ NE¼ sec. 34, T. 26 S., R. 4 E.).

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Location	Total depth (m)	Depth interval (m)	Lithologic unit	Data source
SE¼ SE¼ sec. 17, T. 25 S., R. 4 E.	298	0–235 235–296 296–298	*Qcrf* *Qcrc* Limestone	Knowles and Kennedy (1958) well K-13
SE¼ NE¼ sec. 18, T. 25 S., R. 4E.	275	0–88 88–128 128–271 271–275	*Qcrf* *Qcrc*(?) *Qcrf* Granite	Knowles and Kennedy (1958) well K-14
NW¼ NE¼ sec. 36, T. 25 S., R. 4 E.	331	0–331	*Qcrf*	Knowles and Kennedy (1958) well K-16
NW¼ SE¼ SW¼, sec. 2, T. 26 S., R. 3 E.	219	0–1.5 1.5–219	*Qvy* *Qcrf*	King and others (1971)
NW¼ SE¼ SW¼, sec. 2, T. 26 S., R. 3 E.	123	0–1.5 1.5–123	*Qvy* *Qcrf*	King and others (1971)
SW¼ NE¼ SW¼, sec. 25, T. 26 S., R. 3 E.	161	0–1.5 1.5–161	*Qvy* *Qcrf*	King and others (1971)
SE¼ SE¼ NW¼, sec. 26., T. 26 S., R. 4 E.	65	0–2 2–65	*Qvy* *Qcrf*	King and others (1971)
31°59.2′ N. latitude, 106° 35.1′ W. longitude	189	0–3 3–189	*Qvy* *Qcrf*	Leggat and others (1962)

TABLE 1—SIMPLIFIED LITHOLOGIC LOGS OF WELLS IN OR NEAR ANTHONY 7½-MIN QUADRANGLE, DOÑA ANA COUNTY, NEW MEXICO.