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Geology of Sierra Alta Quadrangle Doña Ana County, New Mexico

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Preface

This bulletin is part of a series of reports on the geology, mineral deposits, and geomorphology of the Rio Grande area between Hatch and Las Cruces, New Mexico. These geologic investigations provide a useful framework within which mineral resource exploration, soil and water resource investigations, and construction activities can be conducted.

The geology of the Sierra Alta quadrangle is also important to an understanding of the regional tectonic framework of this part of southern New Mexico. Oligocene volcanic rocks in the quadrangle were deposited in a major volcano-tectonic subsidence basin that was also the site of intrusive and surface volcanic activity and minor psilomelane mineralization. The floor and filling of the depression along with various structural features that formed during and following subsidence, are well displayed. An excellent record of the rocks, structures, and unconformities associated with late Tertiary rifting in south-central New Mexico is also preserved.

Studies of Santa Fe Group and younger units have been especially important because these units cover a large part of the quadrangle, and are sources of sand, gravel, and fill materials, as well constituting the principal ground-water reservoirs in the area. In addition, such studies provide much information on landscape evolution and soil development. A major purpose in subdividing late Cenozoic units into facies subdivisions was to provide a map detailed enough to be useful to the various individuals and government agencies involved in evaluating and developing land resources along the Rio Grande.

Mapping by Seager was conducted intermittently between 1967 and 1972, by Clemons in 1971-72, and by Hawley throughout 1972. Major financial support for the project was furnished by the New Mexico Bureau of Mines & Mineral Resources. We wish to thank W. H. Cothern of Las Cruces for allowing access to his ranch (headquarters at Hermantano Springs). Assistance by the Hayner Ranch staff and access to their land is also gratefully acknowledged. Many of the ideas expressed herein benefitted from discussions with F. E. Kottlowski, C. E. Chapin, L. H. Gile, W. E. King, and A. L. Metcalf.

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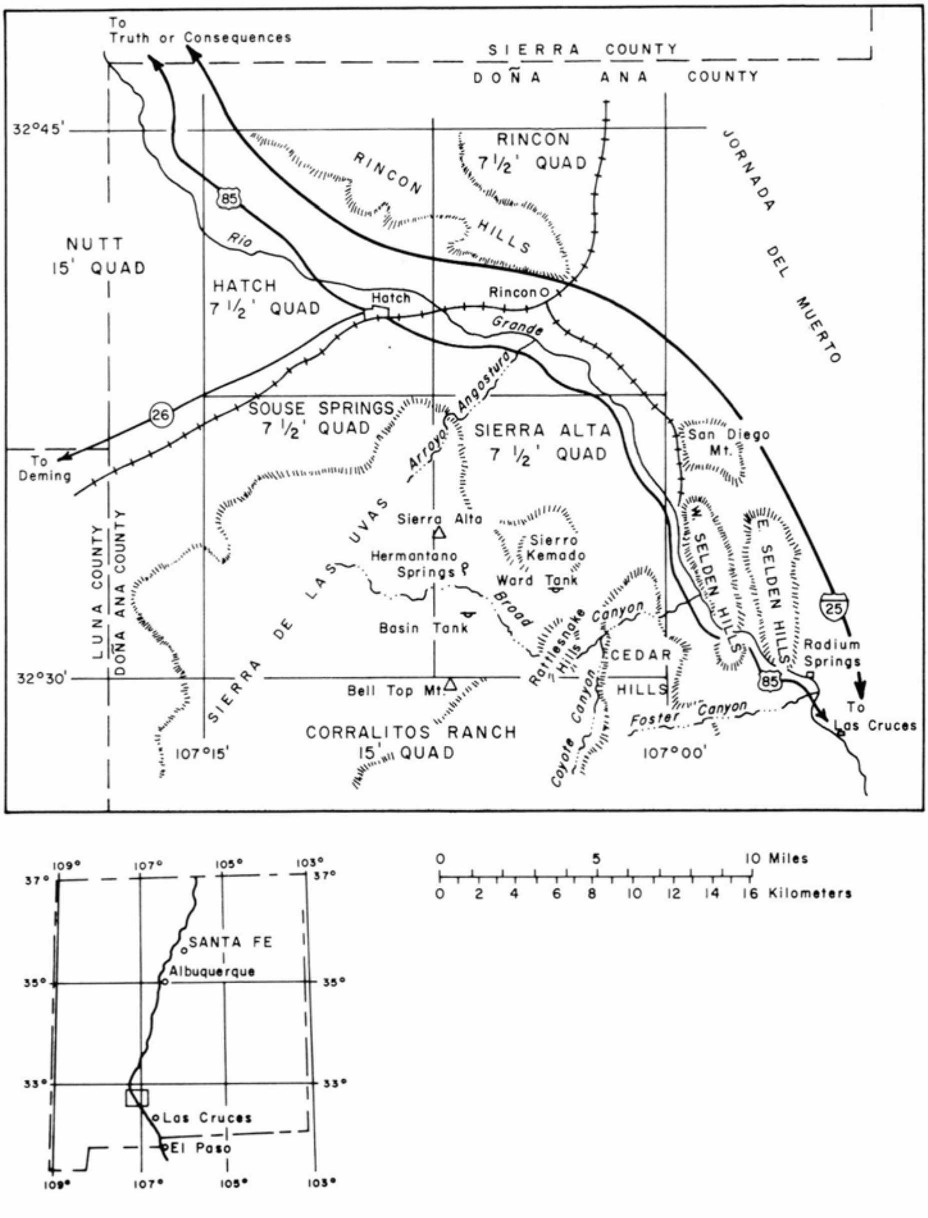

FIGURE 1—INDEX MAP SHOWING LOCATION OF STUDY AREA.

Abstract

Rocks exposed in the Sierra Alta quadrangle range in age from Permian to Holocene. Permian Hueco Limestone and Abo Sandstone, deformed during the Laramide, are unconformably overlain by a tripartite sequence of less deformed Tertiary volcanic and volcaniclastic strata. Basal andesitic epiclastic rocks are referred to the Palm Park Formation (late Eocene). Middle rhyolitic ash-flow tuffs and epiclastic strata of the Bell Top Formation (Oligocene) partly fill the Goodsight-Cedar Hills volcano-tectonic depression; numerous vent structures (Cedar Hills vent zone) form the eastern margin of the depression. The upper Uvas Basaltic Andesite (26 m.y.) consists of a shield-like accumulation of flows centered on the axis of the depression. The Sierra de las Uvas dome and the Sierro Kemado sag probably resulted from resurgent uplift of the central part of the volcanic pile following eruption of the basaltic andesite.

The volcano-tectonic depression appears to be a precursor to Rio Grande rift structure in this area. Miocene to Pliocene faults superimposed across the depression are, in part: 1) reactivated subsidence fractures, 2) new, throughgoing faults, and 3) fractures whose pattern is governed by the geometry of the Sierra de las Uvas dome and its adjoining synclines. Bolson deposits of the lower Santa Fe Group fill Miocene basins.

Fluvial (ancestral Rio Grande) and piedmont-slope deposits of the Camp Rice Formation represent latest stages in the aggradation of late Tertiary fault basins. Middle to late Quaternary evolution of the present landscape was characterized by three major episodes of valley incision by the Rio Grande and its tributaries. Each episode was followed by intervals of partial backfilling and subsequent periods of stability of valley base levels.

Introduction

This report covers the U. S. Geological Survey Sierra Alta 71/2-minute quadrangle. The area is located 3 miles southeast of Hatch and about 25 miles northwest of Las Cruces in northern Doña Ana County (fig. 1). US-85 crosses the northeastern corner of the quadrangle; other access is limited to a few ranch roads and jeep trails. The only permanent residents in the quadrangle live along the Rio Grande flood plain.

Mesas, buttes, cuestas, and deeply incised superimposed canyons are characteristic of the Sierra de las Uvas-Cedar Hills uplands in the western part of the quadrangle. Benches, ridges, broad piedmont-slope remnants, terraces, and fans form the interfluves between major arroyo channels east of the mountains, and terminate in low bluffs flanking the Rio Grande valley floor. Badlands occur in many steeper valley-slope terranes. Elevations range from 5,823 ft on Sierra Alta to about 4,000 ft on the flood plain of the Rio Grande; however, local relief seldom exceeds 1,000 ft.

The climate of the region is arid. About 8 to 10 inches of moisture falls each year, mostly during late summer thunderstorm activity. Further discussion of the area's climate can be found in Bulletin 101 of the New Mexico Bureau of Mines

& Mineral Resources (Seager and Hawley, 1973). Pecans, cotton, lettuce, maize, alfalfa, and onions are grown by irrigation on the Rio Grande flood plain, but the surrounding uplands are used exclusively for grazing. Creosote bush, some grass, mesquite, minor juniper, cacti, and various other desert plants form a discontinuous cover on the rocky higher elevations. Cottonwood, salt cedar, grass, and mesquite grow on the river flood plain and adjacent arroyo fans. Mesquite, desert willow, creosote bush and tar bush are common on the valley and piedmont slopes. Streamflow other than the Rio Grande is ephemeral and only Hermantano Springs actively discharged potable water in the spring of 1972.

Regional Setting

The Sierra Alta quadrangle is located in the east-central part of the Goodsight-Cedar Hills resurgent volcano-tectonic depression of Oligocene age (Seager, 1973). Included is the east-central part of the resurgent Sierra de las Uvas dome, part of the Sierro Kemado sag, and the northern part of the Oligocene Cedar Hills fault zone (fig. 2). The depression is floored by andesitic strata of the Palm Park Formation, and is filled with rhyolitic ash-flow tuffs and epiclastic strata of the Bell Top and lower Thurman formations, and the Uvas Basaltic Andesite. Various types of volcanic vents occur in the Oligocene Cedar Hills vent zone at the eastern margin of the depression.

Superimposed across the volcano-tectonic structure are late Tertiary, high-angle normal faults of the Rio Grande rift zone (Chapin, 1971). North of Hatch a group of these faults forming the graben or half graben west of the Caballo Mountains strike southward toward the Sierra de las Uvas. Near Hatch the graben bifurcates into a short southwest-trending spur and a well-developed southeast-trending prong. The southwestern side of the latter structure crosses the eastern and northern part of the Sierra Alta quadrangle. Movement on four major normal faults in this zone raised the Sierra de las Uvas and Cedar Hills blocks. Exposures in the uplifts are of the volcanic filling and the floor of the older volcano-tectonic depression. Down-dropped blocks adjacent to the uplifts became the sites of thick accumulations of fanglomerates and playa deposits of the lower Santa Fe Group, derived from adjacent uplifts, and intertonguing fluvial (ancient Rio Grande) and piedmont clastics of the upper Santa Fe Group. These are well exposed in tributary arroyos of the Rio Grande between Hatch and Radium Springs.

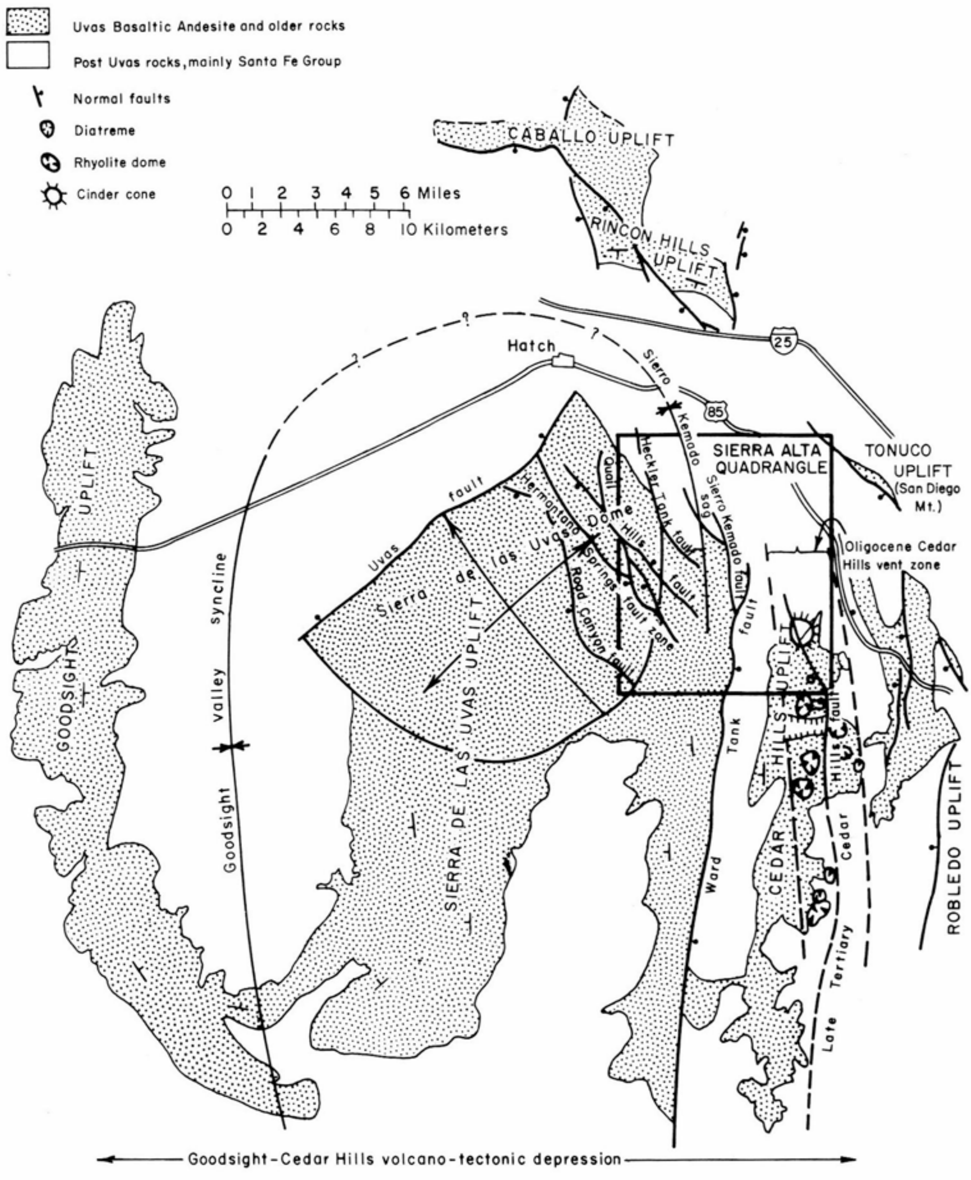

FIGURE 2—STRUCTURE INDEX MAP.

Stratigraphy

Rocks exposed in the Sierra Alta quadrangle range in age from Permian to Holocene. In terms of area of outcrop, Eocene-Oligocene volcanic rocks (exposed in uplifts) and Miocene-Holocene sedimentary rocks (mostly in grabens) are about equal. The volcanic sequence comprises lower andesitic epiclastic rocks (Palm Park Formation; Kelley and Silver, 1952), a middle rhyolitic sequence (Bell Top Formation; Kottlowski, 1953), and an upper basaltic andesite (Uvas basalt; Kottlowski, 1953). Locally, thin rhyolitic tuffaceous sediments occur above the Uvas Basaltic Andesite. These are probably correlative with upper Thurman beds of the southern Caballo area (Kelley and Silver, 1952; Seager and Hawley, 1973). Reconstructed stratigraphic sections through the GoodsightCedar Hills depression (figs. 3 and 4) illustrate relations among the Bell Top-Uvas-Thurman units, and stratigraphic changes that occur in the Bell Top Formation at the eastern margin of the depression. The mapped rock units are summarized in table 1, and measured sections are described in Appendix A. Petrographic data is presented in Appendix B.

Miocene to Pleistocene basin-fill deposits comprise the Santa Fe Group; various Holocene units are primarily river, arroyo, and colluvial in origin.

PALEOZOIC ROCKS

The only outcrops of Paleozoic rocks in the Sierra Alta quadrangle are in the Rattlesnake Hills, adjacent to the Ward Tank fault (geologic map in pocket).

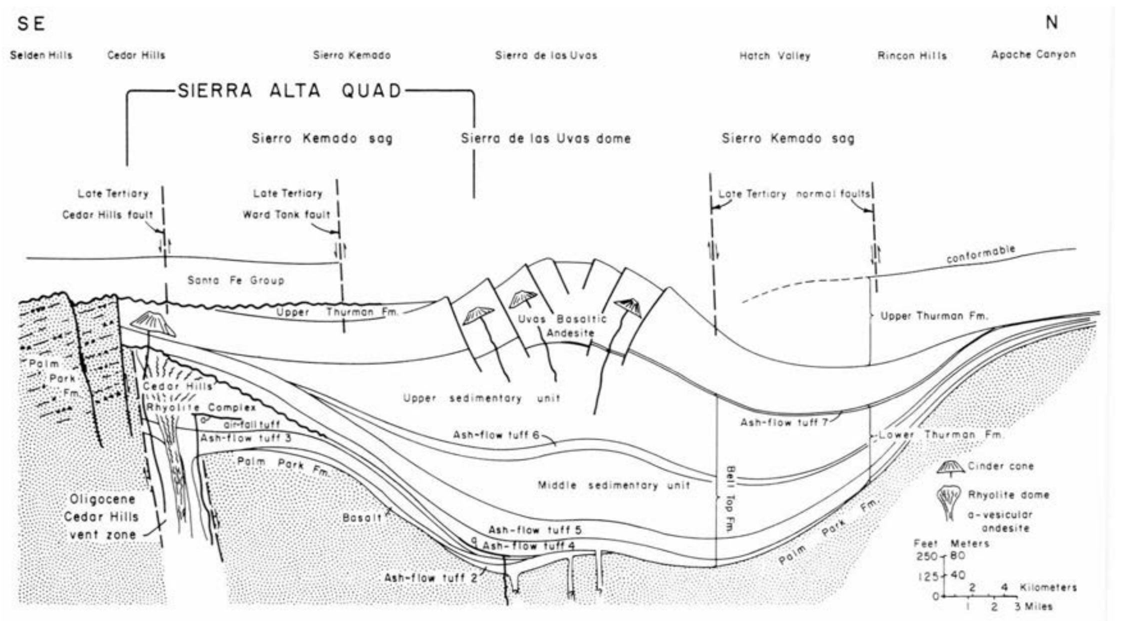

FIGURE 3—DIAGRAMMATIC SOUTHEAST-NORTH CROSS SECTION THROUGH GOODSIGHT-CEDAR HILLS DEPRESSION. EFFECTS OF LATE TERTIARY NORMAL FAULTS REMOVED. (Reprinted from Geological Society of America Bulletin, v. 84, p. 3614.)

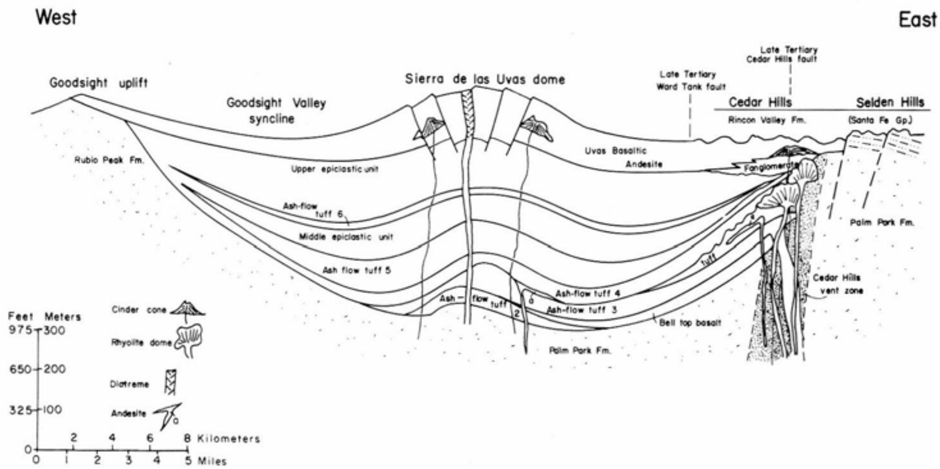

FIGURE 4—DIAGRAMMATIC WEST-EAST CROSS SECTION THROUGH GOODSIGHT-CEDAR HILLS DEPRESSION. EFFECTS OF LATE TERTIARY FAULTS REMOVED. (Reprinted from Geological Society of America Bulletin, v. 84, p. 3614.)

About 300 ft of alternating Hueco Limestone and Abo sandstone of Wolfcampian age is exposed. The gently dipping to overturned strata apparently formed a topographic high in Tertiary time, because they are overlain unconformably by a greatly thinned volcanic section. Lithologic description of the Permian beds is presented in Appendix A (section 7).

EOCENE-OLIGOCENE VOLCANIC ROCKS

The volcanic rocks exposed in the Sierra de las Uvas have been described in detail by Clemons and Seager (1973). The same rock units are present over most of the southwestern part of the Sierra Alta quadrangle, and are little different from exposures in the Souse Springs quadrangle. Stratigraphic relations unique to the Sierra Alta quadrangle are discussed below.

PALM PARK FORMATION

The Palm Park Formation consists almost entirely of epiclastic strata derived from andesitic to latitic tuffs and lavas. These rocks are primarily fluvial and overbank strata, although important deposits of mudflow origin are interbedded. A thin andesite porphyry flow is present about 'A mile northeast of Ward Tank.

The Palm Park Formation is widely exposed between the Ward Tank fault and the Sierra de las Uvas. In this area the Palm Park is generally at least 1,000 ft thick, and may be as much as 2,000 ft thick (Appendix A, section 4). The basal conglomerate is exposed in the Rattlesnake Hills, and is angularly unconformable above the Hueco-Abo sequence (fig. 5). At this locality, however, the Palm Park is only 100 ft thick and apparently buried a bedrock high formed by Hueco-Abo strata.

TABLE 1—ROCK UNITS MAPPED IN SIERRA ALTA QUADRANGLE

Age	Radiometric dates	Rock units			Maximum thickness (ft)	Characteristics
QUATERNARY		Alluvium			70	Stream, flood-plain, and alluvial fan gravels; wind-blown sand; and colluvium
QUATERNARY		Santa Fe Group	Camp Rice Formation		100	Fluvial sandstone and gravel, and caliche-cemented piedmont-slope gravels
PLIOCENE / MIOCENE	9 m.y.[1]	Santa Fe Group	Rincon Valley Formation		500	Fanglomerate, sandstone, conglomeratic sandstone, claystone and gypsiferous siltstone. In Selden Canyon this formation contains an olivine basalt flow (Selden Basalt)
					UNCONFORMITY	
MIOCENE		Upper Thurman unit			80	White to tan tuffaceous sandstone and conglomerate. Present only in Sierro Kemado sag
OLIGOCENE	26 m.y.[2]	Uvas Basaltic andesite			400 ±	Gray to black, platy, vesicular to amygdaloidal basaltic andesite flows, tuff and agglomerate
OLIGOCENE		Bell Top Formation	Ash-flow tuff 7		15	Gray, dense, welded vitric ash-flow tuff
OLIGOCENE		Bell Top Formation	Upper sedimentary unit		250	Light-brown to gray tuffaceous sandstone containing conglomerate lenses. Grades into rhyolite boulder fanglomerate southeastward. Interfingers with Uvas flows
OLIGOCENE		Bell Top Formation	Ash-flow tuff 6		90	Pale-red to tan vitric-crystal ash-flow tuff
OLIGOCENE		Bell Top Formation	Middle sedimentary unit		150	Light-brown to gray tuffaceous sandstone containing conglomerate lenses
OLIGOCENE	35 m.y.[2] 34 m.y.[3]	Bell Top Formation	Ash-flow tuff 5		150±	Tan to light-gray crystal-vitric ash-flow tuff containing abundant pumice lumps
OLIGOCENE		Bell Top Formation	Ash-flow tuff 4		70 to 90	Grayish-purple to brown welded vitric-crystal ash-flow tuff with dark, devitrified, flattened pumice fragments to 1 ft in diameter
OLIGOCENE		Bell Top Formation	Lower sedimentary unit		50	White to gray rhyolitic tuff and sandstone in Sierra de las Uvas. Equivalent to rhyolite complex of Cedar Hills
OLIGOCENE		Bell Top Formation	Cedar Hills Rhyolite complex	Air-fall tuff	500	White to tan rhyolitic air-fall tuff and breccia, with epiclastic sandstone; locally opalized
OLIGOCENE		Bell Top Formation	Cedar Hills Rhyolite complex	Vesicular andesite	50 ±	Dark-gray to black vesicular andesite flows and dikes
OLIGOCENE	33 m.y.[4]	Bell Top Formation	Cedar Hills Rhyolite complex	Ash-flow tuff 3	300	Pink to orange, porous, vitric ash-flow tuff containing 20 percent pumice. Widespread as flow in Sierra de las Uvas, but nearly all intrusive in northern Cedar Hills
OLIGOCENE		Bell Top Formation	Cedar Hills Rhyolite complex	Air-fall breccia	200	White to tan, purple or red rhyolitic air-fall breccia and tuff, locally opalized. Restricted to Cedar Hills
OLIGOCENE		Bell Top Formation	Basalt		100	Black olivine-bearing basalt flow
—?—?—?						
EOCENE	39 m.y.[4]	Bell Top Formation	Ash-flow tuff 2		100	Pale-purple to tan welded vitric ash-flow tuff with well-developed microscopic eutaxitic texture
EOCENE	51 m.y.[4] 43 m.y.[3] 42 m.y.[4]	Palm Park Formation			100 to 2,000	Purple, red, tan, white andesitic sandstone, mudstone, breccia, and conglomerate; minor andesite porphyry flows
					ANGULAR UNCONFORMITY	
PERMIAN		Hueco Limestone and Abo Sandstone			300 +	Interbedded red siltstone and gray to tan fossiliferous marine limestone

[1]Gile, and others, 1970; F. E. Kottlowski, letter 1970
[2]F. E. Kottlowski, letter, 1970
[3]Kottlowski and others, 1969
[4]Kottlowski, letter, 1972

TABLE 1—ROCK UNITS MAPPED IN SIERRA ALTA QUADRANGLE

FIGURE 5—ANGULAR UNCONFORMITY BETWEEN PALM PARK FORMATION (Tpp) AND NEAR VERTICAL HUECO-ABO STRATA (Pah), RATTLESNAKE HILLS. VIEW TOWARD NORTH.

BELL TOP FORMATION

The nine members of the Bell Top Formation described in the Souse Springs quadrangle (Clemons and Seager, 1973) are present in the western Sierra Alta quadrangle (fig. 6). Two additional units have been recognized in the western Sierra Alta quadrangle, and several new informal members, described in a later section, were mapped in the Cedar Hills. New units from the western part of the quadrangle include an intrusive vesicular andesite plug and associated flow appearing in the Bell Top about 0.5 mile west of Basin Tank. The intrusive appears to cut ash-flow tuff 3 and is unconformably overlapped by ash-flow tuffs 4 and 5. In the lower part of the Bell Top, a section of tuffaceous sedimentary rocks and air-fall tuff, not present farther west, is interbedded between ash-flow tuff 2, lower Bell Top .basalt, and ash-flow tuff 3. The unit is designated *lower sedimentary member.* Thickening eastward toward the Cedar Hills, it comprises primarily air-fall breccias associated with vents in the Oligocene Cedar Hills vent zone.

Several of the Bell Top ash-flow and epiclastic units that are well developed in the Sierra de las Uvas thin eastward across the Sierra Alta quadrangle. Ash-flow tuff 2 is confined to the southwestern part of the quadrangle. Ash-flow tuff 6 and the middle sedimentary unit thin gradually eastward across Sierro Kemado and are missing in the Cedar Hills. The lower basalt, discontinuous and perhaps comprising several separate flows, is generally absent from the eastern part of the quadrangle. Ash-flow tuff 3, which was erupted from fissures in the Oligocene Cedar Hills vent zone, changes facies into air-fall debris or pinches out north of a line between Hermantano Springs and lower Broad Canyon. The distribution of tuff 3 suggests a westward flow from the Cedar Hills area to the axis of the Goodsight-Cedar Hills depression (near the southeastern Sierra de las Uvas area) where tuff 3 is 300 ft thick.

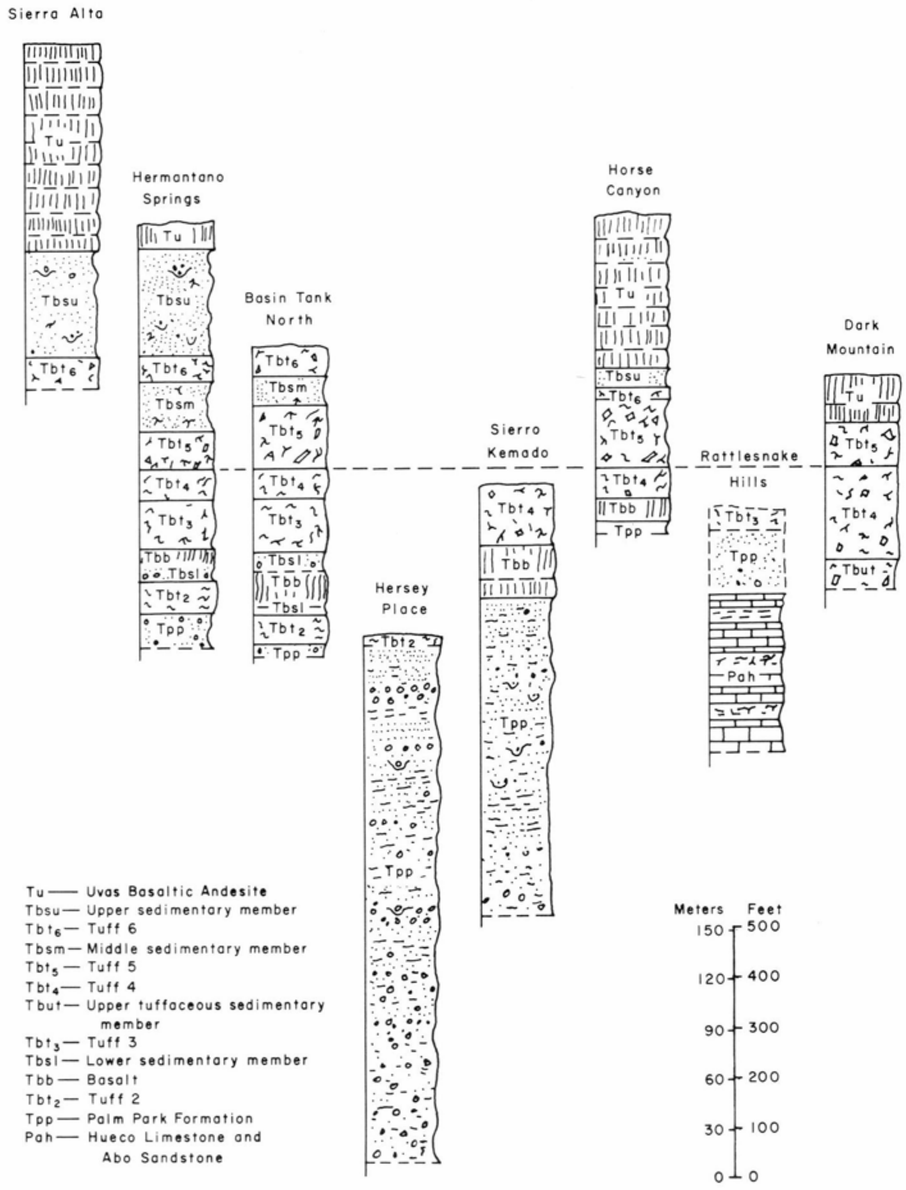

FIGURE 6—MEASURED SECTIONS (NW TO SE) OF FORMATIONS IN THE SIERRA ALTA QUADRANGLE.

The most striking east-west stratigraphic change within the Bell Top is seen in the upper sedimentary member. In the Sierra de las Uvas the unit consists of tuffaceous sandstone and several coarse-grained fluvial conglomerate lenses. Southeastward the unit becomes a thick rhyolite boulder fanglomerate derived from numerous flow-banded rhyolite domes occupying the Oligocene Cedar Hills vent zone. In the northeastern part of the Corralitos Ranch quadrangle the fanglomerate is interbedded in Uvas Basaltic Andesite (26 m.y:, Clemons and Seager, 1973). This relation is taken to demonstrate contemporaneity of Uvas eruptions and initial uplift of the Cedar Hills fault block about 26 m.y. ago. This date probably also identifies initial regional faulting associated with the Rio Grande rift in south-central New Mexico.

Bell Top Formation in Cedar Hills. As illustrated diagrammatically in figs. 3 and 4, the Bell Top Formation in the Cedar Hills consists largely of a wedge of rhyolitic air-fall breccia and associated domes interbedded between ash-flow tuff 4 and the Palm Park Formation. Most of this wedge crops out along the eastern side of the late Tertiary Cedar Hills fault block in the northeastern part of the Corralitos Ranch quadrangle. A small but important part of the wedge crops out in the Sierra Alta quadrangle. The intrusive-extrusive complex, which originated in the Oligocene Cedar Hills vent zone, has been described in general terms by Seager (1973).

Five mappable units comprise the wedge in the Sierra Alta quadrangle (fig. 7). The oldest unit consists of about 200 ft of opalized rhyolitic air-fall breccia (Tblt) exposed 0.25 mile northwest of Porcupine Tank. The breccia overlies Palm Park strata and forms the northern rim of an adjacent diatreme. Breccia clasts consist of Palm Park blocks and angular fragments of vitrophyre, pumice and flow-banded rhyolite. The unit is discontinuous, apparently as a result of erosion prior to emplacement of ash-flow tuff 3.

Intruding or locally overlying the basal air-fall breccia is ash-flow tuff 3. Unaltered parts of the ash-flow are exposed in the Corralitos Ranch quadrangle where they are redder, better welded, and finer grained than equivalent rocks in the Sierra de las Uvas. In the Sierra Alta quadrangle the unit is bleached tan or

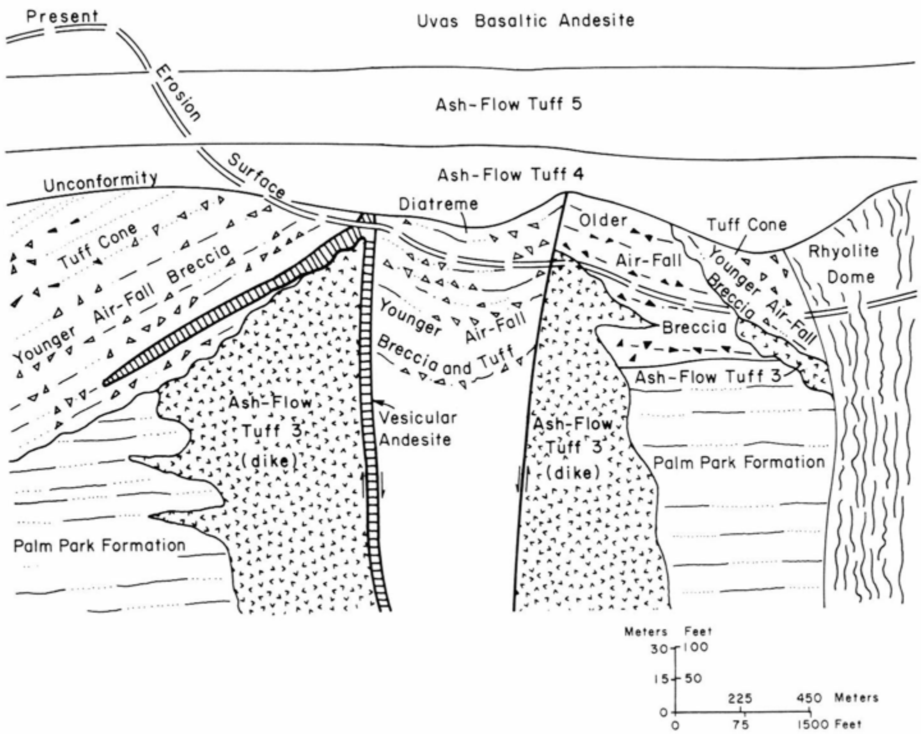

FIGURE 7—West-east diagrammatic section of Bell Top vents near Porcupine Tank, Cedar Hills.

white as a result of alteration. Its characteristic pumice lumps and stratigraphic position are the basis for its identification in the Cedar Hills. Outcrops near Porcupine Tank appear to be mainly intrusive and are described under structure.

Above eroded ash-flow tuff 3 intrusive rocks is a sequence of air-fall breccia and epiclastic tuffaceous sediments (Tbut) 300 to 500 ft thick. These breccias are coarsest (1 to 5 inches) near the diatreme, where they comprise angular blocks of vesicular andesite, ash-flow tuff 3, and various fragments of pumice, vitrophyre, and flow-banded rhyolite. Finer grained, epiclastic strata and pumice air-fall tuff predominates at greater distances. The strata display initial dips up to 30 degrees and apparently form a tuff cone centered either on the diatreme or on a rhyolite dome exposed a few hundred yards southeast. Along the western flank of the cone, a vesicular andesite flow is interbedded with cone breccias. The andesite flow merges with, and was fed by, a vesicular andesite dike occupying part of a ring fracture at the margin of the diatreme.

Youngest of the volcanic units in the wedge are flow-banded rhyolite domes and flows. The domes intrude ash-flow tuff 3 as well as the air-fall tuffs and breccias and, to the south, flows associated with the domes overlie the air-fall strata.

Two flow-banded rhyolite masses (Tbr) are present in the Sierra Alta quadrangle. The larger is formed of steeply dipping, yellow-brown to pink, platy, flow-banded rhyolite that is probably intrusive. Steep foliation wraps around parallel to the western and southern contact, but is cut off on the east by the Cedar Hills fault. The smaller mass, exposed east of Porcupine Tank, may be intrusive, or, a tilted, down-faulted slice of a rhyolite flow. It is dark brown, spherulitic and exhibits steep flow-banding.

Unconformably overlying the air-fall breccia, vesicular andesite, and (to the south) flow-banded rhyolite domes are ash-flow tuffs 4 and 5. The base of tuff 4 transects bedding in the tuff cone; south of the map area, both tuffs are inset against, and overlap, rhyolite domes. The base of these ash-flow tuff units is clearly an erosion surface developed upon the intrusive-extrusive rhyolitic wedge. The absolute age of the wedge occurs between 39 m.y. (ash-flow tuff 2) and 35 m.y. (ash-flow tuff 5). Probably the domes are about the same age as the Lookout Mountain flow-banded rhyolite sill of the Robledo Mountains (K-Ar age of 35 m.y., Kottlowski, and others, 1969).

OLIGOCENE-MIOCENE ROCKS UVAS

BASALTIC ANDESITE AND UPPER THURMAN UNIT

Overlying and interfingering with the Bell Top Formation are numerous thin basaltic andesite flows and associated cinder deposits of the Uvas Basaltic Andesite. These formations once formed a continuous blanket about 400 ft thick between the Sierra de las Uvas and the northern Cedar Hills. In the Sierra de las Uvas and at Sierro Kemado, the flows intertongue vertically with the upper sedimentary unit of the Bell Top; southward toward the Corralitos Ranch quadrangle, the flows interfinger laterally in the flow-banded rhyolite fanglomerate described earlier. Interbedded fan debris and basalt flows are present in the Rattlesnake Hills. Apparently the Uvas is younger than much of the upper unit of the Bell Top, but is essentially contemporaneous with the rhyolite boulder fan. The Uvas has been dated 26 m.y. (Clemons and Seager, 1973).

Several sources of Uvas flows have been identified in the Sierra de las Uvas.

Small lenses of cinders, bombs, and agglomerate appear locally between flows in the Sierra Alta quadrangle. Some of these may be exposures of the edges of buried cones or other types of vents. A spectacular Uvas cinder cone exposed in lower Broad Canyon is described in the chapter on structure.

About 0.5 mile northeast of Hersey Tank, the Uvas Basaltic Andesite is overlain by 80 to 100 ft of fine-grained tuffaceous sandstone and minor conglomerate. These rocks appear similar to the thick tuffaceous sandstones of the upper part of the Thurman Formation of the Rincon Hills a few miles north, and occupy a similar stratigraphic position. At Hersey Tank the unit is unconformably overlain by Pleistocene conglomerate, with an unknown amount of upper Thurman beds removed by erosion. Apparently the tuffaceous sediments, primarily lacustrine in origin, are confined to the synclinal moat (Sierro Kemado sag) between the Sierra de las Uvas dome and the structurally higher outer parts of the volcano-tectonic depression.

SANTA FE GROUP

The three formations making up the Santa Fe Group have been described in adjacent areas by Hawley and others (1969), Seager and others (1971), and Seager and Hawley (1973). The following discussion concentrates on stratigraphic and lithologic features that are particularly well expressed in Sierra Alta quadrangle.

RINCON VALLEY FORMATION

The middle subdivision of the Santa Fe Group, the Rincon Valley Formation, crops out widely over the eastern and northeastern part of the quadrangle. At most localities the Rincon Valley Formation unconformably overlies the Uvas Basaltic Andesite. The formation comprises closed-basin (bolson) deposits that accumulated in late Tertiary grabens. Near San Diego Mountain and in the Rincon Hills the Rincon Valley Formation grades down into thick, coarse- to medium-grained bolson deposits comprising the basal Santa Fe unit, transition beds, and the Hayner Ranch Formation (Seager, and others, 1971; Seager and Hawley, 1973). In the Cedar Hills area of the Sierra Alta quadrangle, the Rincon Valley Formation overlaps uplift margins resulting in a greatly thinned or missing Hayner Ranch section on the uplifts. Hayner Ranch strata may be present in the subsurface in the northeastern part of the quadrangle, but confirming well data are lacking. In most places, the Rincon Valley beds are gently deformed.

Two facies of the Rincon Valley Formation are recognized: a fanglomeratic basin-margin facies (Trvc), and a playa or alluvial flat, basin-floor facies (Trv). The reddish-brown to brown fanglomerate facies is well developed adjacent to the Ward Tank fault (fig. 8). Erosion of the Palm Park, Bell Top, and Uvas units in the Sierra de las Uvas block west of the fault supplied most of the sediment to the Rincon Valley Formation to the east. Judging from the distribution and composition of the fanglomerate near the Cedar Hills, fault blocks of Uvas Basaltic Andesite in this area were also sources of fan material, at least during early stages of block faulting. Eventually, uplifts near the Cedar Hills were buried by Rincon Valley Formation, as indicated by the great thicknesses of fanglomerate that can be projected over the summits of these fault blocks. The petrography of the fanglomerate facies has not been studied in detail. However, recent work by Dr. Theodore R. Walker of the University of Colorado indicates

FIGURE 8—RINCON VALLEY FANGLOMERATE ADJACENT TO WARD TANK FAULT, WHICH PASSES NEAR BASE OF CLIFF, RATTLESNAKE HILLS. VIEW TOWARD NORTH.

that zeolites form an important cementing material in this unit (personal communication, 1972). In contrast with overlying Camp Rice conglomerates, carbonate cements do not appear to be common constituents.

An olivine basalt flow, named Selden Basalt (Kottlowski, 1953), is interbedded in the Rincon Valley Formation (Trvs) near the eastern edge of the geologic map. The K-Ar date of 9 m.y. for the flow is the basis for assigning a late Miocene and Pliocene (?) age to the Rincon Valley Formation.

The basin-floor facies of the formation crops out over much of the northeast part of the quadrangle. Badland-forming, reddish to brownish mudstone, siltstone, and sandstone is characteristic. Gypsum (selenite) is locally present as a cementing agent and as disseminated crystal clusters. Intertonguing of the two facies occurs in a transition zone generally located 1 to 2 miles east of the Ward Tank fault, and northeast of the Sierro Kemado fault.

CAMP RICE FORMATION

The upper subdivision of the Santa Fe group, the Camp Rice Formation, crops out extensively in the northeastern three-quarters of the quadrangle. The formation occurs in the southwestern quarter as scattered deposits forming relatively thin caps on mesas and buttes. The unit marks the final stages of aggradation of the ancient Jornada del Muerto basin, as well as the initial development of the Rio Grande system in southern New Mexico in early to middle Pleistocene time. Two distinct facies of the formation are recognized, both regionally and within the map area: 1) a basin-floor facies, primarily ancient Rio Grande deposits, that intertongues laterally with 2) a piedmont-slope facies composed of alluvium derived from adjacent mountain masses.

Basin floor or Fluvial Facies (Qcrf) comprises channel and flood-plain deposits of a major perennial stream system that probably headed in the same general area of northern New Mexico and southern Colorado now occupied by Rio Grande headwaters. Light-gray to brown sand, gravel, and some sandstone and conglomerate make up the river-channel subfacies. Sands are arkosic, fine to coarse grained, often crossbedded, with individual strata being moderately well sorted. Gravel clasts are generally subrounded to well rounded and in the pebble-size range, but fine cobbles are locally present. Gravel lithology is mixed, with local volcanic types (including a wide range of welded tuff and lava) being dominant. However, significant amounts of rounded pebbles of resistant rocks, notably quartzite, quartz, chert, granite, and traces of obsidian, derived from source areas upstream from Hatch, are frequently present. Limestone gravel is absent or present only in trace amounts. Channel units grade upward into light-brown to reddish-brown, sandy to clayey flood-plain deposits.

The fluvial facies thickens toward the east and northeast and may locally attain a thickness of 50 ft in areas west of the Rio Grande. In the northeast corner of the quadrangle (sec. 25, T. 19 S., R. 2 W.) the formation is probably about 100 ft thick. It is 300 to 400 ft thick farther east and north in parts of San Diego Mountain and Rincon quadrangles where the ancient bolson deposits of the central Jornada del Muerto are still undissected. The individual channel to flood-plain depositional sequences, no more than 30 or 40 ft thick and locally capped with paleosols, are stacked in multiple units in the thicker sections. The fluvial facies wedges out to the southwest along the piedmont toe slopes of the Sierra de las Uvas at an elevation of about 4,500 ft where the fluvial facies intertongues with older and younger piedmont deposits of Camp Rice Formation (fig. 9, and structure sections *A-A'* and *C-C')*. Several hundred feet of the fluvial facies were apparently removed by erosion during middle to late Pleistocene episodes of valley incision in the northeastern part of the quadrangle. The Qcrf unit is generally disconformable on the basal Camp Rice piedmont-slope facies (Qcrc), but locally near the present river valley Qcrf rests with slight angular unconformity on the Rincon Valley Formation (fig. 10).

Piedmont-slope Facies (Qcrp, Qcrc, Qcru) consists of alluvial-terrace, alluvial-fan, and coalescent-fan deposits as well as thin (5 to 10 ft) alluvial and colluvial veneers on erosion surfaces (in part, rock pediments) cut on Rincon Valley and older formations. A basal brown to gray conglomerate to conglomeratic sandstone (subunit Qcrc) is overlapped by the fluvial facies along the margins of the ancient Jornada del Muerto floor at elevations ranging from about 4,200 to 4,500 ft. Above the fluvial facies wedge-out zone, the basal subunit extends southwestward beneath a cover of younger piedmont-slope alluvium (subunit Qcrp). Structural benches capped with the conglomerate are well preserved in broad interfluve-summit areas between elevations of 4,250 and 4,450 ft in the northeastern part of the quadrangle (section *A-A')*. The bench areas are discontinuously veneered with remnants of fluvial sand and gravel, as well as coarse volcanic lag gravel, remaining from erosion of the younger piedmont member, all mapped as Qcrf/Qcrc. The best exposures illustrating these relationships are along Bignell Arroyo (sec. 5, T. 20 S., R. 2 W.) where as much as 60 ft of conglomerate crops out in nearly vertical valley walls between the Rincon Valley Formation and overlapping deposits of the fluvial and younger piedmont facies (fig. 9). The upper piedmont facies (Qcrp) is generally very gravelly and nonindurated. Both piedmont subunits exhibit a large range in clast size, with pebbles and small cobbles being abundant and large cobbles and small boulders (5- to 20-inch diameter) being common. Maximum boulder size is in the medium range (20 to 40 inches). Mixed volcanic rock types reflect the varied lithologic

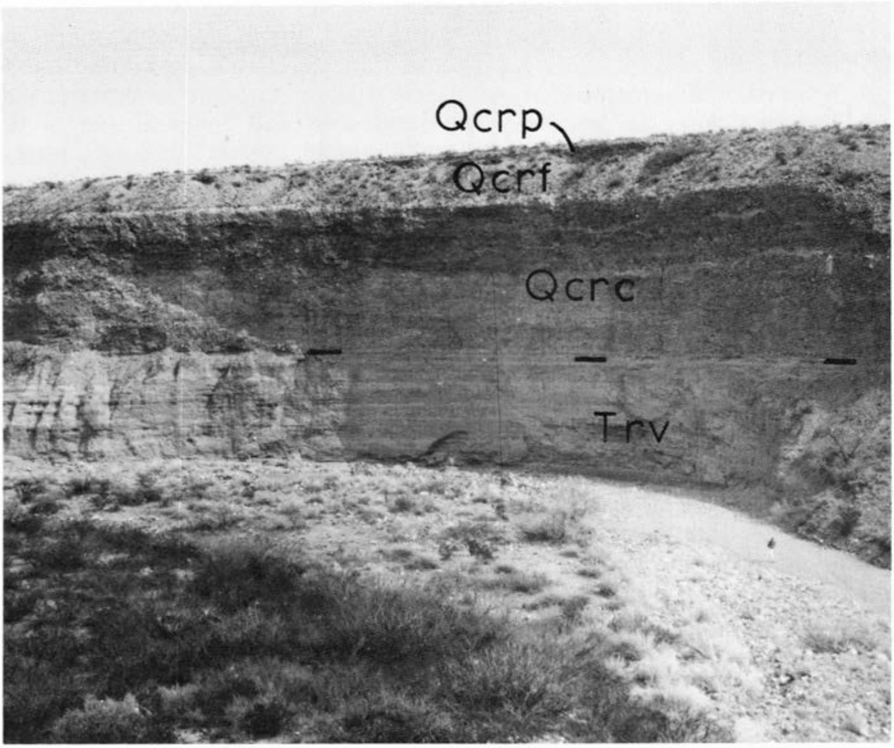

FIGURE 9—EXPOSURES OF CAMP RICE FORMATION IN SOUTH WALL OF BIGNELL ARROYO ABOUT 2.5 MILES ABOVE ARROYO MOUTH (NW¼NE¼ sec. 5, T. 20 S., R. 2 W.). UNCONFORMABLE CONTACT WITH RINCON VALLEY FORMATION INDICATED BY DASHED LINE. ABOUT 55 FT OF BASAL CONGLOMERATE FACIES (Qcrc) IS SEPARATED FROM 5-FT THICK UPPER PIEDMONT-SLOPE GRAVEL (Qcrp) BY ABOUT 15 FT OF FLUVIAL FACIES (Qcrf), SAND, GRAVEL, AND LOAM.

composition of source uplands in Corralitos, Souse Springs, and Sierra Alta quadrangles. However, rhyolitic volcanics (Bell Top) tend to be dominant in the basal subunit of Qcrc, while Uvas Basaltic Andesite is the most common rock type in the Qcrp deposits. Basaltic clasts in the latter subunit appear relatively unweathered, while the same rock types in the basal member are often so deeply weathered that they can be manually broken to sand- and pebble-size fragments.

Calcium carbonate seems to be the major cementing agent in indurated zones of the Camp Rice Formation in Sierra Alta quadrangle. Cementation occurring in the surficial beds of the upper piedmont and fluvial facies is usually related to illuvial accumulations in soil petrocalcic horizons. The origin of carbonate cement in the lower conglomerate zone has not been determined, but cementation may be related to the saturation of basal Camp Rice beds with ground water during the early to middle Pleistocene episodes of aggradation of the Jornada del Muerto basin. A contributing factor might also be the relative impermeability of underlying formations that would tend to perch a zone of saturation in the basal Camp Rice prior to valley incision. With the exception of a small area in the northeast corner of the quadrangle (secs. 25, 35, 36, T. 19 S., R. 2 W.), the formation now appears to be entirely above the water table.

Two additional Camp Rice mapping units are delineated in parts of the quadrangle. Qcru designates undifferentiated piedmont-slope deposits generally equivalent to Qcrp/Qcrc, but includes some caps on buttes and small mesas (Burro Hill) that may be correlative of subunit Qcrc. Qcr designates small ridge-capping remnants of both fluvial and piedmont facies.

The age of the Camp Rice Formation has been generally established throughout the region on the basis of studies of vertebrate faunas, volcanic ash correlations, and paleomagnetic measurements. The presence of Blancan age vertebrates in the lower part of the formation in its Hudspeth County (Texas) type areas (Strain, 1966), suggests that initial stages of deposition may have occurred more than 2.0 m.y. ago (Hibbard and Dalquest, 1973; Johnson and others, 1975). On the basis of petrographic and paleomagnetic properties (Reynolds and Larsen, 1972), a lenticular body of volcanic ash interbedded between fluvial facies and younger piedmont-slope deposits at Ash Mine Mesa in Selden Canyon (fig. 10 and section ***B-B';*** measured section 2a, p. 75, Hawley and others, 1969) is correlated with Pearlette-type "0" tephra derived from a caldera-forming eruption of the Yellowstone volcanic center, Wyoming, about 0.6 m.y. ago (Naeser and others, 1973). Vertebrates of Irvingtonian age collected from the upper part of the fluvial facies near Las Cruces, and K-Ar ages of post-Camp Rice basalt flows emplaced about 200,000 years B.P. support a general middle Pleistocene age designation for the upper part of the formation (Hawley and others, 1969; Hoffer, 1971; Lifshitz-Roffman, 1971). The lower part of the Camp Rice is here considered early Pleistocene age; however, future geochronologic studies may show that the unit extends to late Pliocene.

VALLEY ALLUVIUM

Middle and late Quaternary deposits of the Rio Grande valley system have been described in considerable detail by Hawley (1965), Metcalf (1967), and Hawley and Kottlowski (1969). As mentioned, Camp Rice deposition culminated and valley cutting was initiated sometime between 0.2 and 0.6 m.y. ago. Evolution of the river and arroyo valley system, presently incised as much as 350 ft below remnants of Jornada I piedmont-slope surfaces in Sierra Alta quadrangle, was characterized by several episodes of major valley cutting each followed by intervals of partial backfilling and valley floor stability. Evidence of these geomorphic processes is preserved in the river valley, as well as in valleys of tributary arroyos, in the form of a stepped sequence of graded valley-border surfaces of both constructional and erosional origin including terraces, fans, structural benches, and valley-side slopes. The informal rock-stratigraphic terminology used in this bulletin was initially developed by Seager and Hawley (1973) to facilitate cartographic presentation of the various valley-fill facies in the Rincon quadrangle. In that report the units were also correlated with the more refined geomorphic and stratigraphic subdivisions developed by Ruhe (1962, 1964, 1967), Hawley (1965), Metcalf (1967), Hawley and Kottlowski (1969), and Gile and others (1970) for detailed studies of soil-geomorphic relationships and paleoecology in the region.

Two major alluvial facies units are recognized, one associated with activity of the Rio Grande (fluvial facies), and the other a product of tributary arroyo systems. These units are analogs of the Camp Rice fluvial and piedmont facies, but are areally limited to narrow strips inset below remnants of the blanket-like upper Santa Fe deposits; and are generally non-indurated except in thin surficial zones of soil-carbonate accumulation in older valley-fill units. Trace amounts of fossil mollusks, a tusk fragment, and one mammoth molar tooth have been

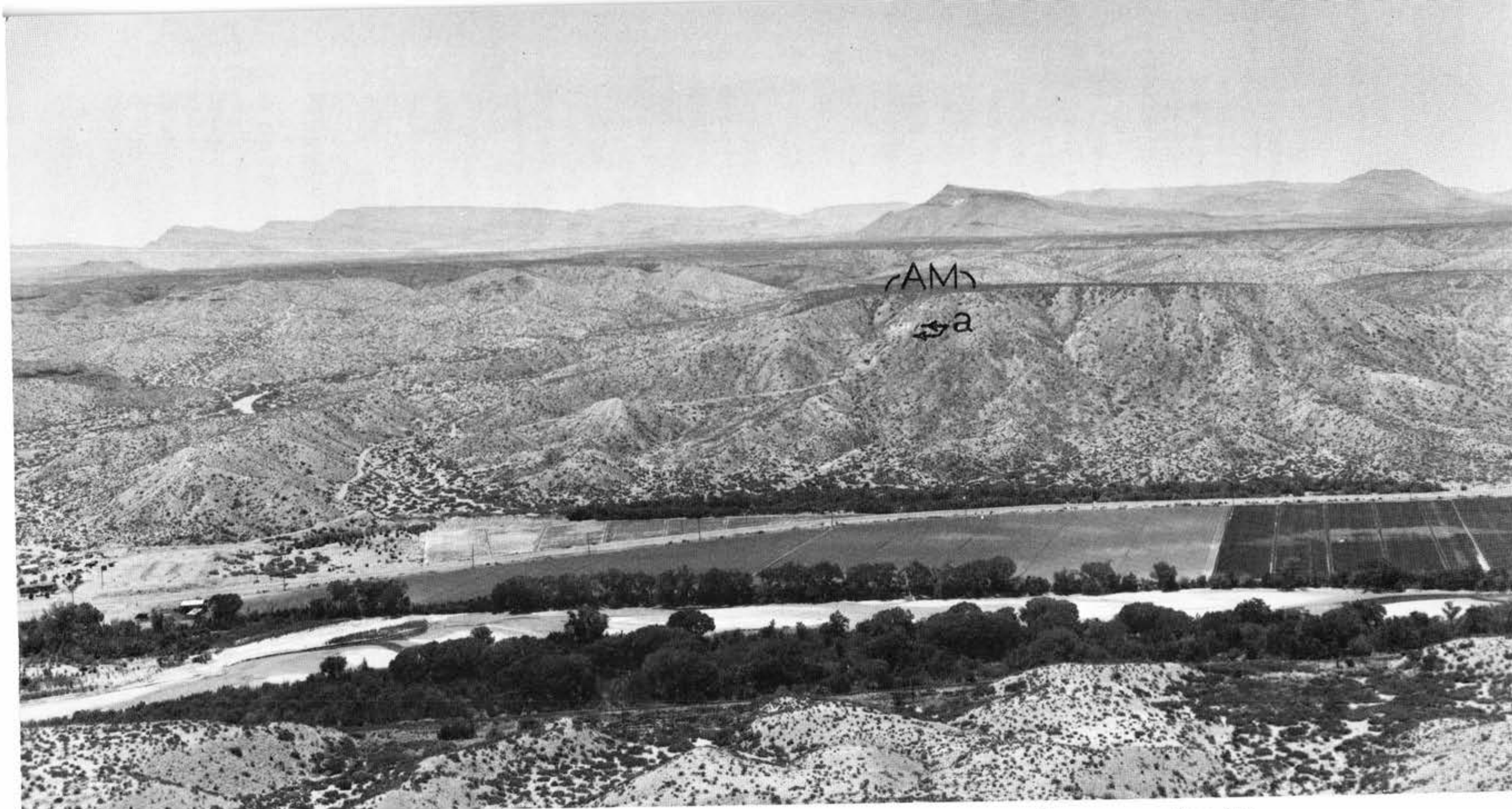

FIGURE 10—Looking west from Selden Canyon and the Rio Grande towards the Sierra de las Uvas. The outlying Sierro Kemado cuesta rises above remnants of the Jornada I piedmont-slope surface. Ash Mesa (AM), a Jornada I remnant, 370 ft above the river flood plain, is capped by 70 ft of upper Camp Rice fan gravel (Qcrp). This lies on a 30-ft thick Camp Rice fluvial (Qcrf) gravel to clay-silt sequence that contains a local veneer of Pearlette type "O" volcanic ash (a). These units unconformably overlie the fanglomerate facies of the Rincon Valley Formation.

recovered from the valley alluvium at areas in or immediately adjacent to the quadrangle. Distinguishing features of individual mapping units are described in the following sections.

OLDER VALLEY ALLUVIUM (Q QVO AND Qvof)

This category includes deposits associated with at least two (possibly three) middle to late Pleistocene episodes of valley entrenchment and partial backfilling that preceded development of present valley topography. Ancestral flood-plain positions that formed the local base levels to which tributary streams were graded, ranged from about 200 ft above to near the present level of the Rincon Valley floor. The morphostratigraphic equivalents of the older valley alluvium, the Tortugas and Picacho geomorphic surfaces, and associated fan and terrace deposits (Hawley, 1965; Ruhe, 1962, 1967; Hawley and Kottlowski, 1969), represent aggradational episodes culminating in particularly long periods of local base-level stability at elevations respectively, 115 to 150 and 70 to 90 ft above the present flood plain.

Unit Qvo comprises arroyo terrace and fan deposits, primarily gravelly sand to sandy loam with common lenses of gravel ranging up to medium-boulder size. Gravel lithology reflects the composition of older units cropping out in source watersheds. The Qvo unit may be as much as 50 ft thick in the alluvial terrace and fan remnants preserved along the lower valleys of the major arroyos (Reed, Bignell, and Hersey), but is generally less than 25 ft thick. Scattered soft to hard segregations of carbonate, and zones of discontinuous carbonate cementation are locally present; but continuous zones of induration are usually restricted to soil-carbonate horizons within 5 ft of the surfaces of broad interfluves formed by the more extensive fan and terrace remnants.

Qvo arroyo-fan deposits intertongue with, and overlap, the fluvial facies of the older valley alluvium (Qvof) in the low bluffs flanking the inner valley. These hills and benches range from about 40 ft to, very locally, as much as 200 ft above the Rio Grande flood plain (about 4,040 to 4,200 ft in elevation in Sierra Alta quadrangle). However, the ancient river deposits are generally confined to elevations no more than 150 ft above the valley floor. Thickness is usually less than 25 ft, but may be as much as 60 ft in areas adjacent to the inner valley. Complexly intertonguing Qvof and Qvo deposits are mapped as an undifferentiated unit, Qvou. Gray to brown channel gravel and sand deposits are the dominant subfacies, but locally these grade upward into brown to reddish-brown, loam to clay flood-plain sediments. Where not protected by an overlapping wedge of Qvo fan alluvium, the upper fine-grained deposits have generally been removed during subsequent valley erosion, leaving the underlying and more resistant channel deposits exhumed in several low structural benches. Gravel is generally subrounded to well rounded and in the pebble range, but cobbles and some very small boulders are locally present. The mixed suite of rock types is similar to that in the Camp Rice fluvial facies. Widely scattered zones of carbonate cementation have been noted throughout the unit. Discontinuously cemented horizons only a few inches thick often occur in thicker, nonindurated accumulations of soil carbonate one or two feet beneath the summit surfaces of the broader structural benches outlined by map unit Qvou.

Dr. A. L. Metcalf (written communication June, 1971) has collected and studied fossil mollusks from an outcrop of the flood-plain subfacies in the west wall of Bignell Arroyo. The exposure (Qvou) extends for about 1,500 ft from a point 250 ft south of the quadrangle boundary to old US-85 in Rincon quadrangle (sec. 25, T. 19 S., R. 2 W.). Mollusks collected from the northern end of the exposure are listed in table 2. Occurrence of these forms in various morphostratigraphic units of the valley-fill sequence (Metcalf, 1967, 1969) is also noted. The position of the sediments and the tentatively identified species indicate the deposits are correlative with the Tortugas morphostratigraphic unit of middle to late Pleistocene (pre-Wisconsinan) age. The presence of the aquatic snail, *Biompha-!aria,* indicates a depositional environment close to an ancestral river channel.

YOUNGER VALLEY ALLUVIUM (Qvy AND Q v fy)

This category includes deposits associated with late Wisconsinan (< 25,000 years B.P.) and Holocene episodes of valley entrenchment and partial backfilling. Morphostratigraphic equivalents, in order of decreasing age, include the Leasburg, Fillmore and (Historical) flood-plain and arroyo members of the Fort Selden group (Hawley and Kottlowski, 1969; Seager and Hawley, 1973). Major compositional features are similar to those of the older valley alluvium. Unit Qvy comprises arroyo channel, terrace and associated fan deposits, mainly brown to light-brown sand to sandy loam, with common pebble to boulder gravel zones, and some loam to clay. Surfaces of terraces and fans are usually within 10 ft of arroyo channel floors and are graded to local base level near the elevation of present Rincon Valley 'floor. Maximum thickness may approach 50 ft at the mouths of major arroyos just above the zone of intertonguing with Rio Grande deposits (Qvyf), but the unit is generally less than 15 ft thick. Its base is usually buried. Deposits are entirely nonindurated; zones of secondary carbonate accumulation are limited to thin coatings on gravel clasts, and to scattered filamentary bodies and small nodules in zones with low content of gravel. Mollusk shells and charcoal fragments are locally present in trace amounts.

Exposures of the younger valley alluvium-fluvial facies (Qvyf) are limited to the banks of the Rio Grande, irrigation canals, and drainage ditches. Dark-brown to grayish-brown surficial deposits are generally gravel-free, and range from clay

TABLE 2—Fossil mollusks from older valley alluvium (fluvial facies, Qvou), west wall of Bignell Arroyo near north edge of Sierra Alta quadrangle. (Collected and identified by Dr. A. L. Metcalf, University of Texas at El Paso. Refer to Metcalf, 1967, 1968.)

UTEP No.	Species	No. of specimens	Occurrences: Tortugas	Picacho	B-2 Alluv.	Fillmore
2281	*Biomphalaria* sp.	4		X		X
2290	*Cionella lubrica*	1	X		X	
2287	*Gastrocopta cristata*	95	X	X	X	X
2288	*Gastrocopta pellucida*	31	X	X	X	X
2289	*Gastrocopta armifera*	30	X		X	
2291	*Pupoides albilabris*	45	X	X	X	X
2292	*Pupoides hordaceus*	2	X	X		X
2293	*Pupilla sonorana* (?)	2				X
2284	*Vallonia cyclophorella*	1	X	X		
2286	*Vallonia perspectiva*	1	X		X	
2285	*Vallonia gracilicosta*	3	X	X	X	
2283	Succineids, sp. indet.	1	X	X	X	X
2282	*Discus cronkhitei* (fragment)	1	X	X		
2295	*Helicodiscus singleyanus*	3	X	X	X	X
2294	*Hawaiia minuscula*	2	X	X	X	X
2280	*Zonitoides arboreus*	4	X	X	X	

to sand in texture. Water well logs (Conover, 1954; Davie and Spiegel, 1967; King and others, 1971) indicate that most of the flood-plain area is underlain by a fining-upward sequence of late Quaternary river sediments ranging from 55 to 70 ft in thickness. Examination of surface exposures and well cuttings indicate that composition is similar to that of older fluvial deposits, except without cementation or appreciable buildup of zone of secondary carbonate accumulations. Mollusk shells and fragments of wood and charcoal have also been noted in the younger alluvium. The log of a well in the northwest corner of sec. 12, T. 20 S., R. 2 W. (King and others, 1971) shows a 68 ft-thick Qvyf sequence consisting of 5 ft of soil successively underlain by 42 ft of sand and 22 ft of gravel. A gray clay unit penetrated at 68 ft is interpreted as possibly belonging to the Santa Fe Group clay facies, a unit equivalent to the Rincon Valley Formation (Try). The base of the fluvial facies is probably unconformable on the Rincon Valley Formation throughout the map area except where the river beds are inset against Camp Rice and younger units along the valley margins. Carbon-14 dates of charcoal recovered from the Leasburg and Fillmore morphostratigraphic subdivisions of the younger valley alluvium (Hawley and Kottlowski, 1969; Seager and Hawley, 1973), show that river aggradation to essentially the present base level had occurred by 9,400 years B.P. and that fans associated with tributary arroyos have been encroaching on the flood plain during the past 7,500 years.

Colluvial and alluvial deposits (Qca), usually less than 6 ft thick, have been mapped in areas where they form a relatively continuous cover on older units. The Qca unit shows a great range in lithologic character and age. Most deposits are colluvium on steeper mountain- and valley-side slopes, but some undifferentiated alluvium in valley-floor and low gradient piedmont-slope positions has also been included. The bulk of the mapping unit is an equivalent of, and intertongues with, both subdivisions of the arroyo alluvium (Qvo and Qvy); a few bodies probably correlate with the younger piedmont-slope facies of the Camp Rice Formation. Older deposits may be partly cemented with carbonates of pedogenic origin.

Structure

Structural features in the Sierra Alta quadrangle are divided into two groups: 1) those associated with evolution of the resurgent Goodsight-Cedar Hills volcano-tectonic depression, and 2) late Tertiary features, mainly normal faults, that are superimposed across the older volcano-tectonic structures. In the Sierra de las Uvas, distinguishing faults related to resurgent doming from those faults that are more regional late Tertiary Basin and Range is sometimes difficult. Late Tertiary faults appear to be throughgoing, show evidence of more recent movement, are associated with fanglomerates of the Santa Fe Group, and appear to border the larger fault blocks.

VOLCANIC STRUCTURES

Major volcanic structures in the Sierra Alta quadrangle include 1) the eastern edge of the Sierra de las Uvas dome, 2) the Sierro Kemado sag, and 3) the northern exposed part of the Oligocene Cedar Hills vent zone (fig. 2).

SIERRA DE LAS UVAS DOME

The central part of the Sierra de las Uvas dome in the adjacent Souse Springs quadrangle has been described by Clemons and Seager (1973); evidence for its resurgent origin was presented by Seager (1973). In the Sierra Alta quadrangle only the eastern edge of the dome is present. From Hermantano Springs Ranch northward, Uvas flows on the dome flank dip 10 degrees eastward. The Hermantano Springs fault zone and numerous associated faults that splay from it have segmented the limb into a complex, braided pattern, especially between Broad Canyon and Sierra Alta. In the adjoining Souse Springs quadrangle these faults form a broad horsetail pattern across the northern flank of the Sierra de las Uvas dome. Most of the faults are downthrown to the west, toward the axis of the dome. Stratigraphic displacements range from about 1,000 ft near Silva Spring to a few hundred feet elsewhere.

South of Broad Canyon the original configuration of the Sierra de las Uvas dome has been modified by northwesterly tilting along the late Tertiary Ward Tank fault (section *E-E')*. Erosion of the footwall block has removed all the rocks in the upper part of the dome and produced a wide pediment surface on the Palm Park Formation. Dips on Palm Park or Bell Top strata from Broad Canyon and the Rattlesnake Hills southward are generally west to northwest, reflecting this uplift and tilting. The Road Canyon fault near the southwestern corner of the map is the northeastern boundary fault of an axial graben crossing the Sierra de las Uvas dome in the Souse Springs quadrangle.

Near Hermantano Springs Ranch a prominent northwest-trending horst exposing Palm Park beds is present near the boundary of the Sierra de las Uvas dome and Sierro Kemado sag (section *C-C')*. The horst trends northwestward obliquely across the eastern limb of the dome and continues into the Souse Springs quadrangle. The significance of the structure is not clear. It may represent the structurally high block created by down-to-the-east blockfaulting of late Tertiary age and down-to-the-west grabenfaulting in the crestal area of the Sierra de las Uvas dome. The fault that bounds the horst on the southwest appears to be part of the braided Hermantano Springs fault zone. The Quail Hills fault on the northwest has many of the characteristics of the late Tertiary faults.

The Quail Hills fault is down toward the Rio Grande, is exceptionally long and continuous, and appears to cut and offset faults associated with doming in both the Sierra Alta and Souse Springs quadrangles.

SIERRO KEMADO SAG

The broad belt of structurally lower north-dipping rocks between the Sierra de las Uvas dome and the Cedar Hills is named the Sierro Kemado sag. The structure appears to have originated as a poorly developed moat adjacent to the Sierra de las Uvas dome. The moat or sag, much modified by late Tertiary block faulting, is inferred to continue northwestward beneath the Hatch and Rincon valley and then westward around the northern plunge of the Sierra de las Uvas dome. There it may connect with the well-developed Goodsight Valley syncline on the western side of the dome (fig. 2). Thus, the moat may be contiguous with the Sierra de las Uvas dome on three sides. Upper Thurman lacustrine and alluvial beds appear to be restricted to the moat, at least in the area east and north of the dome.

South of Sierro Kemado cuesta, the sag, like the adjacent dome, has been modified by uplift and west to northward tilting along the Ward Tank fault. Although some dips in the Palm Park Formation south of the Sierro Kemado still suggest a northward-plunging syncline, most dips are northwest to west in agreement with the sense of more recent tilting of rocks adjacent to the fault.

OLIGOCENE CEDAR HILLS VENT ZONE

The Oligocene Cedar Hills vent zone (fig. 2) is interpreted to be a major zone of subsidence and contemporaneous volcanic activity at the eastern margin of the Goodsight-Cedar Hills volcano-tectonic depression (Seager, 1973). The vents associated with this zone include an ignimbrite dike, 21 flow-banded rhyolite domes and associated flows, and a diatreme and related tuff cone, all part of the Bell Top Formation. An Uvas Basaltic Andesite cinder cone and other scattered basaltic intrusives are present also. All were formed between 35 and 26 m.y. ago. The much younger Selden Basalt (9 m.y.) was apparently erupted from the same zone.

In the Sierra Alta quadrangle, northernmost exposures of vents in the zone occur in the southeastern corner of the quadrangle. Undoubtedly the vent zone continues northward in the subsurface, buried beneath younger rock units. Vent features exposed in the Sierra Alta quadrangle include an ignimbrite dike, a diatreme and associated tuff cone, a flow-banded rhyolite dome, and a cinder cone of Uvas Basaltic Andesite. Mutual relations of the first 4 are illustrated in fig. 7.

Ash-flow tuff 3 apparently is intrusive in the southeastern Sierra Alta quadrangle. In the vicinity of the diatreme near Porcupine Tank, the unit is in the form of a north-trending dike at least 1,000 ft wide, and exposed along strike for 1.5 miles. The dike intrudes older air-fall breccia north of the diatreme, but cuts Palm Park beds to the south. Small apophyses that diverge from the dike clearly project into older rocks proving the intrusive nature of the ignimbrite. The eastern contact of the dike dips generally westward at steep angles; foliation in the dike adjacent to the contact is also steep. In the interior of the dike at low levels of erosion, pumice fragments, flattened by compaction, dip 10 degrees westward, an attitude resulting from late Tertiary westward tilting of the Cedar Hills fault block. The western contact of the dike also dips west at steep angles. In most places, however, this contact is covered by younger air-fall tuff deposits or vesicular andesite flows. Much of the dike is bleached by alteration to light buff or cream. Dense welding is characteristic of some contacts, all of the apophyses, and of irregular internal patches within the dike.

Just west of Porcupine Tank, a diatreme cuts across the eastern contact of the ignimbrite dike and Palm Park beds. The circular feature is about 0.4 mile in diameter and is formed of centroclinally dipping air-fall breccia and tuff. The border of the diatreme is formed by a circular inward-dipping fault that has been invaded by a vesicular andesite ring dike along the western and southern sides (fig. 11 and section *E-E'*). The dike has fed a flow that is interbedded with air-fall tuffs preserved around the western side of the diatreme. These tuffs form the tuff cone that is symmetrical about either the diatreme or the flow-banded rhyolite dome located a few hundred yards to the southeast. Crossing the central part of the diatreme are numerous north-trending psilomelane veins 0.5 to 2.0 inches in width. These are associated with mild alteration and opalization of air-fall breccias.

The diatreme probably originated through one or a series of explosions that drilled a pipe upward through the older ignimbrite dike. The large volume of breccia and pumice blown out formed at least the lower part of the tuff ring. Subsidence of the pipe-filling was followed by, or concurrent with, intrusion of the vesicular andesite ring dike. Air-fall breccia above the andesite flow in the tuff cone resulted either from further explosions at the diatreme or from vent-clearing explosions that preceded intrusion of the flow-banded rhyolite dome to the southeast.

Flow-banded rhyolite domes in the Oligocene Cedar Hills fault zone are roughly circular features averaging 0.5 mile in diameter. Strike and dip measurements of flow banding show that most are funnel shaped, although a few

FIGURE 11—Southern half of diatreme exposed near Porcupine Tank in the Cedar Hills. Semicircular ridge is formed of various silicified tuff units along the ring fault. View toward west. Diameter of ridge on right side of photo is 0.4 mile.

are steeply inclined cylinders. Some are associated with short, thick, stubby, spherulitic rhyolite flows, but others apparently are not. At least one dome near Foster Canyon is composite, consisting of two or three types of crosscutting rhyolite. Only one dome is present in the Sierra Alta quadrangle. It is transected by the late Tertiary Cedar Hills fault so that only the western half of the dome is preserved. Limited strike-and-dip data suggest that the dome is essentially cylindrical at the present level of erosion.

About 1.5 miles north of these rhyolitic vents, Broad Canyon and its tributaries have exhumed an Uvas Basaltic Andesite cinder cone (Tuv). The cone is about one mile in diameter and has been segmented into halves by displacement on the Cedar Hills fault. The western flank of the cone is exposed in the Cedar Hills fault block just north of Broad Canyon (fig. 12). The eastern flank constitutes part of the next fault block to the east. Santa Fe gravels bury the presumed summit of the cone in the intervening graben. Initially dipping lapilli tuff and agglomerate constitute most of the cone. Locally dikes cut both flanks. Younger Uvas flows, fed in part by these dikes, buried most of the cone flanks.

LATE TERTIARY STRUCTURES

Major late Tertiary structural features in the Sierra Alta quadrangle are four normal faults: Cedar Hills fault, Ward Tank fault, Hackler Tank fault, and Black Hills fault. All are north- to northwest-striking faults, downthrown toward the east. Collectively, they appear to constitute the step-faulted western side of a late Tertiary graben, the deepest part coinciding approximately with the present position of the Rio Grande.

The Cedar Hills fault block (section *E-E'* and fig. 2) was uplifted and tilted westward in late Tertiary time by movement along the Cedar Hills fault.

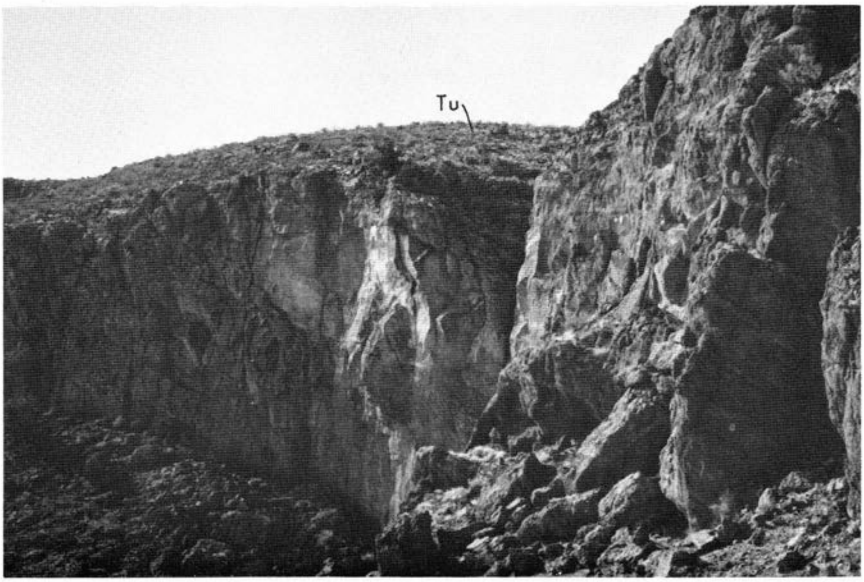

FIGURE 12—WESTERN FLANK OF UVAS BASALT CINDER CONE EXPOSED IN THE NORTHERN CEDAR HILLS. INITIALLY DIPPING CINDER BEDS AND AGGLOMERATE DIP WESTWARD (RIGHT) AND ARE OVERLAPPED BY UVAS FLOWS (Tu). VIEW TOWARD SOUTH; CLIFF IS ABOUT 120 FT HIGH.

Stratigraphic separation of about 1,200 ft is indicated by the juxtaposition of Santa Fe and Palm Park strata near Porcupine Tank. Northward the throw decreases until the fault dies out in Santa Fe beds north of Broad Canyon. In the Corralitos Ranch quadrangle to the south, stratigraphic separation increases to a maximum of about 1,800 ft near Foster Canyon. The fault zone appears to follow closely the strike of the Oligocene Cedar Hills vent zone. Although evidence suggests that the Oligocene structure was downthrown to the west (Seager, 1973), late Tertiary movements were clearly in an opposite sense.

At least three episodes of movement occurred along the Cedar Hills fault. The earliest, about 26 m.y. ago, is indicated by fanglomerate, derived from rhyolite domes in the Cedar Hills block, interbedded with Uvas Basaltic Andesite. The Uvas cinder cone described earlier also apparently formed on the Cedar Hills fault at this time. A second interval of faulting is recorded by the Rincon Valley Formation, about 9 m.y. old, whose source, in the *Selden* Canyon area, was also the Cedar Hills fault block. A third interval of faulting in Pliocene time is indicated by major offset of Rincon Valley Formation by movement on the Cedar Hills fault.

Longest of the late Tertiary faults in the quadrangle is the Ward Tank fault. This north-trending fault can be traced almost continuously from the vicinity of Interstate 10 west of Las Cruces, northward to Sierro Kemado (fig. 2). There it splits, and a western segment, Sierro Kemado fault, continues northwestward several miles farther toward Hatch. Throughout the length of the Ward Tank fault, Santa Fe strata are in contact with various older rock units along a fault surface which dips between 65° and 75° E.

Movement on the Ward Tank fault is primarily responsible for uplift and northwesterly tilting of the Sierra de las Uvas fault block. Stratigraphic separation appears to reach a maximum of about 2,000 to 2,500 ft in the area near, and to the south of, the Rattlesnake Hills. Seven to ten degrees of northwesterly tilting that accompanied this uplift appears to be responsible for the present northwesterly plunge of the Sierra de las Uvas dome and for its lack of closure on the southeastern side. Removal of this tilt indicates the southeastern part of the dome near Bell Top Mountain originally plunged southeastward, completing the domal structure.

The Rincon Valley Formation exposed adjacent to the fault in the Rattlesnake Hills, and near Ward Tank consists of very coarse boulders of Bell Top ash-flow tuffs (fig. 8). Doubtless when these deposits accumulated, a prominent escarpment formed by Bell Top ash-flow tuffs was adjacent to the fault. Today the escarpment is 3 to 4 miles farther west; pedimented Palm Park beds form the immediate footwall. Erosion of the Sierra de las Uvas block probably produced most of the Rincon Valley Formation that fills the graben and half-graben system east of the Ward Tank fault. Major post-Rincon Valley displacement has occurred along the fault; middle Pleistocene or younger movement is recorded by a continuous fresh scarp, about 10 ft high, cutting the Jornada I surface and underlying Camp Rice piedmont-slope alluvium between Horse Canyon and the Rattlesnake Hills (sections ***B-B'*** and ***D-D')***. Similar offsets and warping of the Jornada surface occur along the Sierro Kemado fault (sections ***B-B'*** and *C-C')*.

The eastern edge of the Quail Hills is formed in part by the Hackler Tank fault. This fault is arranged en echelon with, and to the northwest of, the Ward Tank and Sierro Kemado faults. Maximum stratigraphic separation is difficult to estimate, but may be several hundred feet in the vicinity of Hackler Tank. The fault is buried along most of its length by conglomerate of the Rincon Valley Formation. It is exposed near Hersey Tank and is inferred farther northwest by a

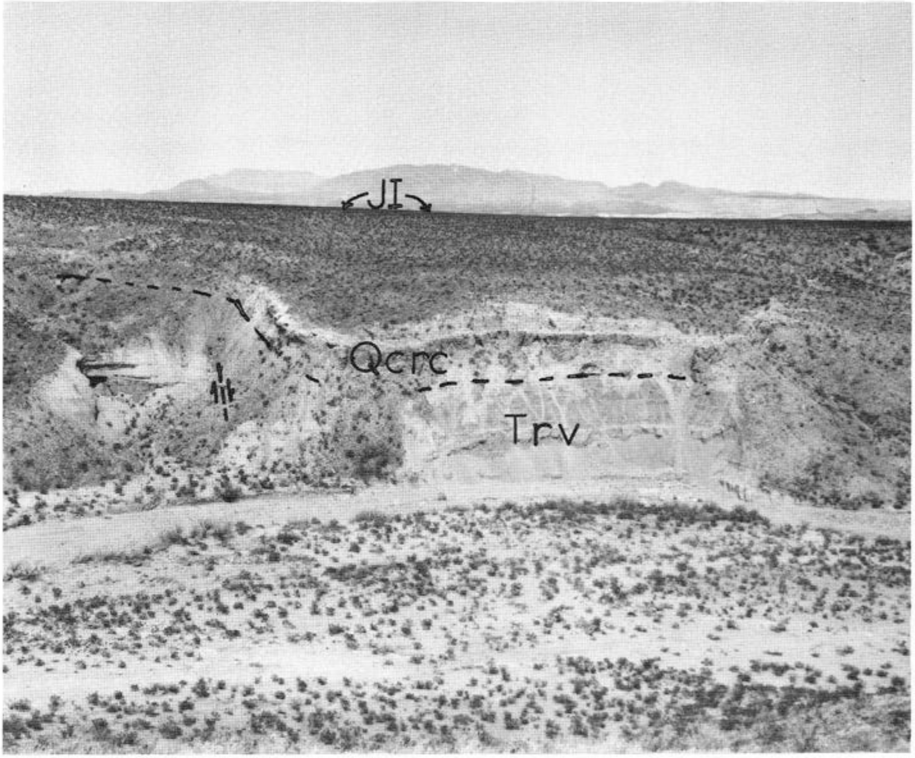

FIGURE 13—VIEW OF HACKLER TANK FAULT EXPOSED IN NORTH WALL OF ANGOSTURA ARROYO. JORNADA I SURFACE (JI) AND ASSOCIATED CAMP RICE PIEDMONT AND FLUVIAL DEPOSITS (Qcrp/Qcrf/Qcrc) ARE DOWNWARPED ABOUT 20 FT TO THE EAST ALONG THE NORTH-TRENDING HACKLER TANK FAULT. THE UNDERLYING RINCON VALLEY FORMATION (Trv) IS FAULTED BUT THE AMOUNT OF DISPLACEMENT IS UNKNOWN.

straight escarpment of Uvas Basaltic Andesite against which Rincon Valley strata are inset. Thus, the fault appears to predate the Rincon Valley Formation. Middle Pleistocene or younger movement is indicated, however, along two small segments of the fault by warping or breaking of the Camp Rice piedmont units and the Jornada I surface near the northwest corner of the map. About 20 ft of fault displacement can be observed in the Santa Fe Group in the north wall of Arroyo Angostura (fig. 13).

The Quail Hills are bordered on the west by the Quail Hills fault. The fault forms the eastern edge of the prominent horst east of Hermantano Springs. Stratigraphic separation is at least 800 ft, perhaps considerably more. This fault appears to mark the southwestern edge of the wide graben containing the Rio Grande, and separates the predominantly down-to-the-east late Tertiary faults of the graben from down-to-the-west faults related to the Sierra de las Uvas dome. The Quail Hills fault is also noteworthy because it truncates older faults associated with the dome, and because of the slices, wedges, and blocks of various formations caught in the fault zone.

Geologic History

Precambrian and early to middle Paleozoic rocks are not exposed in the Sierra Alta quadrangle. Paleozoic marine limestone, dolomite, sandstone, and shale occur in nearby areas, and, presumably are present in the subsurface in the Sierra Alta quadrangle. Hueco Limestone and Abo sandstone (both Wolfcampian) exposed in the Rattlesnake Hills, were apparently deposited in tidal flat to shallow marine environments that fluctuated with supratidal, probably deltaic, conditions. The Yeso and San Andres Formations (Leonardian) and Cretaceous strata are present in the Caballo and San Andres Mountains (Kelley and Silver, 1952; Kottlowski and others, 1956), but are missing in the Sierra Alta quadrangle probably because of early Tertiary erosion associated with the Laramide. Folded Hueco-Abo strata in the Rattlesnake Hills are also a result of Laramide deformation, but the fanglomerate associated with uplifts of this age elsewhere (Seager and others, 1971), is absent. Palm Park (Eocene) strata overlie the deformed Permian sequence with angular unconformity. Judging from the uneven thickness of the Palm Park Formation, considerable topographic relief was present by Eocene time.

The Tertiary rock record is represented by volcanic and volcaniclastic rocks of Eocene to Oligocene age and by Miocene to Pliocene fanglomerate associated with Basin and Range faulting. Palm Park strata are nearly all epiclastic, derived from andesitic to latitic flows, tuffs, and subvolcanic plutons. River, overbank, and mudflow deposits predominate, forming a plateau-like sequence of variable thickness (mostly greater than 2,000 ft) that may represent a thick fan or bajada sequence of unknown source.

Development of the Goodsight-Cedar Hills volcano-tectonic depression commenced in early Oligocene time and continued until the end of the epoch. About 650 ft of ash-flow tuff and lavas accumulated near the depression axis in the western part of the Sierra Alta quadrangle together with a nearly equal thickness of tuffaceous sedimentary rocks and tuff. Eruptions of the earlier ash flows were accompanied by intrusion of rhyolite domes and dikes, and formation of diatremes, sunken areas, and tuff cones along the Oligocene Cedar Hills vent zone bordering the depression on the eastern side. This complex of flow-banded rhyolite and tephra is interbedded between ash-flow tuffs 2 and 4, indicating an age of between 35 to 39 m.y. An alluvial fan derived from the dome-flow complex is interbedded in the sedimentary part of the volcano-tectonic filling, as are numerous fluvial channel lenses derived from Palm Park strata that formed the eastern rim. The depression apparently was a broad, regional sag bordered on the east by a north-trending zone of vents and faults. In this respect the depression differs fundamentally from the well-known, steep-sided, circular cauldrons of the Jemez, San Juan, and other areas of the western interior of the United States.

Rhyolitic volcanic activity was interrupted about 26 m.y. ago with eruption of Uvas Basaltic Andesite. In the Sierra Alta quadrangle about 400 ft of basaltic andesite flows and associated tephra were deposited on the flank of a broad basaltic shield whose main vents and summit were located west of the Sierra Alta quadrangle near the center of the volcano-tectonic depression. A well-developed cinder cone, buried partly by flows, formed along the Oligocene Cedar Hills vent zone on the eastern flank of the shield.

Between 26 m.y. ago and 20 to 24 m.y. ago the central part of the volcanic pile was arched to form the Sierra de las Uvas dome. In the Sierra Alta quadrangle the Road Canyon fault and Hermantano Springs fault zone are part of a complex graben system on the crest and northeastern flank of the dome. The Sierro Kemado sag appears to be part of a poorly developed moat-like syncline adjacent to the dome. Upper Thurman rhyolitic tuffaceous sediments appear to be lacustrine, fluvial, and deltaic deposits that collected in the subsiding sag. Locally, in adjacent areas they grade upward into Santa Fe fanglomerate.

In some respects the Goodsight-Cedar Hills volcano-tectonic depression appears to be a forerunner of Basin and Range structure. The depression is a northerly elongated structure aligned parallel to the regional trend of late Tertiary faults. Locally, Oligocene faults or lines of vents became the sites of late Tertiary faulting. This appears to be true of the late Tertiary Cedar Hills vent and fault zone. The Sierro Kemado sag received sedimentation at least locally to the inception of rifting, and the anomalous northwest and northeast fault patterns in the Goodsight and Rincon Valleys appear to be controlled by the geometry of the Sierro Kemado sag and Goodsight Valley syncline. Probably volcano-tectonic features of Oligocene to Miocene age significantly control late Tertiary regional fault patterns or modify them locally (Seager, 1973).

Basin and Range faulting commenced about 26 to 24 m.y. ago in the Rio Grande rift (C. E. Chapin, personal communication, 1974). Earliest evidence of this deformation in the Sierra Alta quadrangle is the Uvas cinder cone and the fanglomerate interbedded in Uvas Basaltic Andesite. The cinder cone apparently formed on the late Tertiary Cedar Hills fault, indicating that throughgoing faulting of the Rio Grande rift style was in progress at least 26 m.y. ago. Fanglomerate derived from the rising Cedar Hills fault block became interbedded with Uvas flows that spread southward from the cinder cone. The earliest Santa Fe fanglomerates of early Miocene age (Hayner Ranch Formation) exposed at San Diego Mountain (Tonuco Uplift) and in the Rincon Hills document further rift development by fan deposition in deep basins no longer part of the landscape (Seager and others, 1971; Seager and Hawley, 1973). Much of the early Santa Fe fanglomerate was derived from ancestral Sierra de las Uvas and Cedar Hills. Middle to late Miocene Santa Fe deposits (Rincon Valley Formation) also were derived from these uplifts, and locally completely buried the Cedar Hills block, and partly buried the pedimented edges of the Sierra de las Uvas. About 9 m.y. ago an olivine basalt, Selden Basalt, was erupted onto a fan surface of the Rincon Valley Formation in the present Selden Canyon area. Post Rincon Valley (Pliocene?) displacement on the Ward Tank, Cedar Hills, Quail Hills, and other faults raised the Cedar Hills, Quail Hills, and Sierra de las Uvas essentially to their present positions. Faulting of the same age in adjoining quadrangles also segmented the early rift basins into smaller intrabasin horsts and grabens, such as the Rincon Hills and Tonuco Uplift. Comparatively small-scale faulting continued into the Quaternary.

The main points of Quaternary history have been mentioned in sections on stratigraphy. Valley and canyon elements of the present topography are the result of river and arroyo erosion. However, many other landscape features are the product of constructional (basin- and valley-filling) processes. Relatively recent structural adjustments have occurred in areas of limited extent in or adjacent to the quadrangle. Maximum local displacement along monoclinal warps and high-angle faults in early to middle Pleistocene time probably did not greatly exceed 250 ft (Hawley and Kottlowski, 1969; Seager and others, 1971; Seager and Hawley, 1973). Middle to late Pleistocene displacement that affected the Jornada I surface and youngest Camp Rice deposits and possibly the oldest valley alluvium, were generally less than 20 ft. Considering the thickness of Quaternary units and the local topographic relief, structural displacements of such magnitude have certainly been significant, and have controlled the general position of the river valley and many segments of tributary valleys.

During early Pleistocene, and possibly latest Pliocene time, a widespread piedmont erosion surface now preserved as both pediments and suballuvial benches (Lawson, 1915) was developed across Rincon Valley and older formations flanking the Sierra de las Uvas. This surface, which includes the unconformity at the base of the Camp Rice Formation, probably was graded to a precursor of the Rio Grande that shifted widely over the Jornada del Muerto basin floor east and west of the Tonuco Uplift. The ancestral Angostura, Broad Canyon, and Coyote Canyon stream systems, heading in the Sierra de las Uvas highlands (Clemons and Seager, 1973), were the main agents of slope gradation above the zone also affected by erosional activity of the ancient river (above present elevation of about 4,500 ft). The upper Broad Canyon system (watershed area above Silva Spring now about 15 square miles, with elevations ranging from 4,800 to 6,600 ft; Clemons and Seager, 1973) was the major source of water and sediment in the area bounded by the present valleys of Reed and Broad Canyon arroyos. Only the Burro Hill and Sierro Kemado areas, and the hills capped by Uvas Basaltic Andesite northeast of Hermantano Springs escaped erosion to levels that are usually within 100 ft of the existing arroyo-valley floors. The present relief between the highest outlier, Sierro Kemado cuesta, and the apices of Camp Rice alluvial fans along Broad Canyon and Hersey Arroyo is about 500 ft. Valleys flanking these three upland areas contained fan bays, whose relict deposits are designated Qcru or Qcrp/Qcrc on the geologic map. Differential movement of various structural blocks west of the Sierro Kemado fault resulted in local uplift of older segments of the Camp Rice piedmont facies, incision of fan-head and fan-bay trenches, and marked shifts in the loci of gradational activity over the central part of the quadrangle.

Throughout early to middle Pleistocene time, deposition on the piedmont slopes was concurrent with the general aggradation of broad Jornada del Muerto basin floor. More than 350 ft of fluvial sediments were deposited during a period of more than one million years (including parts of the Blancan and Irvingtonian land mammal ages) by river distributaries fanning out from the narrow Palomas Basin floor above Hatch. Studies of nearly complete Qcrf sections in Rincon and San Diego Mountain quadrangles (Hawley and others, 1969; Seager and others, 1971; Seager and Hawley, 1973) show that basin sedimentation at any given locality was episodic and that the locus of deposition shifted widely during aggradation of a plain that extended some 15 miles between the toes of the Sierra de las Uvas and San Andres piedmont slopes. The aggrading floor of the Lake Cabeza de Vaca basin near El Paso (Strain, 1966, 1970; Hawley, 1969; Reeves, 1969) encompassing parts of the present Mesilla, Hueco, and Los Muertos Bolsons, formed the regional base level for river activity during much of this interval.

Large remnants of the constructional surfaces of Camp Rice deposits, as well as their erosional extensions on mountain-foot slopes (rock pediments), still exist in the region. In order of decreasing age, these include the Rincon (basin floor and piedmont slope), La Mesa (extensive basin floor), and Jornada I (extensive piedmont slope and restricted basin floor) geomorphic surfaces (Ruhe, 1964; Hawley, 1965; Gile and Hawley, 1968; Hawley and Kottlowski, 1969; Seager and Hawley, 1973). Only piedmont-slope components are preserved in Sierra Alta quadrangle. The oldest surfaces occur in areas such as the Ward Tank and the

Sierro Kemado-Hackler tank fault zones (and in the Rincon Hills) where differential uplift raised large segments of the ancient basin landscape above the level of aggradational activity, while elsewhere Camp Rice deposition continued.

Studies by Kottlowski (1958), Ruhe (1962), Strain (1966, 1970), Metcalf (1967, 1969), Hawley and Kottlowski (1969), and Reeves (1969) indicate that initial river and arroyo valley entrenchment in the El Paso to Elephant Butte area occurred in middle Pleistocene (Irvingtonian) time. The triggering event is presumed to have been final integration of ancestral upper and lower Rio Grande systems, and development of through drainage to the Gulf of Mexico.

Middle through late Quaternary valley evolution resulted in the formation of the stepped sequence of graded geomorphic surfaces located between the present valley floors and the Jornada I piedmont slopes. Correlation of geomorphic surfaces and associated fills (Tortugas, Picacho, and Fort Selden morphostratigraphic units; and Qvo and Qvy rock units) is possible over long distances upstream and downstream from the Rincon Valley (Ruhe, 1964; Hawley, 1965; Metcalf, 1967, 1969) indicating that other than local factors played a major role in the development of valley landscapes. The effects of episodic shifts in climate from the semiarid to arid conditions, associated with pluvial and interpluvial intervals, were apparently the most important influences; however, structural deformation may have had significant local effects.

A model of river valley evolution has been developed that seems to fit the available information on the age of stratigraphic units, erosional and depositional features, fossil molluscan faunas, and paleoclimatic fluctuations recognized throughout the upper Rio Grande watershed (Kottlowski, 1958; Metcalf, 1967; Hawley and Kottlowski, 1969). This model or scheme of river activity (particuularly well stated by Schumm, 1965, p. 790-792) includes the following stages: entrenchment of the axial valley and lower segments of arroyo valleys during waxing and full pluvial intervals; deposition during waning pluvial and early interpluvial times; and relative stability during the remainder of a given interpluvial interval. Late Pleistocene pluvial and interpluvials appear to correlate, respectively, with glacial and interglacial intervals recognized in glaciated parts of the Rio Grande drainage basin in southern Colorado and northern New Mexico (Birkeland and others, 1971).

Carbon-14 dating of units Qvy and Qvyf (Fort Selden) of late Quaternary age demonstrates that the Holocene interval (characterized by relatively low river discharge, sparse vegetative cover on local watersheds, and high sediment yield from tributary arroyos) was a time of either valley-floor aggradation or local base-level stability and steady state conditions. Significant encroachment of arroyo fans onto the river flood plain has occurred during the past 7,500 years, with local episodes of arroyo incision triggered by trimming of fan toes by laterally shifting river channels. The generally sandy to clayey fills (with some gravelly channel zones) occupying the upper 30 to 40 ft of section beneath the river valley floor probably also date from this period.

The preceding episode of deep valley entrenchment (from local base levels some 60 to 80 ft above, to as much as 75 ft below present flood-plain level) appears to correlate with the last major (late Wisconsinan, Pinedale) expansion of mountain glaciers and pluvial lakes recognized to have occurred soon after 25,000 years B.P. elsewhere in the Southern Rocky Mountain and Basin and Range Provinces (Birkeland and others, 1971). Much greater river discharge, better vegetative cover, and less sediment production from local arroyo watersheds appear to have been the most significant factors controlling the initiation of that episode of deep valley incision. The bulk of the gravelly to sandy fluvial sediments comprising the basal 30 to 40 ft of the inner valley fill were probably deposited during waning stages of the Wisconsinan glacial-pluvial interval subsequent to 18,000 years B.P.; the flood plain had aggraded to a level close to that of the present valley floor by about 9,400 years B.P. (Hawley and Kottlowski, 1969). Major degradation-aggradation-steady state sequences of fluvial activity appear to have occurred at least twice prior to late Wisconsinan-Holocene events just described and following initial river-valley incision. The older valley alluvium units Qvo and Qvof (Picacho and Tortugas morphostratigraphic units) are the product of depositional phases of these sequences involving partial backfilling of valleys cut during intervals of degradation.

Ground Water

The only aquifer in the mapped area capable of producing large quantities of good quality water is the fluvial facies of the younger valley alluvium (Qvyf) in the Rincon Valley. A number of irrigation wells capable of sustained production at rates of hundreds of gallons per minute have been developed in sand and gravel zones of this unit (Conover, 1954; King and others, 1971). Water table depths usually range from 5 to 15 ft beneath the river flood plain. The fluvial facies of the upper Santa Fe Group, the major aquifer in the region (Davie and Spiegel, 1967; King and others, 1971), appears to be entirely above the water table except for a small area in the northeast corner of the quadrangle.

Elsewhere in the area production is limited to widely scattered localities where small quantities of potable water (a few gallons per minute to about 20 g.p.m.) have been obtained from shallow, and normally localized, zones of saturation in rocks of Tertiary age and Qvy arroyo deposits. As a general rule, medium- to coarse-grained elastic facies of the Rincon Valley, Bell Top, and Palm Park Formations have a fine-grained matrix component and are relatively impermeable. Ash-flow tuffs and lavas of Bell Top-Uvas sequence, however, could locally have significant fracture porosity and permeability. The only perennial spring in the area, Hermantano Spring, produces water from a faulted zone in the Bell Top Formation. Poorly welded zones of ash-flow tuff 3 also have good porosity and permeability.

Most of the existing and abandoned wells and home sites are located near former springs and seeps in channels of major arroyos. Production from livestock and domestic wells drilled at such sites appears to have caused enough decline in local water tables to dry up these areas of former surface discharge.

Records on well construction and materials penetrated are not available. However, geologic information obtained at several localities shows how various structural, stratigraphic, and physiographic features permit the storage and recharge of enough water to support low, but sustained, yields from shallow subsurface reservoirs.

A simple example of structural and physiographic controls on ground-water occurrence is at Loco well (W 1/2 sec. 35, T. 19 S., R. 3 W.). A fault block of Uvas Basaltic Andesite west of the Hackler Tank fault forms a dam across Arroyo Angostura, while a downfaulted block of the Rincon Valley Formation upstream from the horst comprises the reservoir unit. The site is particularly favorable in terms of recharge potential, because of the 7-square-mile surface-water catchment area upstream from the well.

A combination of factors control the ground-water reservoir in the area of the Hersey Place well in Broad Canyon (NE 'A sec. 6, T. 21 S., R. 2 W.). Relatively impermeable beds in a west-tilted block of the Palm Park Formation form a dam across the arroyo, while more permeable zones of the formation downdip and upstream from the barrier form at least part of the ground-water reservoir. The zone of saturation probably also extends into the arroyo (Qvy) sediments. A 19-square-mile surface-water catchment area above the site indicates very favorable recharge conditions.

The Hayner Ranch well site, located on a Hersey Arroyo tributary in the NW 'A sec. 9, T. 20 S., R. 2 W., appears to be a stratigraphic-trap reservoir. The well is completed in essentially undeformed Rincon Valley strata in a narrow transition zone between the fanglomerate (Trvc) and basin-floor (Trv) facies. Impermeable Try mudstones downstream from the site serve as the barrier, and sandstones and pebbly sandstones of the transition zone comprise the reservoir. These facies relationships can be observed in outcrops along the more deeply entrenched valley of Bignell Arroyo, 1.25 miles northwest of the well (NW 1/4 sec. 5, T. 20 S., R. 2 W.). The small surface-water catchment area (about half a square mile) upstream from the site indicates that ground-water inflow from other parts of the Hersey Arroyo watershed is contributing to the recharge of the aquifer.

The preceding examples illustrate geologic settings conducive to the recharge, storage, and recovery of ground water in quantities usually adequate for livestock and domestic needs. The conditions described at Loco well and Hersey Place exist in other parts of the quadrangle, with particularly favorable sites located in Broad and Coyote Canyons near Kimball Place and in the center of sec. 35, T. 20 S., R. 2 W. Conditions at the Hayner Well site are probably duplicated at a number of places along the Trvc/Try transition zone extending east-southeast from sec. 36, T. 19S., R. 3 W. to sec. 11, T. 20 S., R. 2 W.

Nonmetallic Resources

Sand, gravel, caliche, and clay are plentiful in the Rincon Valley area, particularly in the Camp Rice and younger deposits in bluffs adjacent to the Rio Grande. The reader is referred to the discussion in the Rincon quadrangle report (Seager and Hawley, 1973).

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APPENDIX A—Measured Sections

SECTION 1—SIERRA ALTA

Formations: Upper part of Bell Top Formation and lower part of Uvas Basaltic Andesite
Location: North slope of Sierra Alta, sec. 14, T. 20 S., R. 3 W.; west-central Sierra Alta quadrangle.
Measured by: R. E. Clemons
Date: August 5, 1972

Unit	Description	Thickness (ft)
	Uvas Basaltic Andesite (total thickness)	407
17	Basaltic andesite, medium-dark-gray (N4), dense; platy joints; scoriaceous tops; slope- and ledge-former	30
16	Basaltic andesite, medium-dark-gray (N4), dense, vesicular; ledge-former	38
15	Covered slope with abundant red scoria	55
14	Basaltic andesite, grayish-black (N2), dense, vesicular; scoriaceous tops; two flows; cliff-former	42
13	Basaltic andesite, medium-dark-gray (N4), vesicular; platy joints; probably several flows; partly covered slope	80
12	Basaltic andesite, dark-gray (N3), dense, vesicular; ledge-former	20
11	Covered slope	50
10	Basaltic andesite, grayish-black (N2), dense, vesicular; several feet of angular flow-breccia at base; ledge-former	25
9	Sandstone, fine-grained, moderate-reddish-brown (10R4/6), poorly bedded; contains vesicular basaltic andesite cobbles and boulders; slope-former	15
8	Basaltic andesite, brownish-black (5 YR2/1), massive, vesicular; dark-reddish-brown (10R3/4) sandstone lenses; ledge- and slope-former	27
7	Basaltic andesite, grayish-black (N2), dense, vesicular; lower 5 to 10 ft composed of bombs and blocks in yellowish-brown (10YR6/4) matrix	25
	Bell Top Formation (total thickness)	278
	Upper sedimentary member (total thickness)	208
6	Sandstone, fine-grained, moderate-yellowish-brown (10YR5/4), thin-bedded, cross-bedded, porous; few pebbles of volcanic rock fragments; slope-former	60
5	Sandstone, medium-grained, tuffaceous, pale-yellowish-brown (10YR 6/2); poorly sorted with few granules of volcanic rock fragments; some pumice in lower part; few conglomeratic lenses; poorly bedded; slope-former	84
4	Air-fall tuff, grayish-pink (5R8/2), massive, no bedding; angular, white pumice fragments up to 1-inch diameter; slope-former	29
3	Sandstone, fine-grained, tuffaceous, yellowish-gray (5Y7/2), thin- to medium-bedded, porous; slope-former	35
2	Covered slope with occasional small exposure of tuffaceous sandstone similar to unit 3	50
	Tuff 6 member	
1	Vitric-crystal ash-flow tuff, pale-red (10R6/2), medium-welded; slightly darkened, flattened pumice fragments; sanidine, quartz, plagioclase, and biotite crystals; ledge-former; base not exposed	70

SECTION 2—HERMANTANO SPRINGS

Formations: Upper part of Palm Park Formation, Bell Top Formation, and lower part of Uvas Basaltic Andesite
Location: Ridge northwest of Hermantano Springs Ranch, SE¼ sec. 23, T. 20 S., R. 3 W.; west-central Sierra Alta quadrangle.
Measured by: R. E. Clemons
Date: September 7, 1972

Unit	Description	Thickness (ft)
	Uvas Basaltic Andesite	
20	Basaltic andesite, grayish-black (N2), dense, vesicular; several flows with scoriaceous tops	50+
	Bell Top Formation (total thickness)	722
	Upper sedimentary member (total thickness)	211
19	Sandstone, very fine-grained, pale-reddish-brown (10R4/4), poorly sorted, massive-bedded, well-indurated; few small pebbles; ledge-former	15
18	Sandstone, fine-grained, light-brown (5YR6/4), poorly sorted, medium-bedded, friable; few small pebbles; slope-former	75
17	Sandstone, medium-grained, pale-yellowish-brown (10YR6/2), poorly sorted, thin- to medium-bedded, very friable; no cement; abundant thin lenses of granule-conglomerate with prominent festoon crossbedding; granules are very angular, dark-colored volcanic rock fragments; slope-former	95
16	Pebble conglomerate, sandy, grayish-pink (5R8/2), poorly sorted; few rounded boulders up to 12-inch diameter; smaller fragments subrounded to very angular; channel fills; poorly bedded; slope-former	16
15	Covered slope, light-colored sandstone and conglomerate	10
	Tuff 6 member	
14	Vitric-crystal ash-flow tuff, pale-red (10R6/2), medium-welded; slightly darkened pumice fragments up to 4-inch diameter, cause cavities on weathered surface; sanidine, plagioclase, quartz, and biotite crystals; ledge-former	45
	Middle sedimentary member	
13	Poorly exposed in slope; friable, pale-yellowish-brown (10YR6/2), fine- to medium-grained sandstone near base; friable, grayish-orange-pink (5YR7/2) very fine grained to fine-grained sandstone at top; few rounded andesite-latite cobbles in slope debris	105
	Tuff 5 member	
12	Crystal-vitric ash-flow tuff, pale-red-purple (5RP7/2), medium-welded; sanidine, plagioclase, quartz, and biotite crystals; ledge-former	75
	Tuff 4 member (total thickness)	60
11	Vitric-crystal ash-flow tuff, pale-grayish-red (5R7/2), moderately welded; abundant, flattened, darkened, pumice fragments; few lithic fragments; sanidine and biotite crystals; slope-former	10
10	Vitric-crystal ash-flow tuff, grayish-red-purple (5RP4/2), medium-welded; similar to unit 11; ledge-former with poorly developed columnar joints	25
9	Vitric-crystal ash-flow tuff; same as unit 10, except poorly welded and slope-former	25
	Tuff 3 member (total thickness)	93
8	Vitric ash-flow tuff, moderate-orange-pink (5YR8/4), poorly welded; porous, abundant, small, unflattened, darkened, pumice fragments; slope-former	38
7	Vitric ash-flow tuff; similar to unit 8, except moderately welded; ledge-former	35
6	Vitric ash-flow tuff; similar to unit 8; includes some tuffaceous sediments; slope-former	20
	Basalt member	
5	Basalt, olivine-bearing, medium-dark-gray (N4); 2 to 6 ft of scoriaceous breccia at base; dense, platy-jointed above; scoriaceous top; ledge-former	41
4	Sandstone, fine-grained, tuffaceous, light-brown (5YR6/4), poorly sorted, few basalt cobbles; poorly indurated; slope-former	22
	Tuff 2 member	
3	Vitric ash-flow tuff, grayish-pink (5R8/2), medium-welded; abundant, flattened, pale to moderate red pumice fragments; few biotite flakes; generally a slope-former but middle part forms ledges locally	70
	Palm Park Formation (total thickness)	61+
2	Conglomerate, sandy, tuffaceous; light-gray to grayish-red-purple colors; poorly sorted, clay to 3-ft diameter boulders, majority cobble-size; subrounded to well-rounded latite-andesite clasts; poorly indurated; slope-former	36
1	Sandstone, fine-grained, tuffaceous; pale-red (5R6/2),. poorly sorted, poorly indurated; slope-former; base not exposed	25

SECTION 3—BASIN TANK NORTH

Formation: Bell Top Formation (base through tuff 6)
Location: Section starts in small arroyo 0.15 mi. north of Basin Tank, NW¼ sec. 36, T. 20 S., R. 3 W., and runs north into SW¼ sec. 25; southwest corner of Sierra Alta quadrangle.
Measured by: R. E. Clemons
Date: August 6, 1972

Unit	Description	Thickness (ft)
	Bell Top Formation (total thickness)	611
	Tuff 6 member (total thickness)	60
16	Vitric-crystal ash-flow tuff, grayish-pink (5R8/2), medium-welded; abundant, small, flattened, pumice fragments; biotite, sanidine, plagioclase, and quartz crystals; ledge-former	25
15	Vitric-crystal ash-flow tuff; same as unit 15, except not as medium-welded; slope-former	35
	Middle sedimentary member	
14	Sandstone, fine- to medium-grained, poorly sorted, tuffaceous, light-brownish-gray (5YR6/1), poorly bedded, friable; sand is mostly angular crystal fragments; slope-former; mostly covered	57
	Tuff 5 member (total thickness)	125
13	Crystal-vitric ash-flow tuff, pale-red-purple (5RP7/2), moderately welded; abundant white pumice fragments and black biotite flakes; sanidine and quartz crystals; slope-former; gradational into unit 12	30
12	Crystal-vitric ash-flow tuff; same as unit 13, except medium-welded; cliff-former; crude columnar joints	55
11	Crystal-vitric ash-flow tuff; similar to unit 13; slope-former	40
	Tuff 4 member (total thickness)	57
10	Vitric-crystal ash-flow tuff, pale-grayish-red (5R7/2) to grayish-red-purple (5R4/2), medium-welded; abundant, flattened, darkened, pumice fragments up to 8 inches in length; few ash-flow tuff lithic fragments and golden biotite flakes	42
9	Covered slope; may include a few feet of tuff number 3 as well as base of tuff number 4	15
	Tuff 3 member (total thickness)	121
8	Vitric ash-flow tuff, very pale orange (10YR8/2), moderately welded, porous; abundant darkened pumice fragments; slope-former	70
7	Vitric ash-flow tuff, orange-pink (10R7/4); same as unit 8, except medium-welded; cliff-former; poorly developed columnar jointing	40
6	Vitric ash-flow tuff, grayish-orange-pink (10R8/2), poorly welded, friable, porous; slope-former	11
5	Conglomerate and sandstone, pale-red-purple (5RP6/2) to grayish-pink (5R8/2), poorly sorted, poorly bedded, poorly indurated; well-rounded andesite-latite pebbles and cobbles scattered in tuffaceous sand matrix; few boulders up to 1 ft diameter; slope-former	52
	Basalt member	
4	Basalt, olivine-bearing, brownish-black (5YR2/1), dense; platy joints; vesicular base and crumbly, scoriaceous, irregular top	68
3	Conglomerate; similar to unit 5	8
	Tuff 2 member	
2	Vitric ash-flow tuff, pale-red-purple (5RP6/2), medium-welded; abundant pale-red, flattened pumice fragments; slope-former	63
	Palm Park Formation	
1	Sandstone, very fine grained, tuffaceous, grayish-pink (5R8/2) to pale-red (5R6/2), thin-bedded, poorly indurated; slope-former; weathers to badland topography south of Basin Tank	4+

SECTION 4–HERSEY PLACE-BASIN TANK

Formation: Upper Palm Park and lower part of Bell Top Formation
Location: Section starts 0.3 mi. southeast of Hersey Place in SE¼ sec. 6, T. 21 S., R. 2 W.; runs westward up arroyo to sec. 1, T. 21 S., R. 3 W.; then northwestward up ridge to center of sec. 1; up south slope of hill on line between sec. 1 and sec. 36, T. 20 S., R. 3 W.; up south slope of small hill just south of Basin Tank; southwest corner Sierra Alta quadrangle.
Measured by: R. E. Clemons
Date: August 6, 1972

Unit	Description	Thickness (ft)
	Bell Top Formation	
	Tuff 2 member	
20	Vitric ash-flow tuff, pale-red-purple (5RP6/2), medium-welded; abundant pale-red, flattened, pumice fragments; sharp contact with Palm Park conglomerate; ledge-former at top of hill	20
	Palm Park Formation (total thickness)	1018
19	Conglomerate, tuffaceous, pale-grayish-red-purple (5RP5/2), well-rounded andesite-latite cobbles and boulders in tuffaceous, sandy matrix; poorly bedded, poorly indurated; grayish-red (10R4/2), sandy mudstone interbedded; slope-former	40
18	Sandstone, very fine grained, tuffaceous, grayish-red (10R4/2), poorly sorted, abundant montmorillonite; slope-former	52
17	Conglomerate, tuffaceous, sandy, pale-red (10R6/2); similar to unit 19, except angular pebble-size clasts; slope-former	83
	Offset 0.5 mile northwest to base of small hill on south side of Basin Tank.	
16	Mudstone, sandy, tuffaceous, pale-red (5R6/2); weathers moderate-yellowish-brown (10YR5/4); few angular pebble-size tuff fragments; abundant montmorillonite; slope-former, top of conical-shaped hill	34
15	Conglomerate, muddy; pale-red (5R 6/2) with pinkish-gray (5YR8/1) angular granule- and pebble-size tuff fragments; abundant montmorillonite; medium- to massive-bedded; slope-former	10
14	Tuff; pale-pink (5RP8/2) with few white pumice fragments up to 3mm diameter; slope-former	12
13	Mudstone, tuffaceous, pale-red (5R 6/2); conglomeratic base, gradational upward to pale-red (10R6/2), sandy mudstone; similar to unit 16; slope-former	40
12	Conglomerate, muddy, pale-red (5R6/2); same as unit 15; slope-former	72
11	Conglomerate, muddy; pale-red (5R6/2) matrix with pinkish-gray to grayish-red-purple angular andesite-latite fragments up to 2-ft-boulder size, average 1 to 3 inches; abundant hornblende and biotite crystal fragments; medium- to massive-bedded; ledge- and slope-former	55
10	Conglomeratic mudstone; similar to unit 11, except largest fragments are pebble size; slope-former	65
	Offset 0.5 mile north, downdip, to hill with badland topography	
9	Conglomerate, pale-red (10R6/2), subangular to subrounded pebbles and cobbles of andesite, latite, and intensely altered light-colored, hornblende-rich rock; interbedded with tuffaceous, fine- to coarse-grained sandstone; few tuffaceous mudstone beds; 6-inch to 5 ft beds; slope-former with rounded ledges; capped with 20 ft of pediment gravel	115
8	Conglomerate, pale-reddish-brown (10 R5/4), rounded cobbles and boulders of andesite-latite porphyries in coarse sandy matrix, poorly bedded, poorly indurated	18
7	Conglomerate, sandstone, mudstone, interbedded; similar to unit 9, except clasts generally more angular	120
6	Conglomerate, pale-red (5R6/2), angular pebbles and cobbles of andesite-latite porphyries in tuffaceous sand matrix; well-indurated; ledge-former	25
5	Sandstone, fine- to coarse-grained, tuffaceous; grayish-pink (5R8/2) to grayish-red (10R4/2) beds; medium- to massive-bedded; crossbedding common; channel fills of cobble-boulder conglomerate	80

Unit	Description	Thickness (ft)
4	Conglomerate, grayish-red-purple (5RP4/2), cobble- to boulder-size clasts of andesite-latite porphyries; about ⅓ of unit consists of mudstone and tuffaceous sandstone interbedded; 4-ft bed of very angular cobble conglomerate at top; poorly indurated; slope-former	35
3	Sandstone, poorly sorted, tuffaceous, pale-red-purple (5RP5/2), medium-bedded; conglomerate lenses of subrounded pebbles and cobbles of andesite-latite porphyries; few shaly beds; slope- and ledge-former	32
2	Conglomerate, grayish-red-purple (5RP4/2); similar to unit 4; thick-bedded, well-indurated; ledge-former	30
	Fault, down to the west, cuts out some of section.	
1	Conglomerate, sandstone, mudstone, interbedded; predominantly grayish-red-purple (5RP4/2), poorly sorted, well-bedded in 1-ft to 5-ft thick beds; slope-former, base not exposed	100+

SECTION 5—SIERRO KEMADO

Formations: Upper part of Palm Park Formation and lower part of Bell Top Formation

Location: South slope of Sierro Kemado, west side of sec. 29, T. 20 S., R. 2 W.; central part of Sierra Alta quadrangle.

Measured by: R. E. Clemons

Date: May 18, 1972

Unit	Description	Thickness (ft)
	Bell Top Formation (total thickness)	219
	Tuff 4 member	
9	Vitric-crystal ash-flow tuff, grayish-red-purple (5RP5/2), medium-welded; abundant, flattened, darkened, pumice fragments; biotite, sanidine, plagioclase crystals; cliff-former	114
	Basalt member	
8	Basalt, olivine-bearing; brownish-black (5YR2/1); 2 to 4 ft scoriaceous zone at base; dense, platy basalt grades upward to vesicular basalt, and scoria at top; slope-former	105
	Palm Park Formation (total thickness)	629
7	Sandstone, fine-grained, tuffaceous; red-baked zone	3
6	Sandstone, medium-grained, tuffaceous, light-brownish-gray (5YR6/1), poorly bedded, poorly cemented; few boulders up to 10-inch diameter	34
5	Conglomerate; color varies from light-gray and brownish-gray to grayish-red-purple, poorly bedded, poorly sorted; predominantly rounded pebble- and cobble-size clasts hornblende andesite and latite, few boulders up to 5-ft diameter; also some light-colored biotite and feldspar-rich rocks and vesicular basalt as clasts; channel fills present, and few 2 to 3 ft well-indurated sandstone beds; slope-former	205
4	Sandstone, fine- to medium-grained, tuffaceous, grayish-pink (5R8/2), poorly bedded, poorly sorted; granule- to boulder-size clasts of light-colored biotite and feldspar-rich rock; few pebble-cobble conglomerate lenses	23
3	Conglomerate, sandy, tuffaceous, pale-red-purple (5RP7/2) predominate, poorly bedded, poorly sorted, poorly indurated; well-rounded cobbles and boulders up to 6 ft diameter of same lithologies as in unit 5; slope-former	302
2	Sandstone, fine- to medium-grained, tuffaceous, pale-yellowish-brown (10YR6/2), few pebble-size clasts of light-colored hornblende-biotite-feldspar rock; abundant hornblende fragments in sand matrix; friable; slope-former	11
1	Sandstone, coarse-grained, conglomeratic, tuffaceous, pale-red-purple (5RP7/2), medium- to thick-bedded, crossbedded, poorly indurated; subangular cobbles to subrounded boulders up to 3-ft diameter; sand-size material predominantly hornblende, quartz, feldspar crystal fragments; slope-former, base not exposed	51

SECTION 6—HORSE CANYON

Formations: Bell Top Formation and Uvas Basaltic Andesite
Location: Section starts in NW¼ sec. 28, and runs north across west side of sec. 21, T. 20 S., R. 2 W.; central part of Sierra Alta quadrangle.
Measured by: R. E. Clemons
Date: May 16, 1972

Unit	Description	Thickness (ft)
	Camp Rice	
16	Pediment gravel	11
	Uvas Basaltic Andesite (total thickness)	301
15	Basaltic andesite, medium-dark-gray (N4); dense, massive, vesicular flows with scoriaceous tops	97
14	Covered slope	17
13	Basaltic andesite, medium-dark-gray (N4); weathers light-brownish-gray (5YR6/1); platy joints resulting from flow banding; scoriaceous zones; probably several flows	91
12	Basaltic andesite; flow breccia	11
11	Basaltic andesite, dark-gray (N3) to brownish-black (5YR2/1), dense; lower part is coarser crystalline; vesicular at top	34
10	Basaltic andesite, medium-dark-gray (N4); scoria breccia at base; vesicular amygdaloidal to reddish scoria at top	51
	Bell Top Formation (total thickness)	303
	Upper sedimentary member (total thickness)	40
9	Siltstone, tuffaceous, pale-red (5R6/2), massive, poorly bedded, porous; 2 ft opalized zone at top	23
8	Sandstone, fine-grained, tuffaceous, very pale orange (10YR8/2), porous; few rounded granules of volcanic rock fragments	6
7	Covered slope	11
	Tuff 6 member	
6	Vitric-crystal ash-flow, pale-red-purple (5RP6/2), poorly welded; porous	17
	Tuff 5 member (total thickness)	137
5	Vitric ash-flow tuff, pale-pink (5RP 8/2), poorly welded, porous; abundant, large, white pumice fragments; slope-former	22
4	Vitric-crystal ash-flow tuff, pale-red-purple (5RP6/2), medium-welded; abundant, flattened, light-gray pumice fragments in upper part; biotite, quartz, sanidine, and plagioclase crystals; cliff-former except for 8-ft poorly welded zone at base	115
	Tuff 4 member	
3	Vitric-crystal ash-flow tuff, grayish-red-purple (5RP5/2), medium-welded; abundant darkened pumice fragments; sanidine, plagioclase, and biotite crystals; upper 10 ft is slope-former; basal zone is moderate-red (5R5/4) and very dense	63
	Basalt member	
2	Basalt, olivine-bearing, brownish-black (5YR2/1), crumbly, vesicular; scoriaceous top	46
	Palm Park Formation	
1	Conglomerate; rounded cobbles and boulders of andesite and latite in coarse, sandy, tuffaceous matrix; poorly bedded; base not exposed	20+

SECTION 7—RATTLESNAKE HILLS

Formations: Hueco-Abo Formations (partial sections)
Location: North wall of canyon, 1 mile west-northwest of Kimball Place; SE¼ sec. 32, T. 20 S., R. 2 W.; south-central part of Sierra Alta quadrangle.
Measured by: R. E. Clemons
Date: May 19, 1972

Unit	Description	Thickness (ft)
	Hueco-Abo Formations (total thickness)	305
18	Limestone, biosparrite, pale-yellowish-brown (10YR6/2); weathers light-olive-gray (5Y6/1); medium-bedded; ledge-former; covered by pediment gravel	5
17	Dolomite, finely crystalline dismicritic; pale-brown (5YR5/2) with white calcite fillings, weathers grayish-orange (10YR7/4); thin- to medium-bedded; slope-former	16
16	Sandstone, very fine grained, pale-red (5R6/2); weathers grayish-red (5R4/2); laminated- to thin-bedded at base gradational upward to thick-bedded; low-angle crossbedding; ledge-former	15
15	Mudstone, calcareous, moderate-red (5R5/4); weathers light-brown (5YR6/4); medium-bedded; slope-former	6
14	Dolomitic limestone, biosparrudite, brownish-gray (5YR4/1); weathers yellowish-gray (5Y7/2); shaly to medium-bedded; slope-former	17
13	Shale, calcareous, moderate-red (5R 4/6); slope-former; mud cracks; partly covered	25
12	Dolomite, aphanocrystalline biogenic, pale-red (5R5/2); weathers grayish-orange (10YR7/4); medium-bedded; ledge-former	10
11	Partly covered slope; shale, micaceous, pale-red (5R6/2); low-angle cross-bedding present near middle of unit	63
10	Limestone, biosparrudite, light-brownish-gray (5YR5/1); weathers yellowish brown (10YR6/4); shaly bedding grades into medium beds at top	22
9	Dolomite; same as unit 17	4
8	Shale; same as unit 13	30
7	Limestone, biosparrite, medium-gray (N5); weathers light-olive-gray (5Y6/1); thin- to medium-bedded; slope-former	30
6	Mudstone, calcareous, grayish-red (5R4/2), weathers reddish-brown (10R4/4); thin-bedded; crossbedded; beds near top of unit are moderate-yellowish-brown (10YR5/4) and contain mud cracks	10
5	Limestone, biosparrudite, medium-dark-gray (N4); weathers light-brownish-gray (5YR6/1); thin- to medium-bedded; wavey bedding with shale partings; abundant echinoid spines and plates; slope-former	14
4	Limestone, slightly silty biosparrite, dark-gray (N3); weathers light-gray (N6); ledge-former	2
3	Limestone, biosparrudite gradational upward to biosparrite; brownish-gray (5YR4/1); weathers dusky yellow (5Y6/4); thin- to medium-bedded with 1- to 2-inch shale partings; ledge-former; abundant brachiopods, gastropods, lacy bryozoa, echinoid spines and plates	18
2	Limestone, slightly fossiliferous intrasparrite, medium-dark-gray (N4); weathers medium-light-gray (N6); thick-bedded; ledge-former	3
1	Limestone, fossiliferous intrasparrudite, light-olive-gray (5Y5/1); weathers dusky yellow (5Y6/4); thin-bedded with shale partings; slope-former; base not exposed	15

SECTION 8—DARK MOUNTAIN

Formations: Upper part of Bell Top Formation and lower part of Uvas Basaltic Andesite

Location: Southeast slope Dark Mountain, NW¼ sec. 11, T. 21 S., R. 2 W.; southeast corner of Sierra Alta quadrangle.

Measured by: R. E. Clemons

Date: July 31, 1972

Unit	Description	Thickness (ft)
	Uvas Basaltic Andesite (total thickness)	93
10	Basaltic andesite, grayish-black (N2), dense, vesicular; includes several flows, each with scoriaceous tops	88
9	Basaltic lapilli tuff, pale-reddish-brown (10R5/4), thin-bedded, pinkish-gray (5YR8/1); opalized zone at base	5
	Bell Top Formation (total thickness)	367
	Tuff 5 member (total thickness)	137
8	Vitric-crystal ash-flow tuff; grayish-orange-pink (10R8/2), poorly welded; abundant golden biotite books, quartz, sanidine, and plagioclase crystals; slope-former	5
7	Vitric-crystal ash-flow tuff, grayish-pink (5R7/2), medium-welded; same composition as unit 8, plus small white pumice fragments; cliff-former	57
6	Vitric-crystal ash-flow tuff, grayish-pink (5R8/2), moderately welded; same composition as unit 8 except biotite appears black; steep slope-former	25
5	Covered slope; probably includes poorly welded basal part of tuff number 5, tuffaceous sediments, and poorly welded top of tuff number 4 which are exposed in small gully 0.25 mile to north	50
	Tuff 4 member (total thickness)	180
4	Vitric-crystal ash-flow tuff, pale-red-purple (5RP6/2); weathers dusky red-purple (5RP3/2); medium-welded; flattened, dark pumice fragments up to 10 inches long; sanidine, plagioclase, and biotite crystals; cliff-former with crude columnar jointing	80
3	Vitric-crystal ash-flow tuff; similar to unit 4; moderately welded; slope-former	60
2	Vitric-crystal ash-flow tuff, pale-red (10R6/2); similar to unit 4 but contains grayish-red angular lithic fragments; poorly welded; slope-former	40
	Cedar Hills member	
1	Covered slope; light-pinkish-gray (5YR8/1) air-fall tuff and tuffaceous sediments exposed in small gullies	50+

APPENDIX B—
Petrographic Data for Bell Top Formation

COMPOSITION OF ASH-FLOW TUFF 2

Sample	Matrix	Quartz	Sani- dine	Plagio- clase	Bio- tite	Horn- blende	Rock fragments	Fe oxide	Pore space
70RC33	92.8	0.4	1.0	2.6	1.6	–	0.2	0.4	1.0
70RC102	82.3	0.2	0.5	0.3	0.6	–	0.6	tr.	15.5
70RC118	86.8	0.8	1.8	5.2	1.8	–	1.4	0.6	1.6
70RC124	94.4	0.6	1.0	0.8	0.8	–	0.2	0.6	1.6
72RC51	88.2	0.2	0.8	1.0	1.0	–	2.8	0.4	5.6
Average	88.9	0.4	1.0	2.0	1.2	–	1.0	0.4	5.1

Sample Locations:
70RC33: Southwest slope Bell Top Mt., Corralitos Ranch quad.
70RC102: SW¼ Sec. 35, T. 20 S., R. 3 W.; Sierra Alta quad.
70RC118: NW¼ Sec. 34, T. 20 S., R. 3 W.; Souse Springs quad.
70RC124: NE¼ Sec. 33, T. 20 S., R. 3 W.; Souse Springs quad.
72RC51: Hermantano Springs, Sierra Alta quad.

COMPOSITION OF ASH-FLOW TUFF 3

Sample	Matrix	Quartz	Sani- dine	Plagio- clase	Bio- tite	Horn- blende	Rock fragments	Fe oxide	Pore space
70RC36	91.4	4.4	2.2	–	tr.	–	–	0.2	1.8
70RC37	94.0	1.8	1.8	–	tr.	–	–	0.4	2.0
70RC38	65.5	2.0	2.0	–	–	–	–	tr.	30.5
70RC56	77.6	1.8	2.8	–	0.2	–	0.8	0.2	16.6
70RC125	78.2	1.6	3.2	–	–	–	4.8	0.4	11.8
72RC11	80.4	tr.	1.1	–	0.1	–	–	tr.	18.4
72RC52	77.6	–	2.4	–	0.4	–	–	0.4	19.2
71WS2	95.2	2.2	2.2	–	–	–	–	tr.	0.4
71WS11	92.4	3.4	3.8	–	tr.	–	–	0.4	–
71WS13	92.4	1.4	1.8	–	–	–	–	0.8	3.6
71WS29	89.8	2.2	2.8	–	0.2	–	–	0.6	4.4
71WS31	89.4	0.6	0.6	–	–	–	–	tr.	9.4
71WS32	93.0	1.0	4.4	–	tr.	–	0.4	0.6	0.6
71WS33	86.4	1.2	3.2	–	–	–	3.0	0.6	5.6
71WS44	92.2	1.8	1.4	–	0.2	–	3.0	tr.	1.4
71WS45	96.4	0.8	0.8	–	–	–	0.2	0.2	1.6
71WS46	91.6	1.4	1.6	–	–	–	–	0.4	5.0
71WS47	87.0	1.2	4.0	–	0.2	–	5.6	0.4	1.6
Average	87.3	1.6	2.3	–	0.07	–	1.0	0.3	7.4

Sample Locations:
70RC36: Southwest slope Bell Top Mt., Corralitos Ranch quad.
70RC37: Southwest slope Bell Top Mt., Corralitos Ranch quad.
70RC38: Southwest slope Bell Top Mt., Corralitos Ranch quad.
70RC56: SE¼ Sec. 4, T. 21 S., R. 3 W.; Souse Springs quad.
70RC125: NE¼ Sec. 33, T. 20 S., R. 3 W.; Souse Springs quad.
72RC11: NW¼ Sec. 11, T. 21 S., R. 3 W., Sierra Alta quad.
72RC52: Hermantano Springs, Sierra Alta quad.

71WS2: SE¼ Sec. 2, T. 21 S., R. 2 W., Sierra Alta quad.
71WS11: NE¼ Sec. 11, T. 21 S., R. 2 W.; Corralitos Ranch quad.
71WS13: NE¼ Sec. 11, T. 21 S., R. 2 W.; Sierra Alta quad.
71WS29: SE¼ Sec. 2, T. 21 S., R. 2 W.; Sierra Alta quad.
71WS31: Center, Sec. 2, T. 21 S., R. 2 W.; Sierra Alta quad.
71WS32: Center, Sec. 2, T. 21 S., R. 2 W.; Sierra Alta quad.
71WS33: Center, Sec. 2, T. 21 S., R. 2 W.; Sierra Alta quad.
71WS44: NE¼ Sec. 14, T. 21 S., R. 2 W.; Corralitos Ranch quad.
71WS45: NE¼ Sec. 14, T. 21 S., R. 2 W.; Corralitos Ranch quad.
71WS46: NE¼ Sec. 14, T. 21 S., R. 2 W.; Corralitos Ranch quad.
71WS47: SE¼ Sec. 14, T. 21 S., R. 2 W.; Corralitos Ranch quad.

COMPOSITION OF ASH-FLOW TUFF 4

Sample	Matrix	Quartz	Sani-dine	Plagio-clase	Bio-tite	Horn-blende	Rock fragments	Fe oxide	Pore space
70RC39	90.0	–	7.8	–	0.4	–	0.4	0.2	1.2
70RC40	78.4	–	9.0	1.8	1.0	–	–	1.2	8.6
70RC55	79.0	–	7.8	0.2	0.6	–	0.2	tr.	12.2
70RC110	83.8	–	8.0	0.2	0.6	–	0.2	0.4	6.8
70RC111	85.4	–	11.2	tr.	0.2	–	tr.	0.2	3.0
70RC112	81.6	0.2	15.6	tr.	0.1	–	0.1	0.4	2.0
70RC113	84.3	0.2	4.2	tr.	0.1	–	0.8	0.1	10.3
70RC126	83.3	–	12.9	–	0.2	–	0.8	0.3	2.5
71RC64	89.0	–	6.8	0.1	tr.	–	–	0.2	3.9
71RC65	88.8	–	7.4	–	0.3	–	0.1	0.3	3.1
72RC4	73.6	0.3	7.0	4.2	1.1	–	0.1	0.5	13.2
72RC5	74.3	0.4	16.2	4.4	1.2	–	–	0.4	3.1
72RC10	83.6	–	7.5	–	0.2	–	–	0.1	8.6
72RC21	86.4	0.1	5.9	–	0.2	–	4.9	0.2	2.3
72RC22	88.7	0.1	8.5	0.1	–	–	1.0	0.2	1.4
72RC53	88.5	–	7.9	–	–	–	0.4	1.6	1.6
Average	81.8	0.08	9.0	0.7	0.4	–	0.6	0.4	5.1

Sample Locations:

70RC39: Southwest slope Bell Top Mt., Corralitos Ranch quad.
70RC40: Southwest slope Bell Top Mt., Corralitos Ranch quad.
70RC55: SW¼ Sec. 3, T. 21 S., R. 3 W.; Souse Springs quad.
70RC110: NW¼ Sec. 34, T. 20 S., R. 3 W.; Souse Springs quad.
70RC111: NW¼ Sec. 34, T. 20 S., R. 3 W.; Souse Springs quad.
70RC112: NW¼ Sec. 34, T. 20 S., R. 3 W.; Souse Springs quad.
70RC113: NW¼ Sec. 34, T. 20 S., R. 3 W.; Souse Springs quad.
70RC126: NE¼ Sec. 33, T. 20 S., R. 3 W.; Souse Springs quad.
71RC64: NE¼ Sec. 6, T. 20 S., R. 3 W.; Souse Springs quad.
71RC65: NE¼ Sec. 6, T. 20 S., R. 3 W.; Souse Springs quad.
72RC4: SW¼ Sec. 35, T. 20 S., R. 2 W.; Sierra Alta quad.
72RC5: SW¼ Sec. 35, T. 20 S., R. 2 W.; Sierra Alta quad.
72RC10: SW¼ Sec. 2, T. 21 S., R. 3 W.; Sierra Alta quad.
72RC21: NE¼ Sec. 5, T. 21 S., R. 2 W.; Sierra Alta quad.
72RC22: NE¼ Sec. 5, T. 21 S., R. 2 W.; Sierra Alta quad.
72RC53: Hermantano Springs, Sierra Alta quad.

COMPOSITION OF ASH-FLOW TUFF 5

Sample	Matrix	Quartz	Sani-dine	Plagio-clase	Bio-tite	Horn-blende	Rock fragments	Fe oxide	Pore space
70RC41	72.1	3.2	17.5	4.5	2.0	–	–	0.2	0.5
70RC50	63.6	16.7	7.7	3.8	1.0	–	–	tr.	7.2
70RC54	70.2	6.7	14.7	6.0	1.4	–	–	tr.	1.0
70RC81	73.7	1.5	15.2	3.6	2.0	–	–	0.2	3.8
70RC105	64.4	8.8	17.9	1.8	1.7	–	–	–	5.4
70RC106	61.7	5.4	19.0	0.4	0.7	–	–	0.2	12.6
70RC107	61.6	6.9	22.0	tr.	1.3	–	–	tr.	8.2
70RC108	74.6	4.8	11.6	1.2	3.4	–	–	0.4	4.0
70RC109	76.6	5.1	9.7	5.9	1.7	–	–	0.3	0.7
71RC66	72.2	7.1	12.6	tr.	2.6	–	0.2	0.2	5.1
72RC1	64.0	6.8	21.6	6.0	1.1	–	–	0.3	0.2
72RC2	65.6	14.0	10.4	6.4	3.1	–	–	tr.	0.5
72RC3	71.0	6.8	16.4	2.0	1.6	–	–	0.8	1.4
72RC8	62.2	10.6	11.6	6.2	1.4	–	–	0.2	7.8
72RC23	69.7	8.2	15.2	0.4	1.1	–	–	0.2	5.2
72RC26	64.2	6.8	14.4	9.7	1.6	–	0.4	0.2	2.7
72RC27	70.8	5.8	12.6	7.8	2.4	–	–	0.5	0.1
72RC54	79.5	2.5	7.7	6.1	2.2	–	–	1.0	1.0
70WS51	74.8	3.6	10.0	6.8	2.4	–	–	0.6	1.8
71WS48	57.6	14.4	16.2	7.2	1.4	–	–	0.7	2.5
Average	68.5	7.3	14.2	4.3	1.8	–	tr.	0.3	3.6

Sample Locations:

70RC41: Bell Top Mt. peak; Corralitos Ranch quad.
70RC50: NE¼ Sec. 10, T. 21 S., R. 3 W.; Corralitos Ranch quad.
70RC54: SW¼ Sec. 11, T. 21 S., R. 3 W.; Corralitos Ranch quad.
70RC81: Valles Tank; Souse Springs quad.
70RC105: SW¼ Sec. 27, T. 20 S., R. 3 W.; Souse Springs quad.
70RC106: NE¼ Sec. 34, T. 20 S., R. 3 W.; Souse Springs quad.
70RC107: NE¼ Sec. 34, T. 20 S., R. 3 W.; Souse Springs quad.
70RC108: NE¼ Sec. 34, T. 20 S., R. 3 W.; Souse Springs quad.
70RC109: NE¼ Sec. 34, T. 20 S., R. 3 W.; Souse Springs quad.
71RC66: NE¼ Sec. 6, T. 20 S., R. 3 W.; Souse Springs quad.
72RC1: NW¼ Sec. 35, T. 20 S., R. 2 W.; Sierra Alta quad.
72RC2: NW¼ Sec. 35, T. 20 S., R. 2 W.; Sierra Alta quad.
72RC3: NW¼ Sec. 35, T. 20 S., R. 2 W.; Sierra Alta quad.
72RC8: NW¼ Sec. 35, T. 20 S., R. 3 W.; Sierra Alta quad.
72RC23: NE¼ Sec. 5, T. 21 S., R. 2 W.; Sierra Alta quad.
72RC26: SW¼ Sec. 19, T. 20 S., R. 2 W.; Sierra Alta quad.
72RC27: SW¼ Sec. 21, T. 20 S., R. 2 W.; Sierra Alta quad.
70RC54: Hermantano Springs, Sierra Alta quad.
70WS51: Rincon Hills, Rincon quad.
71WS48: Apache Canyon, Southern Caballo Mts.

COMPOSITION OF ASH-FLOW TUFF 6

Sample	Matrix	Quartz	Sani-dine	Plagio-clase	Bio-tite	Horn-blende	Rock fragments	Fe oxide	Pore space
70RC13	72.0	3.8	7.2	12.0	1.8	tr.	0.4	0.2	2.6
70RC14	83.3	0.9	5.1	4.0	1.2	0.1	–	0.2	5.2
70RC15	87.8	0.6	6.0	3.6	1.2	tr.	–	0.4	0.4
70RC30	72.6	1.2	10.6	12.0	1.6	0.6	–	0.6	0.8
70RC74	84.8	1.4	5.6	5.4	1.8	0.2	–	0.6	0.2
70RC88	78.0	2.6	5.2	5.3	1.4	0.2	–	0.8	6.5
70RC92	67.8	2.8	13.2	13.0	1.8	0.2	–	0.4	0.8
70RC93	82.0	1.6	6.8	6.4	1.0	–	–	0.2	2.0
70RC119	70.0	2.6	8.8	13.4	1.6	0.4	–	0.2	3.0
70RC122	68.0	1.6	10.6	13.4	2.4	0.6	–	0.6	2.8
70RC165	75.6	1.2	9.6	9.6	0.8	0.2	–	0.6	2.4
70RC168	69.2	1.4	11.0	13.6	2.8	0.2	0.2	0.2	1.4
71RC35	77.9	3.5	6.4	6.9	1.6	0.1	–	0.5	3.0
71RC36	70.8	2.4	9.9	7.8	2.1	–	–	1.1	5.9
71RC42	77.8	1.5	8.4	5.1	2.1	–	–	0.8	4.3
71RC60	75.6	1.8	5.6	1.8	1.4	–	–	0.8	13.0
72RC20	82.7	1.2	8.6	5.3	1.1	–	–	0.7	0.4
72RC49	72.6	2.6	9.4	3.2	0.6	–	tr.	0.4	11.2
72RC55	77.2	3.6	8.2	8.0	1.8	–	0.2	0.8	0.2
Average	76.1	2.0	8.2	7.9	1.6	0.1	tr.	0.5	3.5

Sample Location:

70RC13: SE¼ Sec. 6, T. 21 S., R. 3 W.; Souse Springs quad.
70RC14: SE¼ Sec. 6, T. 21 S., R. 3 W.; Souse Springs quad.
70RC15: SE¼ Sec. 6, T. 21 S., R. 3 W.; Souse Springs quad.
70RC30: SE¼ Sec. 32, T. 20 S., R. 3 W.; Souse Springs quad.
70RC74: NW¼ Sec. 3, T. 21 S., R. 3 W.; Souse Springs quad.
70RC88: SE¼ Sec. 33, T. 20 S., R. 3 W.; Souse Springs quad.
70RC92: NW¼ Sec. 3, T. 21 S., R. 3 W.; Souse Springs quad.
70RC93: NW¼ Sec. 3, T. 21 S., R. 3 W.; Souse Springs quad.
70RC119: NW¼ Sec. 32, T. 20 S., R. 3 W.; Souse Springs quad.
70RC122: NE¼ Sec. 36, T. 20 S., R. 4 W.; Souse Springs quad.
70RC165: SE¼ Sec. 1, T. 22 S., R. 4 W.; Corralitos Ranch quad.
70RC168: SE¼ Sec. 21, T. 22 S., R. 2 W.; Corralitos Ranch quad.
71RC35: NW¼ Sec. 7, T. 21 S., R. 3 W.; Souse Springs quad.
71RC36: NE¼ Sec. 27, T. 20 S., R. 4 W.; Souse Springs quad.
71RC42: SW¼ Sec. 8, T. 20 S., R. 3 W.; Souse Springs quad.
71RC60: SE¼ Sec. 5, T. 20 S., R. 3 W.; Souse Springs quad.
72RC20: NW¼ Sec.. 19, T. 20 S., R. 2 W.; Sierra Alta quad.
72RC49: NE¼ Sec. 5, T. 21 S., R. 2 W.; Sierra Alta quad.
72RC55: Hermantano Springs, Sierra Alta quad.

COMPOSITION OF ASH-FLOW TUFF 7

Sample	Matrix	Quartz	Sanidine	Plagioclase	Biotite	Hornblende	Rock fragments	Fe oxide	Pore space
70RC72	98.0	tr.	0.2	–	–	–	–	0.2	1.6
70RC94	96.6	0.2	0.2	–	0.2	–	–	0.4	2.4
70RC95	97.6	1.2	0.6	0.2	0.2	–	–	0.2	–
71RC51	97.0	0.2	0.4	0.2	–	–	–	tr.	2.2
71RC63	98.6	tr.	0.4	–	0.2	–	–	tr.	0.8
Average	97.6	0.3	0.4	0.1	0.1	–	–	0.2	1.4

Sample Locations:

70RC72: Southwest slope Tailholt Mt.; Souse Springs quad.
70RC94: North slope Tailholt Mt.; Souse Springs quad.
70RC95: North slope Tailholt Mt.; Souse Springs quad.
71RC51: SE¼ Sec. 6, T. 20 S., R. 3 W.; Souse Springs quad.
71RC63: NW¼ Sec. 5, T. 20 S., R. 3 W.; Souse Springs quad.

Index follows

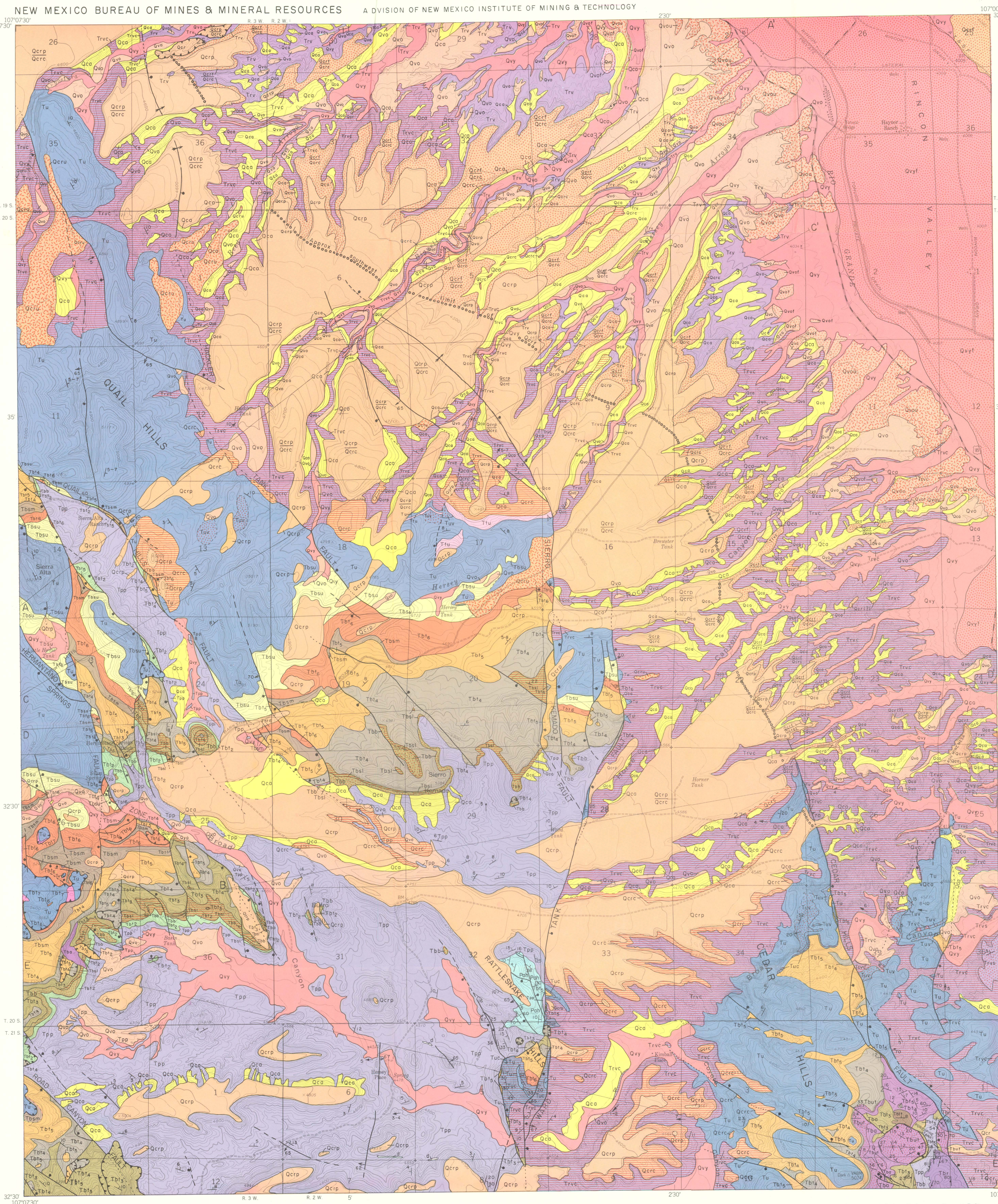
Index

Type faces:
Text—10/11 Times Roman
Appendices—8/9 Times Roman
Index—7/8 Times Roman
Display heads—18 pt. Times Roman
Subheads—12 pt. Times Roman

Presswork:
38" Miehle Single Color Offset
20" Harris Single Color Offset

Binding:
Saddlestitched

Paper:
Text—70 lb. white matte
Cover—10 pt. Supertuff



Qca
Colluvium and alluvium
Thin colluvial and alluvial deposits widely varied in texture, and occurring on mountain, valley, and piedmont slopes. Locally includes undifferentiated alluvium of arroyo valley floor equivalent to "Qvy" and "Qvo"

Qvy Qvyf
Younger valley alluvium
Deposits associated with latest Pleistocene and Holocene episodes of valley entrenchment and backfilling. **Qvy:** *Arroyo channel, terrace, and fan deposits; mainly sand to sandy loam commonly with pebble- to boulder-gravel zones, and some loam to clay.* **Qvyf:** *Fluvial facies, Rio Grande flood-plain and channel deposits; clay to sand in upper part, grading to basal sand and gravel zone*

UNCONFORMITY

Qvo Qvou Qvof
Older valley alluvium
Deposits associated with at least two major episodes of valley entrenchment and backfilling. **Qvo:** *Arroyo terrace and fan deposits; textural range like "Qvy": with gravelly units dominant; locally cemented with lime, particularly in zones of soil carbonate accumulation 1 to 4 ft below surface of broader interfluves.* **Qvof:** *Fluvial facies (ancient river) deposits. Textures like "Qvyf" with carbonate-cemented sandstone and conglomerate zones.* **Qvou:** *Complexly intertonguing arroyo fan (Qvo) and river (Qvof) deposits below elevations of about 4,200 feet*

MIDDLE PLEISTOCENE TO HOLOCENE

UNCONFORMITY

Qcrp Qcru Qcrf Qcr Qcrc
Camp Rice Formation
Intermontane basin fill with three major subdivisions. **Qcrc:** *Basal boulder to pebble conglomerate and conglomeratic sandstone deposits comprising an older piedmont-slope (alluvial-fan and pediment-veneer) facies.* **Qcrf:** *Intermediate sand, pebble to cobble gravel, sandstone, conglomerate, loam to clay, and minor volcanic ash lenses comprising tongues of ancient river deposits. "Qcrf" occurs between units "Qcrc" and "Qcrp" below elevations of about 4,500 ft. (Approximate line of wedge-out of "Qcrf" unit marked by line of circles oooo).* **Qcrp:** *Upper boulder to pebble gravel and sandy gravel deposits comprising a younger piedmont-slope facies; surficial layers commonly contain 2 to 4 ft-thick, calcrete cemented with pedogenic carbonates. Other units include undifferentiated piedmont-slope deposits (Qcru), generally equivalent to "Qcrp/Qcrc", and small bodies of mixed fluvial and piedmont-slope units (Qcr)*

EARLY TO MIDDLE PLEISTOCENE

ANGULAR UNCONFORMITY

Trvc Trvs Trv
Rincon Valley Formation
Bolson deposits. **Trvc:** *Fanglomerate facies.* **Trv:** *Basin-center facies comprising sandstone, mudstone, claystone, gypsiferous in part.* **Trvs:** *Selden Basalt Member*

MIOCENE & PLIOCENE

UNCONFORMITY

Ttu
Thurman Formation
Tuffaceous sandstone and conglomerate. Equivalent to upper Thurman beds in the Rincon Hills

MIOCENE

Tuv Tu Tuc
Uvas Basaltic Andesite
Tu: *Basaltic andesite flows.* **Tuv:** *Cinder and agglomerate beds.* **Tuc:** *Interbedded fanglomerate, gypsiferous sandstone and mudflow deposits*

Bell Top Formation

Tbt_7
Tuff 7
Welded vitric tuff

Tbsu
Upper sedimentary member
Tuffaceous sandstone and conglomerate. Interfingers with "Tuc" member of Uvas Basaltic Andesite

Tbt_6
Tuff 6
Vitric-crystal ash-flow tuff

Tbsm
Middle sedimentary member
Tuffaceous sandstone and conglomerate

Tbt_5
Tuff 5
Crystal-vitric ash-flow tuff containing abundant white pumice lumps near top

Tbt_4
Tuff 4
Welded vitric-crystal ash-flow tuff with devitrified, flattened pumice discs to 1 ft in diameter

LOCAL UNCONFORMITY

Tba
Vesicular andesite
Dark gray to brown vesicular andesite flows and dikes

Tbt_3 Tbsl Tbb
Tuff 3
Tbt 3: *Pumiceous, orange, vitric ash-flow tuff.* **Tbb:** *Black olivine basalt.* **Tbsl:** *Tuffaceous sandstone, mudstone, and air-fall deposits*

Tbt_2
Tuff 2
Welded vitric ash-flow tuff

Cedar Hills intrusive-extrusive rhyolite complex

Tbr
Flow-banded rhyolite
Spherulitic to platy flow-banded rhyolite

Tbut Tba
Younger air-fall deposits
Tbut: *Air-fall tuff and breccia, opalized locally, and fluvial tuffaceous sedimentary rocks.* **Tba:** *Flow and dikes of vesicular andesite. Equivalent in part to "Tbsl" of Sierro Kemado and Sierra de las Uvas*

Tbt_3
Tuff 3
Intrusive pumiceous vitric ash-flow tuff, probably in form of dike

Tblt
Older air-fall breccia
Opalized air-fall breccia. Equivalent to much of "Tbsl" in Sierra de las Uvas

OLIGOCENE

UNCONFORMITY

Tpp
Palm Park Formation
Andesitic sandstone, mudstone, breccia and conglomerate of fluvial, overbank, and mudflow origin

EOCENE

ANGULAR UNCONFORMITY

Pah
Abo and Hueco Formations
Interbedded red siltstone and gray to tan fossiliferous marine limestone

PERMIAN

Basaltic dike

Geologic contact, dashed where uncertain

Normal fault, ball on downthrown side; dashed where uncertain, dotted where concealed

Landslide blocks, barbs on slide block

Strike and dip of bedding

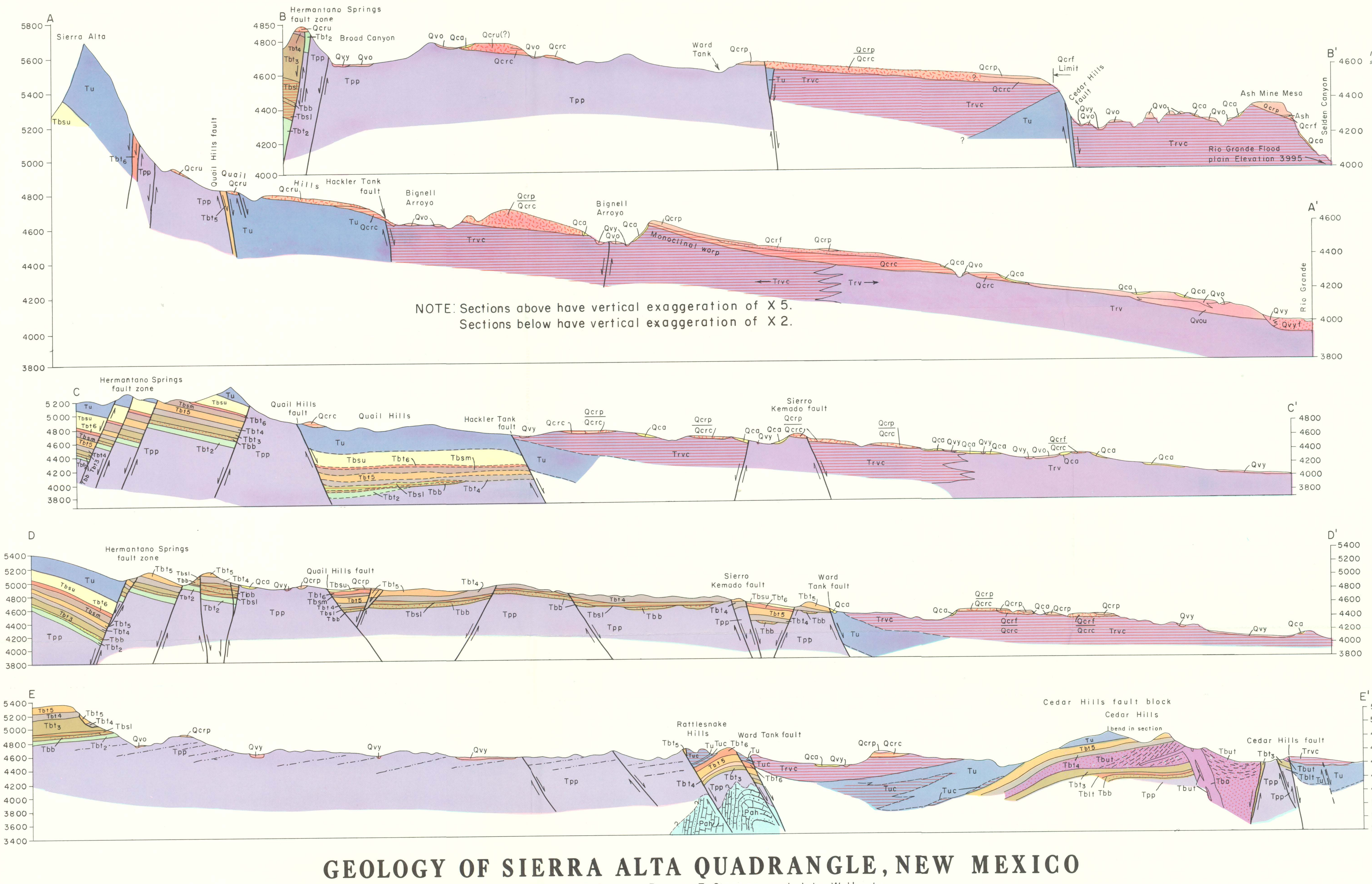
Strike and dip of overturned beds

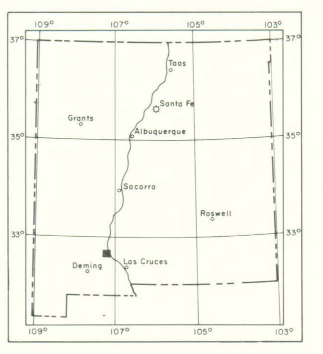
Strike and dip of foliation

Apparent dip of beds

Anticlinal axis

Monocline





APPROXIMATE MEAN DECLINATION 1970

GEOLOGY OF SIERRA ALTA QUADRANGLE, NEW MEXICO

by William R. Seager, Russell E. Clemons and John W. Hawley

SCALE 1:24,000

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