BULLETIN 97

# **Geology** of
# San Diego Mountain Area
# Doña Ana County, New Mexico

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# *Preface*

Since 1966 the authors have been involved in systematic geologic mapping of the Rio Grande trough and adjacent uplifts from the Caballo Mountains southward to Las Cruces. The project was initiated in the San Diego Mountain area because of fine exposures of the Tertiary section, particularly the complete Santa Fe Group. A nearly complete Eocene to Pleistocene section, mainly basin facies, can be pieced together from combined exposures in the Tonuco and Rincon Hills uplifts, and can be used to interpret the less complete Tertiary sections exposed on uplifts adjacent to the trough. Barite and fluorite mineralization in the Tonuco uplift provided further incentives for investigation.

Detailed mapping in the Rincon Hills, Cedar Hills, East Selden Hills and Sierra de las Uvas, and reconnaissance mapping of the Black Range-Cooks Range region is completed or in progress. Our ultimate objective is the synthesis and integration of this data in terms of Laramide tectonics, Tertiary volcanic chronology and structure, and tectonics of the Rio Grande trough in south central New Mexico.

The writers are grateful to the New Mexico State Bureau of Mines and Mineral Resources for partially supporting this work and for providing thin sections. Particularly we would like to thank Frank E. Kottlowski for his interest and encouragement in the project.

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# Abstract

The San Diego Mountain area in north-central Dona Ana County includes two small en echelon uplifts, the Tonuco uplift and West Selden Hills uplift, both located along the eastern side of the Rio Grande a few miles southeast of Hatch. In the Tonuco uplift Precambrian granite and lower Paleozoic Bliss Sandstone and El Paso Group, deformed during the Laramide, are overlain with angular unconformity by more than 8,000 feet of less deformed Tertiary volcanics and sedimentary rocks.

Tertiary rocks were deposited in three different tectonic settings. Limestone-granite boulder conglomerate of the Love Ranch Formation, which forms the base of the Tertiary section, apparently is an orogenic deposit derived from erosion of Laramide folds and fault blocks. In several places the conglomerates are in contact with their deformed source beds. The lower and middle part of the Tertiary section comprises products of Eocene-Miocene volcanic activity in south-central New Mexico.

Three main volcanic sequences are recognized in the San Diego Mountain area: (1) about 2,000 feet of andesite flows, tuffs, tuff-breccias and associated sedimentary rocks of the Palm Park Formation and andesite-latite sequence which overlap the Love Ranch Formation, Paleozoic and Precambrian rocks; (2) nearly 900 feet of rhyolite pebble breccia of the Thurman Formation and ash-flow tuffs of the Bell Top Formation that overlie the andesitic rocks; (3) sparse dikes of basaltic andesite that may be feeders for, or otherwise associated with, the Uvas Basalt of the Broad Canyon-Sierra de las Uvas region. The upper 5,300 feet of the Teritary section consists of clastic rocks formed in late Tertiary graben basins in the Rio Grande trough. In the San Diego Mountain area the base of this section appears conformable with the underlying volcanics, although it is strikingly disconformable where the basin-fill units overlap their source uplifts along graben margins. The bulk of the basin-fill clastics are included in the Santa Fe Group. The Hayner Ranch Formation (new name), about 2,800 feet thick in the Tonuco uplift, forms the lower part of the Santa Fe Group and consists of volcanic-derived fluvial sandstone and conglomerate.

Geologic structures include those of Laramide and late Tertiary age. The Precambrian core and folded lower Paleozoic strata exposed in the Tonuco uplift may be part of a large amplitude, north-striking fold that was deeply eroded and partially buried by Love Ranch conglomerates during Laramide time. A marginal thrust and recumbent fold exposed on the eastern flank of the structure indicate motion away from the axis and may be gravitational in origin. The most important late Tertiary structures are three high-angle normal faults that collectively formed the Tonuco uplift. The core of the uplift is a spindle-shaped horst comprised of Precambrian rocks, and which earlier was part of the core of the Laramide fold. The geometry of low-angle faults and drag folds exposed in rocks both on the core and in adjacent depressed blocks suggests that much of the low-lying moderately deformed rocks adjacent to the core slid to their present position from the core along low-angle fractures, probably in response to a major period of uplift.

Mineral deposits in the Tonuco uplift consist of barite and fluorite (Miocene age) occurring in thin discontinuous veins mainly in Precambrian rocks. Small tonnages of ore have been shipped from some of the larger veins in the past but the area lies idle now and substantial reserves of either mineral do not appear to be present.

# *Introduction*

San Diego Mountain is in north-central Dona Ma County, New Mexico, along the east side of the Rio Grande about 25 miles north of Las Cruces (fig. 1). The mountain is a broad sandstone-capped peak that rises about 1,000 feet above the adjacent flood plain. It forms the highest part of the Tonuco uplift, a complex horst 3 miles long, that consists of rocks of Precambrian, Paleozoic, and Tertiary age. The uplift is a middle to late Tertiary feature, but pre-middle Tertiary rocks exposed in the uplift show evidence of Laramide deformation.

Barite and fluorite deposits provided the earliest impetus for studying San Diego Mountain. Johnston (1928) reported on the mineralization and described some of the rock units. This was followed by Dunham's (1935) brief summary of the geology of the area, and later Rothrock, Johnson, and Hahn (1946) evaluated the mineralized areas. Kottlowski (1953) identified the basic framework of Cenozoic rock-stratigraphic units in the region, thereby providing a foundation on which all subsequent work has been based. The geologic map of the San Diego Mountain area (Kottlowski, 1953) and interpretation of the rock units exposed there represented a major improvement over older attempts. Continuing studies of various stratigraphic units and resources in the region by Kottlowski et al. (1956), Hawley (1965), Kottlowski (1965), Hawley et al. (1969), Kottlowski, Weber, and Willard (1969), King et al. (1969), Hawley (1970), and Gile et al. (1970), have added much enlightenment on the age and nature of Cenozoic volcanism and basin fill in the area and the area's economic value.

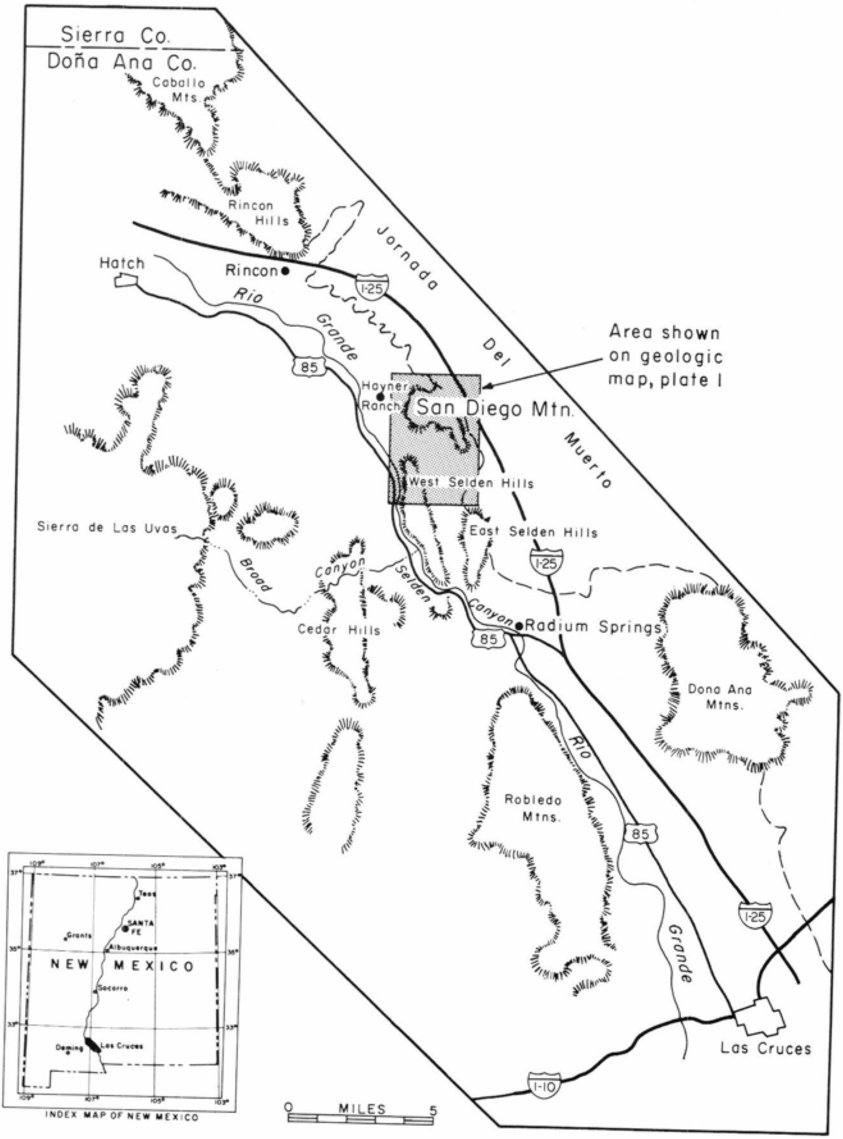



FIGURE 1.
Location Map of the San Diego Mountain Area, Doña Ana County, New Mexico.

# *Stratigraphy*

## GENERAL

The stratigraphic column in the San Diego Mountain area is shown in p1. 2. Nine formations are recognized within the area, four of which are unnamed. Formal names for two of these are proposed in this report. The composite stratigraphic thickness is about 9,000 feet but varies considerably, mainly because of unconformities within rocks of Tertiary and Quaternary age. The strata of Tertiary age exposed in the area, however, document one of the most complete records of Tertiary sedimentation and deformation in Doña Ana County.

## PRECAMBRIAN ROCKS

Precambrian rocks are exposed in the core of the Tonuco uplift over an area of about 1 square mile. Red, coarse-grained microcline granite is the pre dominant rock type, although locally granitic gneiss, schist, and migmatitic bodies are present. Pegmatite pods and diabase dikes occur locally within the older rocks.

## BLISS SANDSTONE

Overlying the granitic rocks is the distinctive dark-brown weathering Bliss Sandstone. The Bliss is primarily siliceous, hematitic quartz sandstone containing numerous interbeds of light-brown shale or siltstone; bright green glauconite is common at certain horizons. Linguloid brachiopods and trilobites locally are common and indicate a Late Cambrian age for the lower part and Early Ordovician age for the upper part of the formation (Kottlowski et al., 1956; Flower, 1959). The scale of mapping precluded subdivision of the unit into the Bliss and Tonuco formations, as proposed by Flower (1959). No physical evidence of unconformity was seen between the units of different age. The formation is about 125 feet thick and grades upward into the El Paso Group.

## EL PASO GROUP

Light-gray limestone beds of the Early Ordovician El Paso Group (Richardson, 1909; Kelley and Silver, 1952) form the crest and dip slope of a hogback near the east-central part of the Tonuco uplift. The strata are characteristically thin- to medium-bedded (6 in to 12 in) and contain numerous thin crenulated siliceous streaks, flakes, and laminae, which impart to
t1, strata a diagnostic mottled appearance Broad slabs of limestone broken

parallel to the siliceous laminae, are distinctive weathered products. The limestone is particularly fine-grained, dense, and hard, and silicified in several areas. Fossils are uncommon, although comminuted fragments occur at some horizons. About 300 feet of the El Paso is exposed; the rest of the formation was removed by erosion or faulting during Late Cretaceous or early Tertiary time, or was buried by the Love Ranch Formation during the same interval.

## LOVE RANCH FORMATION

Overlying the Precambrian, Bliss, and El Paso rocks with nonconformity or angular unconformity are the boulder conglomeratic strata of the Love Ranch Formation (Kottlowski et al., 1956). The conglomerates are entirely locally derived, consisting primarily of Precambrian boulders and cobbles where they overlie the Precambrian and of El Paso or Bliss where they overlie those formations. The clasts are as large as 5 feet in diameter, are embedded in a reddish siltstone matrix, and are poorly stratified in beds that are between 3 and 8 feet thick. From a distance the formation is light gray with a reddish cast, but close at hand the color of the formation is that of the boulders that comprise it. This ranges from red brown with a high granite content to light gray where El Paso boulders are present. Minor lithologies are grayish-red shale and siltstone and a single 5-foot-thick bed of light bluish-gray microcrystalline limestone. Ostracodes collected from the limestone are fresh-water forms of the genus *Darwinula* that range from lower Paleozoic to Recent (Paul Krutak, pers. comm., 1969). The Love Ranch boulder beds apparently represent alluvial-fan and perhaps talus deposits formed by erosion of Laramide(?)-age structures within the San Diego Mountain area. Short-lived spring activity or deposition in local lakes is indicated by the limestone bed.

The age of the Love Ranch Formation is somewhat in doubt. In the Robledo Mountains, in Broad Canyon, and in the Rincon Hills pre-volcanic boulder conglomerates and redbeds that overlie Paleozoic formations grade up into andesite-latite or Palm Park volcanic and volcaniclastic strata. In the Robledo Mountains these volcanics contain a latite flow dated late Eocene (43 m.y. Kottlowski, Weber, and Willard, 1969). The gradational nature of the contacts suggests the underlying conglomerates may also be Eocene. At San Diego Mountain, however, a distinct lithologic break separates the Love Ranch conglomerates from the overlying fine-grained volcaniclastic strata of the andesite-latite volcanic sequence, which locally contain their own basal limestone-pebble conglomerate. The break may represent an important disconformity, suggesting that, at least within the San Diego Mountain area, the Love Ranch is substantially older than the volcanic rocks immediately above it. Placing its age more precisely than Late Cretaceous to Eocene is unjustified at present.

# PALM PARK FORMATION

At least 500 feet of andesite boulder tuff breccia' and associated rocks, tentatively correlated with the Palm Park Formation in the Rincon Hills (Kelley and Silver, 1952), crops out on the western slopes of the West Selden Hills. The base of the formation is not exposed here, but in the Rincon Hills and in Broad Canyon the formation overlies the Love Ranch Conglomerate or Paleozoic strata. Throughout most of the West Selden Hills, the Hayner Ranch Formation overlies the Palm Park with angular unconformity on a surface with 250 feet of local relief. Locally, however, in the northern part of the hills the Bell Top Formation is angularly unconformable above the Palm Park and beneath the Hayner Ranch (pl. 1).

The Palm Park Formation in the West Selden Hills consists mainly of massive, almost totally unsorted andesite boulder tuff breccia. The strata range from pale red and reddish brown to very light gray. Clasts include sizes from lapilli to numerous blocks 15 feet or more in diameter, although the mean diameter may be 6 to 8 inches. The clasts are angular to subangular and arranged in a matrix of ash, crystals, and comminuted rock fragments, much of which has been altered to clay. Internally there appears to be no sorting in single beds, but crude massive stratification that results from concentrations of blocks larger or smaller than those in adjacent beds is apparent from a distance. Individual beds range from 10 to 100 feet thick. Most of the strata contain four to six varieties of porphyritic andesite clasts, many of which exhibit flow banding. Several interbedded units, however, are monolithologic breccias, or tuff breccias. The lapilli and larger-sized fragments show little or no alteration other than the development of clay in some varieties of andesite; the tuff breccias, in general, are only moderately indurated. Weathering produces cliffs and steep slopes studded with clasts of all sizes weathering in relief.

The clasts in the tuff breccias are porphyritic biotite or hornblende andesites. Euhedral plagioclase phenocrysts (0.1 to 2 mm) with moderate to strong oscillatory zoning make up 20 to 40 percent of the andesites. Another 5 to 10 percent of the rocks is composed of euhedral to anhedral hornblende (0.07 to 3 mm), or biotite pseudomorph after hornblende. These crystals are arranged in a pilotaxitic groundmass that consists of andesine laths ($An_{35}$), hornblende, pyroxene and biotite microliter with iron oxide dust and a few vesicles. Tridymite(?) coats and fills a few of the vesicles.

Plagioclase phenocryst zone compositions range from andesine ($An_{35}$) to labradorite ($An_{65}$). The plagioclase appears fresh but invariably possesses

1. The term "tuff breccia" is used here to indicate a type of volcanic rock, in which breccia blocks are surrounded by a tuffaceous matrix of fine fragments (less than 4 mm in diameter) that comprises 25 to 75 percent of the rock by volume (Lydon, 1968).

frayed and absorbed boundaries, and often saussuritized calcic cores. Hornblende phenocrysts are in various stages of resorption by biotite and iron oxide; often only relict outlines of the hornblende crystals remain.

Less conspicuous than the tuff breccias, but volumetrically probably important, are interstratified, laminated to thin-bedded airfall tuffs. Particularly widespread is a very light gray, soft lapilli tuff composed of plagioclase altered to clay, hornblende, and blocks of light gray clayey hornblende andesite. The unit grades vertically into tuff breccia with an increase in proportion of blocks. Although no volcanic-derived fluvial sedimentary rocks have yet been positively identified from the Palm Park in the West Selden Hills, it is likely that reworking by water has given rise to immature tuffaceous sandstones or conglomerates that are difficult to distinguish from tuffs or lapilli tuffs.

In Lytten Canyon a massive, slightly porphyritic hornblende andesite flow about 75 feet thick is interbedded between tuff breccias. The flow is medium gray, dense (except at the base), and exhibits pronounced platy jointing. Euhedral hornblende phenocrysts (0.5 to 3 mm) that are partly to completely replaced by granular iron oxide and augite make up about 10 percent of the rock. The pilotaxitic groundmass consists of 65 percent andesine laths (0.05 to 0.12 mm), 20 percent intergranular pyroxene, and 5 percent iron oxide, biotite and cryptocrystalline material.

The West Selden Hills sequence appears to be part of a rather widespread, predominantly tuff breccia facies of the Palm Park Formation. In its type area in the southern Caballo Mountains the formation consists mainly of volcanic-derived sandstone, mudstone, and conglomerate together with spring deposits. Between the Sierra de las Uvas and the Robledo Mountains-West Selden Hills, however, tuff breccia, fluvial sediments and tuffs, occurring in variable proportions, constitute the bulk of the formation. Farther east, in the East Selden Hills, the Dona Ana Mountains and the Tonuco uplift, a sequence of more indurated darker colored andesite tuff breccias, lavas, and fluvial sedimentary rocks referred to here as andesite-latite sequence may represent a third facies.

The tuff breccia facies of the Palm Park appears similar to andesite tuff breccias described in the Cascade Range by Lydon (1968), Durrell (1944), and Curtis (1954), and in the Absaroka Mountains by Rouse (1937, 1940) and Parsons (1958, 1960). These authors attributed the origin of most tuff breccias to eruptive mudflows. Brecciation of viscous andesite magma within vents near the surface resulted from either violent escape of gas (Durrell, 1944) or from spalling and attrition attending vesiculation of viscous near-surface magma (Curtis, 1954). Hot mudflows, already subjected to high hydrostatic pressure by ground or magmatic water then issue from vents and move downslope away from source areas. A similar mechanism may have formed some of the Palm Park tuff breccias, especially those thick, nonsorted multilithologic units that show evidence of hot-water alteration. The possibility that some mudflows may have originated on the slopes of volcanic highlands by rainfall on loose debris or on previously erupted breccia should not go unconsidered, especially in view of the absence in many tuff-breccia units of chlorite-epidote alteration of matrix and clasts. Probably the monolithologic units are autobrecciated flows. The only known possible source of the eruptive mudflows within the Palm Park Formation are andesite tuff breccia composite dikes exposed in Faulkner Canyon just north of the Robledo Mountains.

The age of the Palm Park Formation may be late Eocene. An age of 43 m.y. was obtained from a latite flow within a correlative volcaniclastic sequence near Picacho Peak (Kottlowski, Weber, and Willard 1969). The only fossils known from the Palm Park Formation are palm frond (?) impressions from travertine, and algae and undated gastropods from associated limestone beds that crop out in the Rincon Hills area.

## ANDESITE VOLCANIC AND SEDIMENTARY SEQUENCE

In the eastern part of the Tonuco uplift at least 2,000 feet of andesitic volcanic and volcaniclastic strata overlie the Love Ranch Formation. The contact between the formations appears disconformable inasmuch as coarse limestone boulder beds below are abruptly overlain by fine to medium-grained volcaniclastic strata. Westward, toward the higher part of the Tonuco uplift, the volcaniclastic strata overlap the Love Ranch, Paleozoic, and Precambrian rocks progressively, although only a few erosional remnants now remain. At the base of these remnants, a few feet of limestone-andesitegranite cobble conglomerate, dissimilar to the Love Ranch beds, overlie Precambrian and grade without a break up into volcaniclastic rocks. The top of the formation is not exposed due to erosion and to faulting along the East Tonuco Fault.

Three informal members, distinguished on the basis of color and lithologic differences, were mapped in the eastern part of the Tonuco uplift. The lower member consists largely of thin to very thick and crudely-bedded gray plagioclase-andesite sandstone and pebble breccia, grayish red and red purple mudstone, and massive, gray to tan tuff breccia. Much of the tuff breccia occurs near the middle of the member in cyclic, very discontinous lenses 3 to 30 feet thick that grade laterally and vertically to sandstone and pebble breccia. The thicker tuff breccia units are a few hundred yards wide along outcrop and occupy irregularly scoured channels in underlying beds. They frequently contain thin scattered lenses of mudstone or sandstone, and display either no sorting or crude graded bedding. The clasts in the tuff breccia include usually 3 to 4 varieties of angular to subrounded andesite lapilli and blocks to 3 feet in diameter, many of which are light yellow green due to chlorite-epidote-carbonate alteration. These are embedded in a matrix of poorly sorted mud and sand-sized plagioclase and andesite fragments, with lesser amounts of hornblende and magnetite. There is locally abundant evidence of invasion of clasts along fractures by epidote-altered matrix material. Plagioclase sandstones and mudstones appear similar to matrix material of tuff breccias. Airfall volcanic breccia' and tuff in graded beds, thin flows, and fluvial limestone-andesite cobble conglomerate comprise a minor part of the unit.

The middle member of the formation consists predominantly of pale red, red purple, and brownish gray fluvial plagioclase sandstone, mudstone, and minor andesite-limestone cobble conglomerate. Thin to medium, even-bedding and local, small scale cross bedding is conspicuous in the lower half of the unit. Coarse-grained plagioclase sandstone and even-bedded, massive, nonsorted andesite boulder tuff breccia comprise much of the upper third of the unit.

The base of the upper member is marked by about 40 feet of reddish purple limestone-andesite cobble conglomerate and sandstone. The conglomerate appears to be widespread in the eastern part of the Tonuco uplift and may be the conglomerate that overlies Precambrian rocks in the higher part of the Tonuco uplift. Succeeding the conglomerate is about 800 feet of thick-bedded, crudely stratified grayish blue andesite boulder tuff breccia and plagioclase andesite porphyry flows that are vertically, and probably laterally, gradational. A typical depositional unit is about 100 feet thick, and consists of basal beds of multilithologic andesite tuff breccia with mud matrix that grades upward to monolithologic tuff breccia with a plagioclase-rich (lava?) matrix, and then into unbrecciated andesite porphyry; thereafter, the sequence completes itself in reverse order. Locally a thin vesicular zone is present in dense tuff breccia at the top of a unit. The sequence or parts thereof are repeated cyclically through much of the member, although thick unsorted tuff breccia units predominate in the lower third. The andesite porphyry flows and breccia blocks are dark gray and consist of euhedral to subhedral plagioclase phenocrysts (1 to 8 mm) in a matrix of plagioclase microliter ($An_{30}$), augite(?), brown glass, and cryptofelsic material, some of which shows evidence of flow. Most of the plagioclase phenocrysts are strongly oscillatory, and progressively zoned, with compositions ranging from oligoclase to labradorite. Minor phenocrysts are biotite and resorbed hornblende.

The tuff breccia, mudstones, and plagioclase sandstone in the andesite-

1. Volcanic breccia is used here to denote a lithified deposit of predominantly volcanic blocks (> 32 mm in diameter) that accumulated as air fall material after being explosively ejected during a volcanic eruption (Williams, Turner, and Gilbert, 1954).

latite sequence may represent mudflow and fluvial deposits that are in part interstratified and in part laterally and vertically gradational. The percentage of altered fragments in tuff breccia, the commonly altered matrix material, and the local matrix intrusions into clasts suggests that much of the tuff breccia was erupted hot, plastic, and susceptible to hot water alteration. Unaltered, multilithologic tuff breccia similar to that described in the Palm Park also occurs, as does graded deposits of airfall ejecta, but not in abundance. Tuff breccias gradational with andesite lava that comprise the upper part of the section apparently represent eruptions of mixed breccia and magma that were affected in the initial and final stages of eruption by high internal fluid and gas pressures and resultant flowage due to decrease in effective strength of the materials.

There seems to be little doubt that the andesite-latite volcanic and sedimentary sequence is, at least in part, correlative with the Palm Park Formation and the Orejon Andesite (Dunham, 1935), and therefore of probable late Eocene age. Predominantly andesitic volcanic or volcaniclastic material and stratigraphic position support this view. However, the andesite-latite sequence in the Tonuco uplift, in the East Selden Hills, and in the Dona Ana Mountains, may be a different facies from the tuff breccia facies of the Palm Park Formation that crops out in the West Selden Hills and westward. The eastern facies includes more indurated, dark gray to purple rocks, largely plagioclase-andesite sandstones, altered tuff breccia and porphyritic flows. This contrasts with the unaltered, thick, moderately indurated tuff breccias in the West Selden Hills and with the predominantly fluvial Palm Park Formation in the type area. It is possible the different facies reflect proximity to source areas, and the corresponding differences in transportation of clasts. The paleotectonic interpretations of the facies are as yet incompletely understood and await further work in the region.

## BELL TOP FORMATION

Two small isolated outcrops of faulted Bell Top Formation (Kottlowski, 1953) occur in the northern part of the West Selden Hills (pl. 1). The formation overlies Palm Park strata with angular unconformity and is in turn overlain disconformably by the Hayner Ranch Formation. The Bell Top here consists of a single reddish brown ash-flow tuff unit, variably welded, that is pumice and crystal rich. It appears lithologically similar to the lowest of three ash-flow tuffs in the Bell Top Formation exposed in the Cedar Hills fault block to the southwest. Inasmuch as the Bell Top and Thurman formations both contain rhyolitic tuffaceous sediments, tuffs, and ash-flow tuffs, it is likely they are at least partially time correlative. The details of correlation, however, are as yet poorly understood. Potassium-Argon dates of 35 m.y.

from ash flows in the Sierra de las Uvas indicate that the Bell Top Formation is mainly Oligocene in age.

## UVAS BASALT

The Uvas Basalt was named by Kottlowski (1953) for a gray to brown vesicular basaltic andesite sequence exposed in the Sierra de las Uvas. The formation crops out in the Selden-Broad Canyon area where it is broken into fault blocks that are partially buried by Hayner Ranch and younger strata. A maximum known thickness of about 320 feet is exposed locally in Broad Canyon. In the Rincon Hills the Uvas Basalt forms a medial tongue near the middle of the Thurman Formation. In the Tonuco uplift no Uvas flows are present in the Tertiary section but several basaltic dikes in the uplift may be Uvas. The Uvas Basalt is probably mainly Miocene in age (26 m.y.) as indicated by a K-Ar date from outcrops in the Sierra de las Uvas (Kottlowski, personal communication, 1970).

## THURMAN FORMATION

The Thurman Formation (Kelley and Silver, 1952) is represented in the Tonuco uplift by about 715 feet of alternating red mudstone and pale purple rhyolite pebble-cobble breccias. The formation, which is steeply to moderately tilted, crops out near the northwestern corner of the uplift above a major low-angle fault; both the upper and lower limits of the exposed section are faults.

The mudstone and breccia beds occur in graded units averaging 20 to 30 feet thick. At the base of each unit is a channel-shaped, pebble-cobble breccia bed that grades upward through pebbly mudstones to red mudstone at the top. Clasts consist of 95 percent flow-banded rhyolite and 5 percent Uvas Basalt and andesite-latite pebbles. The frequency and thickness of basal breccia beds increases downward; in the upper 200 feet of the exposed section, purple volcanic-derived, cross-bedded sandstones and mudstone become predominant. Well-rounded cobbles of white ash-flow tuff are distinctive clasts in some of these beds. Identical clasts characterize the transitional strata underlying the Hayner Ranch Formation at the south side of the Tonuco uplift.

In the Rincon Hills several thin beds of breccia in the upper part of the Thurman Formation, above the Uvas Basalt tongue, closely resemble in texture and composition the breccia units just described. The physical similarities of these distinctive breccias and their similar position beneath the conglomeratic "transitional unit" constitute the basis for extending Thurman terminology into the Tonuco uplift. However, the breccia beds in the Thurman at Rincon Hills occur only as thin tongues in tuffaceous sedimentary rocks and constitute only a small part of a thick and varied formation. In the Tonuco uplift the entire Thurman is represented by breccia beds and associated strata (fig. 3).

An early Miocene age for the breccia beds is indicated by (1) their position just above Uvas Basalt (26 m.y., Kottlowski, personal communication, 1970) at the Rincon Hills, and (2) by their content of Uvas cobbles, and position beneath the transitional unit in the Tonuco uplift.

The graded breccia beds in the Thurman appear to represent an aggrading alluvial apron deposit possibly formed near or at the base of the flow-banded rhyolite dome-flow complexes exposed now in the Cedar Hills. No evidence of significant time breaks between the cyclical graded units was found which suggests denudation of the dome-flow areas was rapid. Distal portions of the alluvial apron may be represented by the thin Thurman breccia beds in the Rincon Hills that intertongue with fine-grained tuffaceous basin-floor sediments.

## UNNAMED TRANSITIONAL UNIT

Along the southern margin of the Tonuco uplift tilted moderate red and pale purple clastic beds form badlands and hogbacks adjacent to the Precambrian core. These have been informally termed "transitional unit" because they probably grade downward into the Thurman Formation and upward into the Hayner Ranch Formation. The lower part of the unit is not exposed because of faulting, but the lowest exposed beds appear similar to the uppermost exposures of the Thurman Formation at the northwest corner of the uplift. The unit has been identified only in the Tonuco uplift-Rincon Hills area. It is probably Miocene in age as indicated by its position above Uvas Basalt in the Rincon Hills.

In the Tonuco uplift the unit consists of two members separated by a low-angle fault. The exposed part of the lower member consists of about 950 feet of bright red micaceous and calcareous siltstone, mudstone, and shale that contains numerous thin interbeds of purple volcanic-derived sandstone. Local conglomeratic zones are conspicuous by their content of white ash-flow tuff cobbles. Two 5 inch thick, laminated limestone beds occur 200 to 300 feet below the top of the exposed member. These limestones are marker beds in the region and have aided recognition of different facies of the unit in faulted areas. The upper unit consists primarily of grayish red to pale purple lithic sandstone, conglomeratic sandstone, and inter-lensing conglomerate and mudstone, about 700 feet thick. The clasts in the coarser fraction are entirely andesite-latite, and welded tuff pebbles and cobbles. The unit forms hogbacks and wide dip slopes.

## HAYNER RANCH FORMATION

In the broad basin between the Tonuco uplift and the West Selden Hills a thick sequence of red to tan conglomeratic beds and mudstone that overlie the transitional unit is considered to represent the basal part of the Santa Fe Group in this area. Part of the section extends several miles southward in the half graben between the East and West Selden Hills, and probably a part of the section comprises the lower part of the conglomeratic sequence in Selden Canyon to the west. The same sequence is well-exposed in the Rincon Hills to the north where the strata are, however, coarser-grained and partly silicified. No fossils have been found within the unit.

The conglomeratic sequence is here named Hayner Ranch Formation for the exposures southeast of Hayner Ranch in the badlands at the southern margin of the Tonuco uplift. A measured section of the formation at this locality was reported by Hawley et al. (1969), and is considered to be the type section. A summary of the section is included in the Appendix of this report (sec. 1). The thickness of the formation exceeds 2,650 feet at this locality. In the type area the formation constitutes the southeastern limb of a broad, faulted anticline, the beds of which dip moderately east or southeast forming a series of hogbacks and valleys. The thicker conglomerate and sandstone beds form cliffs and dip slopes while mudstone units form strike valleys or notches in the cliffs.

For mapping purposes the Hayner Ranch Formation was informally subdivided into 5 units. These are recognizable, however, only along the southern border of the Tonuco uplift. The basal unit probably overlies the pale purple and red sandstones of the unnamed transitional sequence conformably, even though the basal contact is locally a channelled surface. The time represented by the surface is probably small inasmuch as the main distinction between beds above and below is one of color, proportion of mudstone, and, to a lesser extent, sediment maturity. About 375 feet of weak to pale red, soft siltstone, mudstone, and claystone with numerous interbeds of texturally immature conglomerate and conglomeratic sandstone constitute the lower unit (unit A, pl. 2). Being finer-grained and softer than the beds above or below, the unit weathers to a pale tan ledgy slope and strike valley that contrasts with the purplish dip slopes of the underlying strata, and with the red cliffs and dip slopes of the overlying units. The middle part of the Hayner Ranch consists of about 1,550 feet of weak red to reddish-brown cliff and ridge-forming sandstones and pebble conglomerates, many of which are channel-shaped and interbedded with pale mudstones. Most of the clasts in the coarser fraction are pebbles of andesite-latite or, less commonly, rhyolite or Uvas Basalt. The sequence is divided into 2 redbed units (units B and D, pl. 2) by a medial tongue of pinkish gray to light gray conglomeratic siltstone and mudstone (unit C, pl. 2) about 240 feet thick that forms a strike valley or ledgy slope. At the top of the Hayner Ranch about 830 feet of brown or pinkish gray sandstone, conglomerate, and interlensing mudstone (unit E, pl. 2) overlie older units transitionally. These strata are thin-to-thick-bedded, are often cross-bedded internally, and form prominent ledges, cliffs and dip slopes. Clasts in the coarser fraction are primarily andesite-latite pebbles and cobbles, but Paleozoic formations are represented by 15 to 25 percent of the clasts and there are smaller amounts of welded tuff, Uvas Basalt, and granite. The Hayner Ranch is transitionally overlain by the siltstones and claystones of the Rincon Valley Formation in the type area. However, in the Rincon Hills the contact is an angular unconformity and the Hayner Ranch strata are silicified and mineralized.

The Hayner Ranch sequence records stream and flood plain deposition probably near the axis of a broad closed basin. The lack of boulder-sized material in the type section suggests that the Tonuco uplift was not a source during Hayner Ranch time, or else was one of very low relief. Toward the southwest, the lower four members of the Hayner Ranch become coarse-grained and pinch out against their own fault block source areas. The upper member coarsens southwestward also, and in Selden Canyon it fills canyons cut in the Palm Park, Bell Top, and Uvas formations, which are broken into blocks by pre-Hayner Ranch faults (figs. 2, 3). Westward, conglomerates that may be youngest Hayner Ranch or Rincon Valley disconformably overlie the Uvas Basalt and coarsen toward the Uvas uplift. Northward, in the Rincon Hills, the Hayner Ranch contains boulder conglomerate tongues within a thick pebble-cobble conglomerate sequence that overlies older strata conformably.

From the foregoing it appears that the lower two-thirds of the Hayner Ranch strata accumulated in the central part of a broad basin bordered on the south, west, and north by fault block or volcanic source areas (fig. 3). In the Tonuco uplift and Rincon Hills areas, essentially continuous deposition in the basin from Thurman through Hayner Ranch time is indicated by the lack of unconformities in those sections. The basin axis may have approximately coincided with these areas. It seems likely that the Tonuco uplift was buried by the complete thickness of the Hayner Ranch Formation. Overlap and burial of the basin margin uplifts by younger parts of the Hayner Ranch and overlying Rincon Valley formations resulted in spectacular unconformities at the base of those sections (figs. 2, 3). The disconformities and partly exhumed fault blocks are well displayed in the Broad Canyon area. Initial definition of the basin by fault uplift of marginal blocks probably is recorded by the first appearance of conglomerates near the base of the transitional unit.

No fossils are known from the Hayner Ranch strata. The formation lies entirely above the Uvas Basalt (26 m.y.) and probably entirely beneath the Selden Basalt (9 m.y.). It therefore seems likely that the Hayner Ranch is mainly Miocene, although the uppermost unit may be Pliocene.'

## RINCON VALLEY FORMATION

Transitionally overlying the type section of the Hayner Ranch Formation is a sequence of pale red gypsiferous siltstone, claystone, and mudstone that is here given a formation name, Rincon Valley Formation. The formation is well exposed in the bluffs and badlands that border the Rio Grande flood plain from west of Hatch southeastward to the Selden Canyon area. The unit is particularly well displayed and nearly complete in the basin between the Tonuco uplift and Cedar Hill where it is more than 500 feet thick. A measured section of the formation at this locality in S1/2 sec. 8, T. 20 S., R. 1 W. was published by Hawley et al. (1969) and is considered to be the type section. A summary of the section is included in the Appendix of this report (sec. 2). In the type locality and wherever the finer-grained parts of the formation are exposed, the strata weather to bare, gently rounded badlands and cuestas. As the content of gravel increases within the formation, however, steep canyon slopes or coarser-textured badlands become the predominant land form. The formation is overlain at most places with angular unconformity by the Camp Rice Formation.

The Rincon Valley Formation consists of a fine-grained gypsiferous basin floor facies and a conglomeratic basin-margin or piedmont-slope facies (fig. 3). The badland-forming sequence in the type area adequately characterizes the basin floor facies. Pale red, brownish-gray, or gray-red siltstone and clay-stone that contain 1 inch- to 2 foot-thick beds of gypsum constitute most of the type section. Occasional cross-bedded gypsiferous sandstone lenses are interbedded throughout. The uppermost 180 feet consist of very poorly sorted rhyolite pebble conglomerate that appears to intertongue with and overlap the fine-grained beds; they apparently represent a wedge of piedmont-slope alluvium. The top of the Rincon Valley Formation at the type area is not exposed due to faulting.

In the type area, the formation becomes conglomeratic laterally toward the fault block uplifts that are exposed in the Selden-Broad canyon areas as well as toward the Sierra de las Uvas, and near the Caballo Mountains. This transition between basin-floor and piedmont-slope facies is well displayed on the

1. The Mio-Pliocene boundary is placed at 12 m.y. following Newman (1970). However, there is no unanimity among recent authors as to the position of this boundary, estimates of which extend from 7 to 15 m.y. ago. The 12 m.y. date should be considered tentative and subject to change.

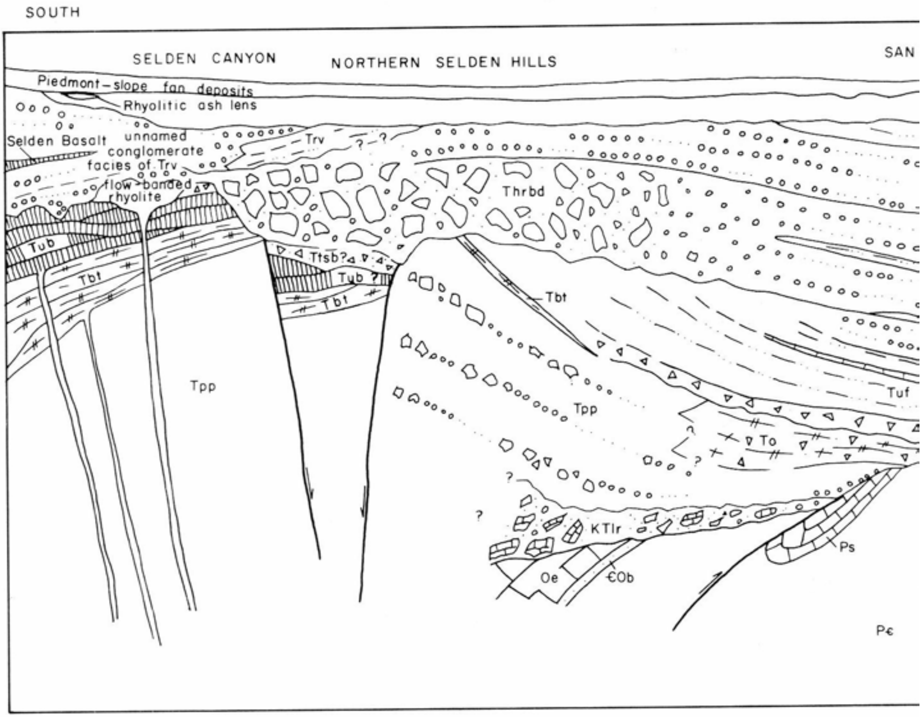
west side of the Rio Grande just north of Selden Canyon, and locally in the Rincon Hills. Good exposures of conglomeratic facies can be seen in the tributary canyons of the Rio Grande in Selden Canyon. Here the facies consists of massive, poorly sorted, brown, red, and pink pebble and cobble conglomerate derived mainly from Uvas Basalt, Bell Top Formation, and Palm Park beds. From the Broad Canyon area southward, one and locally two olivine basalt flows, named Selden Basalt (Kottlowski, 1953), are interbedded in the lower(?) part of the section. The basal bouldery Santa Fe beds that overlie Uvas, Bell Top, or Palm Park formations in this area may be equivalent to part of the upper Hayner Ranch Formation.

The dual facies of the Rincon Valley Formation occupy essentially the same major closed basin that contains the Hayner Ranch Formation and probably represents the late stage of filling of the basin (fig. 3). Overspilling of the basin occurred in the Selden Canyon area, however, as the Rincon Valley conglomerate facies is found completely filling, and locally overflowing, linear grabens that extend southward for several miles. North of Selden Canyon, east of the Sierra de las Uvas, and south of the Caballo Mountains the conglomerate facies appears to represent alluvial fan deposits that inter-finger with the partly alluvial, partly lacustrine basin floor sediments. With the exception of the Tonuco uplift, where the basin floor facies is in fault contact with the uplift, the gypsiferous, fine-grained beds are restricted in occurrence to positions near the restored basin axis and are far removed from uplands bordering the basin; they accordingly appear to be deposits of playa lakes and broad alluvial flats draining toward such lakes. Conglomeratic rocks overlapping the Rincon Valley basin floor facies record flooding of the basin interior by coarse material, probably in response to major late Pliocene faulting along the basin margin.

Although no fossils have been found in the Rincon Valley Formation, the Selden Basalt tongue has given a K-Ar date of 9 m.y. (Gile et al., 1970). Using Newman's (1970) estimation of the Mio-Pliocene boundary, the lower part of the formation is probably late Miocene—early Pliocene, while the upper part may range through late Pliocene. The overlying Camp Rice Formation contains horse teeth of probable early to middle Pleistocene age (Hawley et al., 1969).

## CAMP RICE FORMATION

A sequence of sand, gravel, sandstone, conglomeratic sandstone, and local fine-grained beds crops out in the upper valley slopes that ascend to the Jornada del Muerto Basin surface on the north, east, and southeast flanks of the Tonuco uplift, as well as in scattered patches on and to the west of the



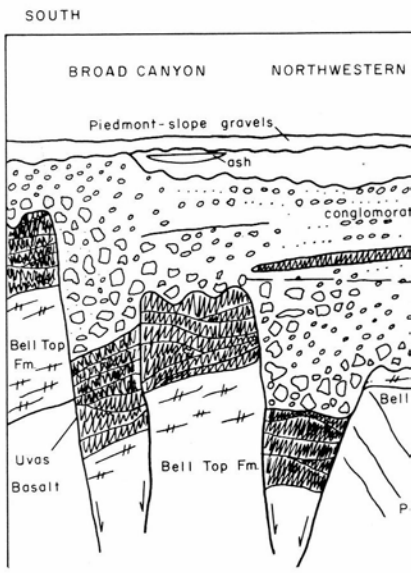




FIGURE 3.

Diagrammatic section of the Santa Fe Group illustrating relations with underlying rocks.

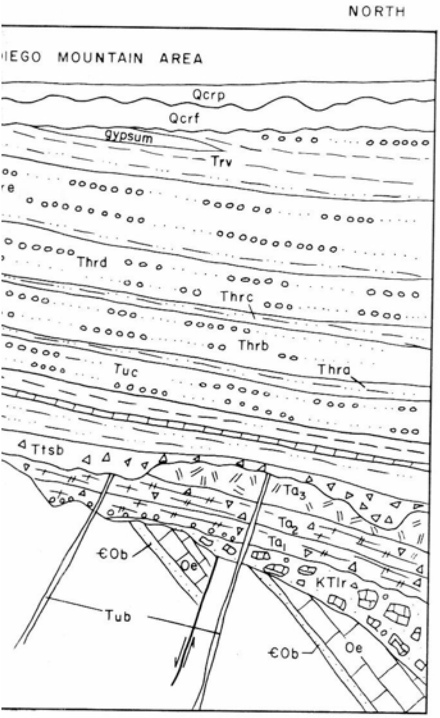
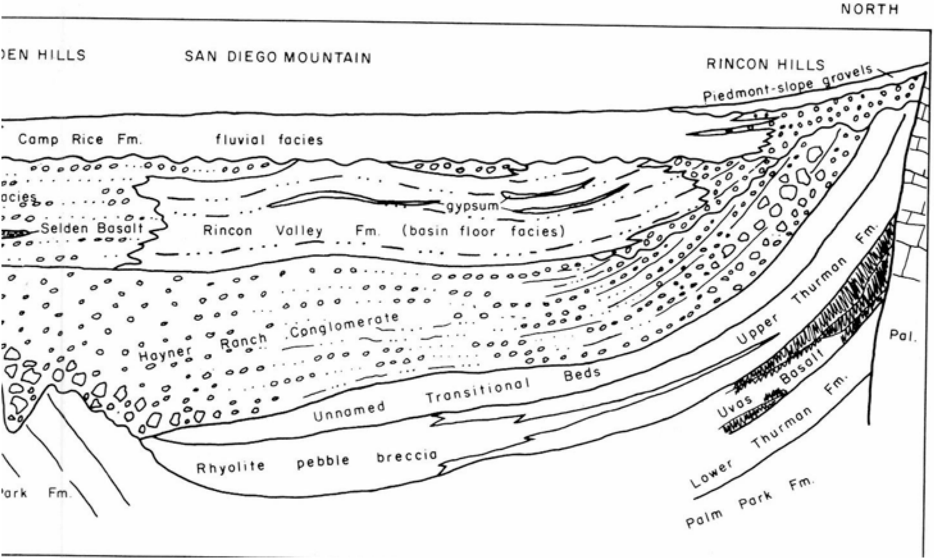



FIGURE 2.

Diagrammatic section illustrating structural and stratigraphic relationships of mapped units. See plate 1 for identification of symbols.



uplift. In the mapped area, this sequence is angularly unconformable on the Rincon Valley or older formations and is part of a widespread unit that forms the upper part of the Santa Fe Group basin fill in south-central New Mexico and western Trans-Pecos Texas. Two basic subdivisions can be identified: (1) a basin-floor facies that consists mainly of sand- and pebble-size clasts, and includes common pebbles of siliceous rocks derived from distant (northern) source areas; and (2) a piedmont-slope facies with textures ranging from pebbly sand and loam[1] to coarse gravel, and with clasts derived from uplands adjacent to sites of deposition. Local induration due to cementation by calcium carbonate, silica, and iron-manganese occurs in both facies, but the units are generally nonindurated.

The piedmont-slope facies, which includes alluvial-fan, coalescent-fan, and pediment-veneer deposits, laterally intertongues with and overlaps the basin-floor facies. The bulk of the basin-floor facies is a complex of channel and flood-plain deposits of the ancestral Rio Grande.

Lenticular beds of volcanic ash (mainly composed of silt-size rhyolitic glass shards) have been discovered in the basin-floor facies at two localities near the mapped area; one in Selden Canyon 3 miles south of San Diego Mountain (Hawley et al., 1969, Appendix, Measured Section 2), and one at Grama Siding (AT&SF Railroad) about 10 miles north-northwest of the Tonuco uplift. In both cases the ash caps a graded sequence of river deposits that includes a basal channel sand (and gravel) unit and an upper fine-grained unit. Petrified wood, horse teeth, fragments of mastodont teeth, and miscellaneous bone fragments of medium-to-large size vertebrates have been recovered from the basin-floor facies. The horse teeth are probably of late Blancan-early Irvingtonian (early to middle Pleistocene) age and are currently being studied by W. S. Strain, University of Texas at El Paso.

At least the upper part of the sequence can be physically traced into the Mesilla-Hueco Bolson region southeast of Las Cruces-El Paso, where this unit is demonstrably part of the Camp Rice Formation as defined by Strain (1966, 1969a, 1969b). The entire sequence of river deposits and intertonguing and overlapping piedmont-slope alluvium, described herein, is mapped as Camp Rice. A reference section near Cedar Hill, first described in Hawley et al. (1969, Appendix, sec. 1, units G and H) is included in the Appendix (sec. 3). The following discussion is inserted in order to better support the writers' decision to formally extend the Camp Rice stratigraphic terminology into the Tonuco area.

According to Strain (1966, p. 12-13), "the Camp Rice Formation . . . (in its type area in the Hueco Bolson, Hudspeth County, Texas, is) . . . a

1. Loam as used in this report refers to non-indurated mixtures of sand, silt, and clay (see Appendix).

sequence of channel gravel, sand, sandy and silty clay, and volcanic ash, capped in most places by caliche and drifting sand. . . . The lower part of the Camp Rice consists of well-rounded river pebbles and fine to coarse sand. The pebbles originated in various areas on the borders of the basin but came principally from the Organ and Franklin mountains. Most of the pebbles are andesite or rhyolite, but some are granite, quartz, or chert.

"Near the mountains alluvial-fan deposits consist of fragments of local rocks, poorly to moderately rounded and poorly sorted.

"Wright (1946, p. 399) stated that basins traversed by a stream of major size will have two types of deposits:

> (a) alluvial fan deposits consisting of gravel near the mountains and grading into sand, silt, and even clay toward the axis of the basin, and
> (b) river gravel distributed along the axis of the basin, with some fine sand, silt, and clay.

"The channel gravel and the alluvial fan deposits of the Camp Rice are typical of the deposits in basins with through-flowing streams and described by Wright (in the Lower Rio Puerco area of central New Mexico)."

In its type area, the lower part of the Camp Rice Formation contains a late Blancan (early Pleistocene) vertebrate fauna. It disconformably rests on strata deposited in a closed-basin environment (the Fort Hancock Fm.) "characterized by peripheral zone of alluvial-fan material, and a central area composed of playa- or lake-deposits, typified by clay, silt, fine sand, gypsum (Strain 1966, p. 12)."

The entire sequence of river and associated piedmont-slope deposits described in the Tonuco area may not be an exact time correlative of the Camp Rice Formation in its type locality. However, this sequence is part of a continuous rock-stratigraphic unit, which has been removed by erosion only in the present valleys of the Rio Grande and major tributary arroyos. Strain's "Camp Rice concept" perfectly fits the upper part of the Santa Fe Group basin-fill sequence as mapped around the Tonuco uplift. Finally tentative correlation of volcanic-ash lenses described in the Selden Canyon and Grama areas with ash lenses in the type Camp Rice[1] (reference sec. 1 and 6, Strain, 1966) and similarity in vertebrate faunas indicates that the units in Dona Ana County, New Mexico, and Hudspeth County, Texas, are partly coeval (of the

1. Samples of ash from the Camp Rice in its type area and from the Selden Canyon and Grama localities are being studied by Ray E. Wilcox of the U.S. Geological Survey, Denver. Possible source areas of middle Pleistocene ash-fall units in this region include the Yellowstone National Park and Bishop, California areas (Izett et al., 1970), and the Valles Caldera, New Mexico (Doell et al., 1968).

same age). The lowermost part of the Camp Rice Formation as described in the Tonuco area possibly intertongues with (or grades to) uppermost Fort Hancock Formation strata described near El Paso by Strain[2] (1969).

In the mapped area, the main body of Camp Rice Formation is exposed in the outer valley slopes that ascend to the Jornada del Muerto surface east of the Tonuco uplift and north of Cedar Hill. Clean, gray to light brown sand, gravel, sandstone, and conglomerate make up the bulk of the formation. This complex of river-channel deposits (map unit Qcrf; unit G in measured sections 3a & c) ranges from 200 to 300 feet in thickness except in wedge-out zones on and adjacent to the uplift. Horse teeth of probable early to middle Pleistocene age have been recovered from the unit and are being studied by Dr. W. S. Strain of the University of Texas at El Paso. Fragments of mastodont molars, bones of as-yet-unidentified large vertebrates, and petrified wood are also locally present.

In the area southeast of the uplift, the thick river-channel complex is in fault contact with the youngest Camp Rice unit (map unit Qcrp., Unit H in sec. 3a & b), which consists of a series of alternating reddish-brown (non- to slightly calcareous) and white (lime impregnated) sandy to loamy layers, with an exposed thickness locally of more than 70 feet. The unit is considered to be the result of episodic sedimentation and soil formation in a piedmonttoeslope setting.

Opposite the south tip of the Tonuco uplift, and to the north, the upper Camp Rice unit is in normal depositional contact with sediments of the basin-floor facies. These form an "intermediate or transitional" sequence of 2 or 3 thin, coarse-grained river-channel deposits, each grading upward into finer-grained flood-plain beds. This "intermediate" zone, designated unit GH in measured section 3a, probably does not exceed 30 feet in thickness. It is included as the basal part of map unit Qcrp, and rests on underlying strata of the Qcrf map unit. At least locally a break of diastemal rank separates the two units.

Because of poor exposure, lateral facies relationships are not clearly shown. However, the "intermediate" zone could represent a transitional facies, deposited near the edge of the ancient basin floor, which graded to (and/or intertongued with) uppermost strata of the river channel complex toward the central part of the basin, and piedmont-slope alluvium in the opposite direction.

2. The upper part of the basin-floor facies of the Rincon Valley Formation may be an age equivalent of lower exposed parts of the Fort Hancock Formation in the latter's type area. However, the Rincon Valley Formation cannot be physically traced as a continuous "rock unit" into either the Hueco or Mesilla bolsons. During Rincon Valley Formation deposition, the Jornada del Muerto and Mesilla-Hueco bolsons may still have been separated by now-buried bedrock highs.

Directly east of the Tonuco uplift the piedmont-slope facies contains tongues of locally-derived, coarse angular gravel (primarily andesite-latite, granite, and quartzite, with some limestone). In places on and immediately adjacent to the uplift, the piedmont-slope facies is very coarse-grained and partly cemented. Conglomeratic pediment and fan deposits, which represent an upper piedmont-slope facies equivalent of river deposits in a basin-floor position, are probably almost everywhere present (if only as a very narrow belt) adjacent to bedrock upland areas. However, exposures in such a land-scape position normally are poor and only a few areas of coarse conglomerates and gravel (Qcrc mapping unit) have been delineated.

As mentioned previously, strata of the Camp Rice Formation are commonly poorly indurated. A major exception to this observation occurs on the central part and north flank of the Tonuco uplift. There the sandy to pebbly beds of the fluvial facies and intertonguing coarse-grained piedmont-slope deposits are cemented with silica and iron oxide into very well-indurated caprock. This cementation becomes less complete both laterally and vertically and is apparently associated with late hydrothermal activity along the East Tonuco Fault.

## POST-CAMP RICE UNITS

The Camp Rice Formation represents culmination of intermontane basin filling in many parts of the south-central New Mexico border region, and formation of the La Mesa and Jornada geomorphic surface. Studies by Ruhe (1962, 1967), Strain (1966), and Hawley et al. (1969) show that initial entrenchment of the Rio Grande valley system occurred in middle Pleistocene (latest Kansan to Illinoisan?) time. The present entrenched network of river and tributary arroyo valleys is the result of integration of the upper and lower Rio Grande systems and development of through drainage to the Gulf of Mexico. Throughout middle to late Quaternary time, episodes of major valley incision have alternated with times of valley-floor stability and partial back-filling. Evidence of this episodic valley cutting and filling is preserved in the mapped area (and elsewhere in the region) in the form of a stepped sequence of erosional and constructional valley-border surfaces, which include fans, pediments, and terraces.

Geomorphic-surface and morphostratigraphic units delineated elsewhere in the region by Ruhe (1964, 1967), Hawley (1965), Hawley and Kottlowski (1969), Metcalf (1967, 1969), and Gile et al. (1970) have not been separately mapped in the Tonuco area; rather, they have been combined into three generalized mapping units "Qp," "Qc," and "Qal." The first includes pediment veneers and other alluvial deposits correlative with middle to late

Pleistocene, Tortugas and Picacho morphostratigraphic units of the Mesilla Valley area; while the third comprises "alluvium (and minor eolian sand deposits) of latest Pleistocene and Holocene age, primarily sediments of Fort Selden morphostratigraphic units (Hawley and Kottlowski, 1969). Undifferentiated colluvial deposits (Map unit Qc) on steep slopes have a wide range in age.

Travertine (spring tufa) deposits (Qpt) at the northwestern base of San Diego Mountain, which are in part radioactive (Boyd and Wolf, 1953), make up a special category of valley fill materials. The travertine is apparently associated with spring activity during an intermediate stage of valley entrenchment in late Pleistocene time.

# *Structure*

## GENERAL FEATURES

The Tonuco uplift is one of the uplifts bordering the eastern margin of the Rio Grande depression in northern Dona Ana County. Generally, the uplift is a northwestward-trending, rectangular horst containing a spindle-shaped core of Precambrian granitic and metamorphic rocks (pl. 1). The core area is locally covered by remnants of Tertiary and Pleistocene formations. The eastern part of the horst consists primarily of lower Paleozoic and Tertiary strata dipping moderately eastward off the core. Santa Fe Group strata constitute most of the exposed parts of the large down-dropped blocks around the margins of the uplift. These rocks are broadly folded except near the uplift where steep to moderate dips are common within the thick Hayner Ranch Formation and underlying transitional beds. To the south the eastward-tilted West Selden Hills fault block is arranged en echelon with the Tonuco uplift. It consists primarily of Palm Park Formation and Hayner Ranch Formation.

## LARAMIDE STRUCTURE

Most of the Late Cretaceous or early Tertiary structural features in the Tonuco uplift have been obscured by younger faulting or buried beneath thick Tertiary and Pleistocene deposits. However, major pre-late Eocene uplift and removal of nearly 7,100 feet of Paleozoic strata is indicated by the relatively large (at least one square mile) erosion surface cut on Precambrian and Paleozoic rocks prior to the deposition of the Love Ranch Formation and andesite-latite volcanic sequence (fig. 2, pl. 1). Remnants of these formations now lie with depositional contact on the Precambrian core and lower Paleozoic strata. Furthermore, removal of about 30° of middle or late Tertiary tilting indicates the pre-Love Ranch attitude of the Bliss and El Paso strata on the eastern side of the uplift to be 25° to 30° to the east. The deformation cannot be unequivocally dated more precisely than post-El Paso- pre-Love Ranch. Yet the bouldery talus and fan deposits of the Love Ranch Formation most probably represent the erosional products of the deformation and thus constitute evidence that the deformation is Late Cretaceous to Eocene in age (Laramide). Stratigraphic and structural studies also indicate that no deformation occurred in south-central New Mexico prior to Laramide time that was of the magnitude or style of that represented in the Tonuco uplift by structures in the Paleozoic rocks. On the other hand, Kelley and Silver (1952) and Kelley and McCleery (1961) present evidence for Laramide deformation in neighboring ranges, much of which is struc-

Several small structures that pre-date the Love Ranch Formation occur in the Paleozoic and Precambrian rocks of the Tonuco uplift (pl. 1, sec. A-A', C-C', D-D'). Near the east-central margin of the uplift, a small recumbent fold in silicified El Paso Limestone is overlain with angular unconformity by coarse Love Ranch Formation. The axial plane of the fold strikes north and dips 10° east. Farther south, the Love Ranch beds were deposited across El Paso, Bliss, and Precambrian rocks juxtaposed earlier by several east-striking normal faults, the largest of which shows at least 600 feet of strike separation. Near the mouth of Picture Rock Canyon, Precambrian granite is thrust eastward onto unidentified silicified Paleozoic limestone. The thrust surface dips 30° west. Although this fault cannot be proven to be pre-Love Ranch in the same manner as the other features, it is thought to be a Laramide product inasmuch as no thrusting involving Tertiary rocks (excluding gravity-sliding) is known in south-central New Mexico.

Although no clear and unequivocal picture of Laramide deformation can be constructed from these very fragmentary data, the available evidence does suggest the general nature of the deformation. The Precambrian core and north-striking, east-dipping lower Paleozoic section suggest the presence of a rather large amplitude Laramide fold striking nearly north, of which only a part of the core and eastern flank is preserved now in the Tonuco uplift. If this hypothesis is accepted, the thrust fault may be marginal to the uplift, directed outward (east) from the core to the eastern limb to accommodate lateral spread of the uplift (fig. 2). Similar thrusting is well-known in the large Laramide structures of the Rockies (Eardley, 1963, 1968), and has been reported from the Fra Cristobal Range in southern New Mexico (McCleery, 1960). The small recumbent fold described appears similar to cascade folds found on the flanks of large anticlines (Harrison and Falcon, 1934, 1935). The motion indicated by the fold is eastward away from the axis of the proposed major anticline. The thrust and recumbent fold thus interpreted would be secondary gravity effects formed in response to uplift.

## MIDDLE AND LATE TERTIARY STRUCTURES

The Laramide anticline, if it ever existed, has been masked to a great extent by the combined effects of middle to late Cenozoic block faulting and volcanism, and by their thick and widespread sedimentary products. Most important of these effects are the faults which outline the present structural blocks.

## HIGH-ANGLE NORMAL FAULTS

Four high-angle normal faults are the main late Tertiary structural features in the map area. The faults are the East and West Tonuco faults, the Adobe Flats fault, and the Selden Hills fault (p1. 1).

The East and West Tonuco faults enclose the spindle-shaped horst of Precambrian, Paleozoic, and Tertiary rocks described earlier. Pre-Camp Rice (pre-Pleistocene) displacement on the West Tonuco fault may be as much as 6,500 feet if the full measured thickness of older formations is present beneath the Hayner Ranch where it is in fault contact with the Precambrian. Much of this apparently resulted from Pliocene(?) movements because Rincon Valley and older formations are involved. No stratigraphic or other evidence for displacement older than Pliocene has been found for the West Tonuco fault, although Miocene uplift of the andesite-latite section elsewhere in the region is required to furnish the andesite and latite pebbles and cobbles that constitute the bulk of the Hayner Ranch and underlying transitional strata (see discussion of Hayner Ranch Formation). The amount of pre-Pleistocene displacement on the East Tonuco fault is unknown, although assumed to be large. Post-Camp Rice movement on the East Tonuco fault is about 100 feet and involves the youngest facies of the Camp Rice Formation (pl. 1, sec. G-G'). Very recent offset is indicated in view of an essentially uneroded fault scarp.

Like the West Tonuco fault which it parallels, the Adobe Flats fault strikes northwest and is downthrown to the west. The fault involves primarily Hayner Ranch Formation and underlying transitional beds which together form a broad, faulted south-plunging anticline near the southern edge of the Tonuco uplift. Stratigraphic separation on this fault is about 2,500 feet near the western base of San Diego Mountain but throw decreases rapidly to the southeast as the fault passes into a monocline in upper Hayner Ranch beds. Farther southeast, another fault on strike with the Adobe Flats fault is down on the east side. The two faults may be parts of a scissors fault, movement on which accommodated downwarping of the basin to the southeast and uplift of the Tonuco and Selden Hills area to the northwest and west respectively (pl. 1).

Uplift and eastward tilting of the West Selden Hills fault block was accomplished by movement on the northerly-trending Selden Hills fault. Palm Park Formation is against Rincon Valley Formation indicating probable Pliocene displacement of 2,500 to 3,000 feet. However, late Eocene or Oligocene uplift and tilting, presumably by movement along the same fault, is suggested by the angular relations between Palm Park strata and overlying ash-flow tuffs of the Bell Top Formation immediately east of the fault trace (fig. 2; pl. 1, sec. E-E'). Furthermore, uplift in post-Uvas, pre-Santa Fe (Miocene) time is suggested by the widespread removal of Uvas Basalt and Bell Top rhyolitic rocks from the West Selden Hills fault block before deposition of the Hayner Ranch Formation. West of the West Selden Hills block Uvas Basalt or Bell Top Formation are still present in grabens or horsts beneath the Santa Fe cover (figs. 2, 3). Three major intervals of uplift are thus suggested.

## LOW-ANGLE NORMAL FAULTS

For a distance of about 0.5 mile at the southern margin of the Tonuco uplift, the West Tonuco fault has been covered by Hayner Ranch and underlying transitional strata which form the hanging wall block above a major fault dipping 20° south (pl. 1, sec. D-D'). These hanging wall strata dip moderately east and form the north-striking eastern limb of the broad, faulted anticline described earlier. The formations strike squarely into the Precambrian core of the Tonuco uplift from which they are separated by the low-angle fault. Numerous smaller low-angle faults, some of which are confined to bedding, have imbricated and locally thinned the section in the hanging wall block. To the east, along strike of the major low-angle fault, the hanging wall rocks have been eroded back away from the Precambrian, thus revealing the West Tonuco fault in the footwall block. In this block, Hayner Ranch strata dipping 30° south are separated from the Precambrian, Love Ranch, and andesite-latite volcanic sequence by the steep West Tonuco fault. Westward these formations and structures pass beneath the low-angle fault and are truncated by it (pl. 1, sec. D-D').

At the northwestern corner of the Tonuco uplift a similar low-angle fault is exposed. Structural relations are clearly portrayed in two windows formed by canyons (pl. 1, sec. A-A'). The fault dips 10° to 15° west and separates Thurman breccia beds in the upper plate from andesite-latite volcanic rocks or Precambrian in the lower plate. Although strata in the lower plate dip gently west, breccia beds above the fault dip steeply to moderately west and locally are overturned near the fault surface. The overturning is interpreted as drag, indicating motion of the upper plate from northeast to southwest. The fault and both plates are truncated by movement on the West Tonuco fault.

The low-angle faults are considered to be secondary effects formed in response to late Tertiary uplift of the Tonuco horst. It is suggested that large parts of the thick Tertiary clastic sections that buried the Precambrian and lower Paleozoic rocks during the Tertiary epochs slid off the Tonuco uplift onto the adjoining depressed blocks during major late Tertiary (mainly Pliocene(?)) uplift of the horst. The attitudes of the fault surfaces and drag features indicate movement from uplift toward adjacent basins. Partly by this process of "tectonic denudation" Precambrian rocks were relatively quickly reexposed, at least in time to be reburied by Pleistocene fanglomerates of the Camp Rice Formation.

## MINERAL DEPOSITS

Barite and fluorite veins are the only important mineralization in the San Diego Mountain area. The veins trend north and northwest and are largely confined to Precambrian rocks, although locally cavity fillings are present in the silicified Hayner Ranch Formation caprock of San Diego Mountain. Most of the veins are short, narrow (8 inches to 1 foot thick), and discontinuous, and consist primarily of barite and quartz with minor fluorite. Mining in the past (Johnston, 1928; Dunham, 1935; Rothrock and others, 1946) has been confined to some of the wider fluorite-rich veins, but the area lies idle now. Economic reserves of either mineral do not appear to be substantial.

The age of the ores probably is Miocene. At San Diego Mountains the barite-fluorite veins are truncated by a locally-derived Camp Rice (Pleistocene) conglomeratic tongue that contains clasts of Precambrian rocks, barite-fluorite ore, and silicified Hayner Ranch Formation. The youngest beds containing primary mineralization belong to the Hayner Ranch Formation (Miocene). Ten miles northwest in the Rincon Hills silicified Hayner Ranch strata containing barite, fluorite and psilomelane in veins and cavity fillings is overlain with angular (?) unconformity by unaltered and unsilicified Rincon Valley Formation (Miocene and Pliocene [1 ). These relations support a probable Miocene age for mineralization.

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# *Appendix*

The Santa Fe Group was measured southeast of the Tonuco uplift and north of Cedar Hill, San Diego Mountain Quadrangle from the NW% see. 16 to SE% sec. 6, T. 20 S., R. 1 W. The formations were measured using Jacobs staffs, Brunton compasses, and tape measures. The Munsell Color Company, Inc. soil color chart was used for colors. In the following descriptions younger units precede older ones.

Section 3. Camp Rice Formation (Reference Sections)

*Introduction:* The formation is best exposed in upper slopes of the eastern valley-rim scarp of the Rincon Valley north of Cedar Hill and east of the Tonuco uplift, in W1/2 sec. 9., NW'% sec. 16, and NE1/4, sec. 17, T. 20 S., R. 1 W. Three measured sections (3a, b, & c) illustrate the main features of the Camp Rice Formation in the mapped area.

*Section 3a.* NW1/4SW1/4NE1/4NW1/4 sec. 9; outer valley-rim scarp about 0.5 miles NE of the south end of the Tonuco uplift; elevation of top of section about 4,395 feet (est. from topo. map). Described by J. W. Hawley, March, 1970.

Thickness

Unit Description (feet)

Top of section at surface of caliche caprock zone (soil petrocalcic horizon) forming the uppermost ledge of the valley rim scarp, at the western extremity of the Jornada del Muerto basin. The caprock and underlying strata have an apparent eastward dip of from 1° to 2°. Patches of uppermost Camp Rice sediments (< 5 feet thick) are preserved over the caliche about 100 feet to the east. These sediments are primarily light brown to reddish brown sandy loam but include a lag gravel concentrate of angular to subrounded clasts derived from the southern Tonuco uplift. A veneer of late Quaternary eolian sand and alluvium-colluvium is commonly present on the upper Camp Rice beds in the western Jornada basin.

*Upper Unit (H)—Piedmont-(Toe) Slope Facies*

H5-4 Caliche-sandy loam to loamy sand texture, with scattered fine pebble gravel. White (N9/0 to 7.5YR 8/1-fresh, and 10YR 8/2-weathered) in upper part, to pinkish white (7.5YR 8/2), pink (7.5YR 8/4-7/4) and light brown to reddish brown (7.5YR-5YR 6/4) in lower part. Upper 2 feet well indurated, with discontinuous induration below; inter-grain voids generally impregnated with secondary (pedogenic) calcium carbonate; however, low carbonate sandy loam to sand zones are present in the middle and basal part of the subunit. Platy, massive, cylindroidal and nodular structures are due to various types of cementation associated with stage III and IV carbonate accumulation in a soil K horizon (Gile et al., 1970). The sand fraction is arkosic 11

,..h1-dae resncief of rnlIrtAaA fn c111..nnerIlLar rloofo of rnivArl unlrnnir,

| Unit | Description | Thickness (feet) |
|---|---|---|
| | rocks, quartz, chest, and granite. Diastems probably occur about 6 feet below the surface and at the base of the subunit. | |
| H3-1 | Sandy loam to loamy sand, with scattered fme pebbles, and lithologic composition as above. Three or possibly 4 repeated sequences of light brown to light reddish brown (7.5YR to 5YR 6/4), compact but nonindurated material in 0.5 to 3-foot thick layers; over pinkish gray (7.5YR 7/2) to pinkish white (7.5YR 8/2), 2- to 4-foot thick zones of secondary carbonate accumulation (pedogenic) that are generally weakly cemented by nonindurated; over discontinuous 1- to 2-foot thick zones of pink to light brown (7.5YR 7/4 to 6/4), soft to loose, loamy sand and sand. The upper sequence is capped with a well-indurated caliche layer about 1 foot thick. Diastems marking sequence boundaries occur 10 feet, 16 feet, and 19 (?) feet below the top of subunit, as well as at its base. Total thickness of unit H (exclusive of thin surface veneer above caliche caprock zone). | 35 |
| | *Transitional Unit (GH) —Basin-Floor Facies* | |
| GH2 | Sandy loam with scattered fine pebbles, light reddish brown to reddish brown (5YR 5.5/4), slightly calcareous with local light-colored carbonate-impregnated zones in upper 2 feet; grades down into calcareous loam to clay, light reddish brown to reddish brown (5YR 6/3 to 5/3), pinkish gray (5YR 7/2), and light brown (7.5YR 6/4) in middle 6 feet. The middle zone in turn grades to basal arkosic sand with pebble gravel lenses. The gravel fraction consists of subangular to well-rounded clasts of mainly acid and intermediate volcanics, some quartz, chert, granite, and traces of limestone, basalt scoria, and obsidian. A few mud balls and cobble-size volcanic rock clasts were also noted. | 10 |
| | Covered; possible diastem in this position. | 2 |
| GH1 | Sandstone and conglomeratic sandstone, white (10YR 8/2-fresh) to light brownish gray (10YR 6/2-weathered); grading down into pale brown (10YR 6/3) sand to pebbly sand; with a lenticular(?) body of light brown (7.5YR 6/4) noncalcareous sandy loam to loamy sand 3 to 7 feet above the base of the subunit. Less than 3 feet of light gray (10YR 7/2) silty arkosic sandstone with dense, pebble to cobble-size lime concretions locally caps the sequence. Sandstones occur as discontinuous calcite-cemented zones. Low-angle cross-bedding is common. Lithology of clasts as above (GH2), with pebbles and cobbles; rhyolite pumice noted occasionally. | 16 |
| | Total thickness of unit GH | 28 |
| | Diastem (?) | |
| | *Lower Unit (G)—Fluvial (River) Fades Sand and Gravel* | |
| G | Interstratified sandy loam to loam, clay loam, and sandy clay loam in upper 9 feet; strong brown to brown (7.5YR 5/6-5/4), reddish browh (6YR 5/4 to 6/4) and light gray (9YR 7/3) to light brown (7.5YR 6/4); grades down into light brown to yellowish brown (7.5YR to 10YR 6/4) arkosic sand and pebbly sand. Unit is noncalcareous. | 12 |
| | Gully bottom; base of exposed section | |
| | Partial thickness of unit G | 12 |

| Unit | Description | Thickness (feet) |
|---|---|---|

*Remarks:* Unit H is interpreted as having been deposited on a gentle piedmont-slope surface on the east flank of the Tonuco uplift that was graded to the ancient Jornada basin floor. Compact reddish brown to brown zones immediately below diastems and underlying zones of secondary lime accumulation are considered to be, respectively, soil "B" and "calcic" horizons (Soil Survey Staff, in Preparation, *Soil Taxonomy, U.S.* Soil Cons. Suc., Washington, D.C.). Such pedogenic features have formed on sandy alluvial-colluvial (including minor eolian) deposits derived primarily from older Camp Rice units and secondarily from still older basinfill and bedrock units. Deposits apparently reflect late stage positive movement of the southeastern Tonuco uplift with respect to the central Jornada del Muerto. Buried soils indicate that piedmont-slope deposition was episodic, possibly partly controlled by occasional climatic shifts as well as by tectonism.

Unit GH is interpreted as a vertical sequence of 2 or 3 thin, river-channel sand and gravel bodies each grading up into fine to medium-grained flood-plain deposits. A reddish brown soil "B" horizon is commonly developed in the uppermost part of the unit. Channel sand and gravel bodies appear to be in the form of thin, lenticular sheets. The unit could represent a transitional facies (deposited at the edge of a broad basin floor) that graded to (or intertongued with) a thick complex of river deposits (uppermost unit G) in one direction and piedmont-slope alluvium in the other direction.

Units H and GH together comprise the "Qcrp" mapping unit. Unit G is described in sec. 3c.

*Section 3b.* Location of top of section is in the NE1/4SE1/4NW1/4NW1/4 sec. 16; outer valley rim scarp, about 0.5 mile NE of crest of Cedar Hill and 1 mile south of section 3a; elevation about 4,450 feet (est. from topo. map). Described by W. R. Seager, May, 1968; with minor additions by J. W. Hawley, Mar., 1970.

Top of section at the western extremity of the Jornada del Muerto Basin. Surface is dune covered and has a gentle gradient ($1^\circ$ to $2^\circ$) to the ENE.

*Upper Unit (H)—Piedmont Slope Fades*

| Unit | Description | Thickness (feet) |
|---|---|---|
| H | Sandy loam to loamy sand, with scattered pebbles; alternating reddish brown to light reddish-brown (5YR 4/4 to 6/5) zones 2 to 4 feet thick, and white (n9/0 & 5YR 8/1) zones 0.5 to 4 feet thick. The former are non- to slightly calcareous, while the latter are partly to wholly impregnated with secondary carbonate; horizons of carbonate accumulation are locally indurated. The upper surfaces of reddish brown zones commonly mark diastems, with the lower parts being gradational to underlying carbonate enriched zones. Unit is in fault contact with sand to sandstone of unit G at this locality. | 70 |
| | Partial thickness of Unit H | 70 |

*Remarks:* As in the case of section 3a, unit H is interpreted as a series of alluvial subunits on which soils have developed, reflecting episodic deposition and landscape stability. Reddish-brown zones represent soil "B" horizons that overlie horizons of pedogenic

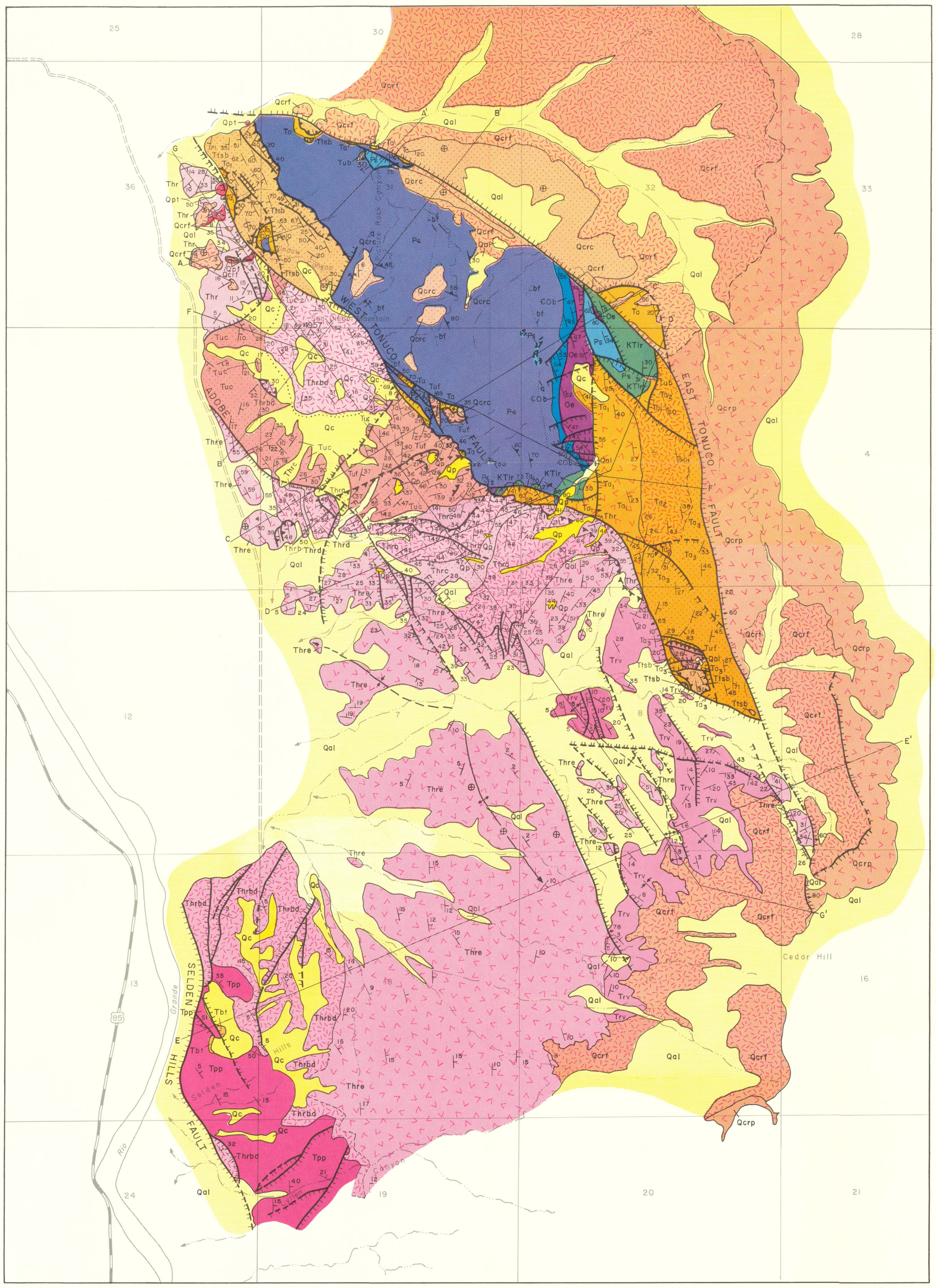
| Unit | Description | Thickness (feet) |
|---|---|---|
| | carbonate accumulation. The uppermost carbonate horizon is probably correlative with the upper caliche zone at section *3a*. | |
| | *Section 3c.* Location of top section is in the SE1/4SW1/4NW1/4NW1/4, sec. 16; outer valley-rim scarp about 900 feet SSW of section 3b; elevation about 4,475 feet (est. from topo. map). Described by Seager and Hawley, May and July 1968. | |
| | Top of section at the western extremity of the Jornada del Muerto Basin. Surface is dune covered and has a gentle (1° to 2°) gradient to the ENE. Locally there is a thin deposit of undifferentiated, late Quaternary alluvium-colluvium (< 5 feet thick) between the dune sand veneer and the eroded surface of the Camp Rice beds. | |
| | *Transitional Unit (GH)?—Basin-Floor Facies* | |
| GH | Sandstone to sand, coarse grained, locally pebbly; gray (N8/0) to light gray (5YR 6/1), with local dark gray zones stained with manganese oxide; discontinuously cemented with calcite; cross-bedded. The sand fraction is coarse-grained and arkosic; pebbles are commonly rounded and include mixed volcanics, granite, quartz, and chert; scattered mud balls and lime concretions. | 8 |
| | Partial thickness of unit GH? | 8 |
| | Diastem? | |
| | *Lower Unit (G)—Fluvial Fades-Sand and Gravel* | |
| G2 | Sandy loam to clay, light reddish brown to reddish brown (5YR 6/4 to 5/3) calcareous with discontinuous white zones of secondary carbonate impregnation. | 7<br>9 |
| G1 | Sand, sandstone, gravelly sand, and conglomeratic sandstone, locally with silty fine sand interbeds; light grayish brown (10YR 6/2) to light gray (n7/ ) and some pale brown to brownish yellow (10YR 7/4-6/6) limonite-stained beds; weakly indurated to unconsolidated; noncalcareous in part; cross-bedding common (very thick trough sets of cross-laminae), but also with thick-bedded, horizontally-laminated to massive subunits. Sand and sandstone are arkosic and medium- to coarse-grained. Conglomeratic and gravelly zones occur as lenticular bodies; gravel fraction mainly rounded pebbles with scattered cobbles of mixed lithology, including mixed volcanics (major constituent), chert, quartz, and granite. One prominent, 4 foot thick lens of pebble to boulder conglomerate, about 50 feet above the base of the subunit, contains subrounded clasts of rhyolite, orthoquartzite, chert (pebbles), basaltic andesite, granite, silty sandstone (Abo), and andesite-latite. The basal 20 feet is mainly limonitic-stained sandstone and conglomeratic sandstone with prominent cross bedding; a 4-inch thick bed of well-indurated nodular carbonate locally occurs at the base. Brown weathering, rounded, spherical to irregularly shaped lime concretions and calcite-cemented sandstone bodies are scattered throughout, but are more common in the lower beds. Varicolored clay and mud balls are also present, along with scattered fragments of bone (large vertebrates) and petrified wood. | 197 |
| | Thickness of Unit G | 204 |

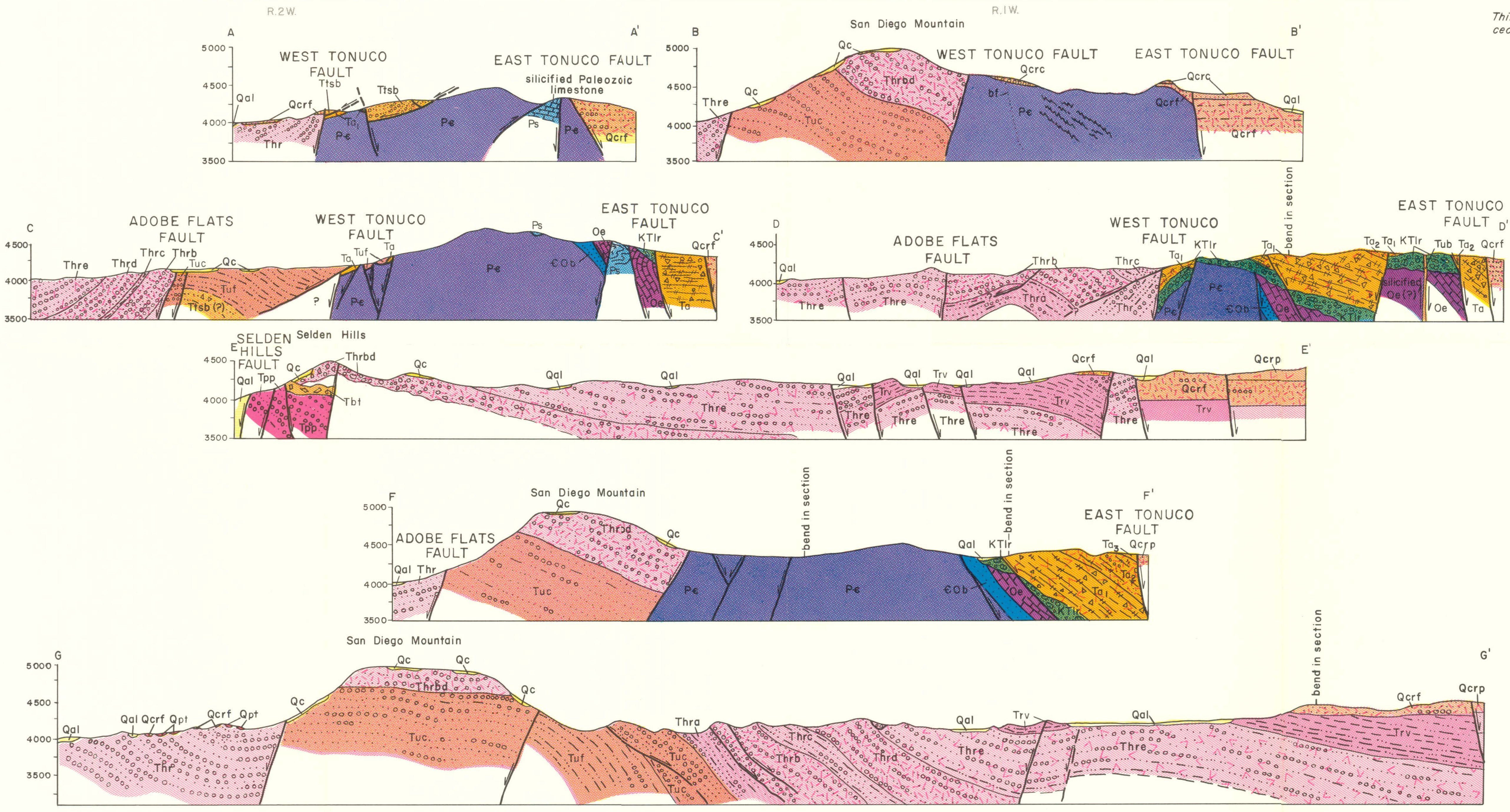
| Unit | Description | Thickness (feet) |
|---|---|---|
| | Total thickness exposed Camp Rice Formation | 260-282 |
| | Angular unconformity. | |
| | *Rincon Valley Formation (basin-floor facies)* | |
| F | Clay, weak red (2.5YR 5/2), poorly exposed in channel bottom. Base of section. | |
| | *Remarks:* Unit GH (?) is interpreted as a possible equivalent of sub-unit GH1 in section 3a. Unit G represents the major body of ancestral Rio Grande deposits in the mapped area, and comprises the Qcrf mapping unit. | |
| | Section 2. Rincon Valley Formation type section: NE1/4N$^{W}$1/4 sec. 8, T. 20 S., R. 1 W. Described by Seager and Hawley, May, 1968. | |
| B | Conglomerate and conglomeratic sandstone, reddish gray (5YR 7/2) to light reddish brown (5YR 6/4); calcareous; very poorly sorted; sandstones commonly silty; gravel fraction consists mainly of sub-angular to subrounded pebbles of rhyolitic volcanics; occasional interbeds of reddish claystone to clay 5 to 8 feet thick; unit is poorly to well indurated, thin- to medium-bedded. Upper contact is an angular unconformity. Unit has the unsorted, heterogeneous appearance of conglomeratic units in the Selden Canyon area. | 180 |
| A | Claystone to clay, reddish brown (5YR 4/4) to pale red (5YR 6/2) or reddish gray (5YR 5/2) weathering pinkish gray (5YR 7/2) to brownish gray (10YR 6/2); gypsiferous in veins and beds 1 to 6 inches thick; unit contains many lenticular beds of cross-bedded gypsiferous, fine-grained sandstone that forms ledges or caps cuestas; unit forms barren badlands and low cuestas. Base of unit is not exposed but appears to be transitional with the underlying Hayner Ranch Formation. | 355 |
| | Partial thickness Rincon Valley Formation | 535 |
| | Section 1. Hayner Ranch Formation type section: SE1/4SE1/4 sec. 6 to NW$^{1}$/4N$^{W}$1/4 sec. 8, T. 20 S., R. 1 W. Described by Seager and Hawley, May 1968. | |
| E | Conglomeratic sandstone to conglomerate, pinkish gray (5YR 6/2 to 7.5YR 7/2) with interlensing brown sandstone and reddish clay (2.5YR); calcareous; poorly to moderately indurated; thin- to thick-bedded, often internally cross-bedded; gravel fraction consists of sub-angular to well-rounded pebbles and cobbles of andesite-latite (65 percent), orthoquartzite-limestone-chert (15 percent), ash-flow tuff (15 percent), basaltic andesite (5 percent), and trace of granite. Conglomerate beds form ledges, hogbacks and dip slopes; 83 feet of soft light reddish brown (5YR 6/3) to grayish brown (15YR 5/2) claystone, mudstone, and minor conglomerate at base of unit forms valley. | 833 |
| D | Alternating and interlensing conglomerate, conglomeratic sandstone, and sandstone, reddish brown (2.5YR 5/4 to 5YR 6/4) to light brown (7.5YR 6/4), containing interbeds of soft, pinkish gray (5YR | 657 |

| Unit | Description | Thickness (feet) |
|---|---|---|
| | 6/2) to weak red (10YR 5/3) mudstone, silty clay, and claystone; calcareous; beds 1 to 3 feet thick; internal cross-bedding in thicker conglomerate and sandstone beds; poorly to moderately indurated; gravel fraction consists of subangular to rounded pebbles, mainly of andesite-latite, flow-banded rhyolite and ash flow tuff with minor basaltic andesite, cherty limestone and orthoquartzite; unit forms hogbacks and dip slopes. | |
| C | Conglomerate, conglomeratic sandstone, silty sandstone, and silt-stone, pinkish gray (5YR 7/2 to 7YR 7/2) to light gray (5YR 7/1); calcareous, poorly indurated, thin- to medium bedded; conglomerates are channel-shaped, poorly sorted, and consist mainly of rounded to subrounded pebbles and cobbles of andesite-latite, with flow-banded rhyolite and minor basaltic andesite, Paleozoic limestone, and chert; unit forms slope or strike valley, and is distinctly lighter colored than unit 4 or 2. | 242 |
| B | Sandstone, conglomeratic sandstone, and conglomerate, reddish brown (2.5YR 5/4) to weak red (10YR 4/3 to 5/3), and interbedded light reddish brown (2.5YR 6/4) mudstone; calcareous; moderately to well indurated; lenticular bedding to 5 feet thick contains internal trough-shaped cross-bedding; gravel fraction consists of subangular to rounded pebbles of andesite-latite, rhyolite, and minor basaltic andesite; unit forms hogbacks, dip slopes, cliffs, and ledges. | 653 |
| A | Interbedded sandstone to clayey siltstone and conglomerate to sand-stone, weak to pale red (10R 4/3, 5/2, 6/2); calcareous; mostly poorly to moderately indurated; sandstone and conglomerate occurs in lenticular, ledge-forming beds 5 to 15 feet thick and is well-indurated; gravel fraction is mainly pebbles of rounded to subangular andesite-latite, with flow-banded rhyolite, ashflow tuff, and minor basaltic andesite; unit forms mainly a ledgy slope or strike valley. Top of unit is not exposed owing to faulting; contact with underlying "unnamed transitional unit" is a channelled surface with less than 10 feet relief. | 375 |
| | Total thickness of Hayner Ranch Formation | 2760 |

# *Index*

Numbers in boldface indicate main sections




# GEOLOGIC MAP OF THE SAN DIEGO MOUNTAIN AREA
# DOÑA ANA COUNTY, NEW MEXICO

by William R. Seager, John W. Hawley, Russell E. Clemons, 1971

SCALE

0 0.5 1 Mile

BULLETIN 97 PLATE I

## EXPLANATION

**MIDDLE PLEISTOCENE TO RECENT**

Qal

**Alluvium**

*Chiefly stream deposits of larger arroyos, sands, silts, and gravels of Rio Grande flood plain and windblown sand*

Qc

**Colluvium**

*Coarse carbonate-cemented conglomerates forming veneers on slopes of San Diego Mountains and West Selden Hills*

Qp, Qpt

**Pediment gravels**

*Coarse carbonate-cemented conglomerates forming veneers on erosion surfaces of middle to late Pleistocene age. Travertine (Qpt) occurs in old valleys and along faults.*

*ANGULAR UNCONFORMITY*

**Santa Fe Group**

**EARLY TO MIDDLE PLEISTOCENE**

Qcrp, Qcrc, Qcrf

**Camp Rice Formation**

*Consists of lower river-deposited yellow to gray sandstone and conglomerate of early to middle Pleistocene age (Qcrf), correlative with Camp Rice Formation in the El Paso area. Overlain by intertonguing piedmont-slope and basin-floor deposits with multiple paleosols. Thin conglomerate beds (Qcrc), derived from San Diego Mountain intertongue with both facies*

*ANGULAR UNCONFORMITY*

**PLIOCENE & MIOCENE(?)**

Trv

**Rincon Valley Formation**

*Pink gypsiferous claystone, siltstone, and minor conglomerate in lower 350 feet that form extensive badlands. Grades into poorly sorted, reddish-brown conglomerate and conglomeratic sandstone in upper 180 feet.*

**MIOCENE & PLIOCENE(?)**

Thr, Thre, Thrd, Thrc, Thrb, Thra, Thrbd

**Hayner Ranch Formation**

*Pebble-cobble conglomerate, conglomeratic sandstone, siltstone, and claystone sequence divisble into five members on the basis of grain size and color variations. Thra: light-gray to buff siltstone, claystone, and conglomerate that pinches out southward. Thrb: red to orange conglomerate and conglomeratic sandstone member. Thrc: light-gray to light-tan siltstone, claystone, and conglomerate that pinches out southward. Thrd: red to orange conglomerate and conglomeratic sandstone member; continuous with Thrb where the medial Thrc member is not present. Thre: tan to yellow-brown conglomerate and conglomeratic sandstone member. In the northern Selden Hills Thrbd is a coarse, red boulder conglomerate derived from flowbanded rhyolite and Uvas Basalt*

**MIOCENE**

Tuc, Tuf

**Unnamed transitional unit**

*Consists of an upper grayish-red conglomerate, conglomeratic sandstone, and mudstone sequence (Tuc) underlain by red siltstone, mudstone, shale, and minor andesite-latite-welded tuff sandstone and cobble conglomerate (Tuf).*

**OLIGOCENE-MIOCENE**

Ttsb, Tub, Tbt

**Thurman Formation**

*Consists mainly of about 700 feet of alternating pale-purple rhyolite sedimentary breccia channel deposits and red mudstone in graded units averaging 30 feet thick (Ttsb) which probably are correlative with thin similar strata in the Thurman Formation of the Rincon Hills. Tub: Uvas basaltic andesite dikes; similar rocks dated at 26 m.y. in Selden Canyon. Tbt: Bell Top Formation; tan ash-flow tuff that occurs as small faulted blocks in the northern Selden Hills; similar flows at base of Thurman Formation in Rincon Hills dated at 34 m.y.*

**EOCENE-OLIGOCENE (?)**

Tpp

**Palm Park Formation**

*Andesite-latite boulder conglomerates, various andesite-latite sandstones, siltstones, mudstones, and tuffs that are greenish, light-gray, red, and light-purple; includes a 100-foot-thick non porphyritic andesite flow exposed in Lytten Canyon. It is not known whether the Palm Park Formation overlies or is equivalent to part or all of the andesite volcanic and sedimentary sequence*

Ta, $Ta_3$, $Ta_2$, $Ta_1$, Tpp

**Andesite volcanic and sedimentary sequence**

*Equivalent in part to the Orejon Andesite in the Organ Mountains. Separated into three members on the basis of vertical changes in lithology and color. $Ta_1$: light-gray, massive laharic(?) tuff breccias, tuffs, lapilli tuffs, andesite-latite pebble to boulder conglomerate, and volcanic-derived sandstone. $Ta_2$: volcanic-derived red and purple siltstone, mudstone, and sandstone with few thick channel conglomerates; interbedded laharic(?) tuff breccias in upper 100 feet. $Ta_3$: light-grayish-blue to purple andesite porphyry, and laharic tuff breccias in massive beds; 40 feet of mixed cobble conglomerate at base.*

*DISCONFORMITY*

**LATE CRETACEOUS OR EARLY TERTIARY**

KTlr

**Love Ranch Formation**

*Reddish-gray boulder conglomerate derived entirely from El Paso Limestone, Bliss Sandstone, and Precambrian granite; contains minor red shale and 5-foot-thick ostracode-bearing limestone bed.*

*ANGULAR UNCONFORMITY*

**PALEOZOIC**

Ps

**Silicified Paleozoic limestone**

**ORDOVICIAN**

Oe

**El Paso Group**

*Thin-to medium-bedded, gray, fossiliferous limestone with a mottled appearance due to numerous thin siliceous and argillaceous streaks, flakes, and bands.*

**CAMBRIAN AND ORDOVICIAN**

€Ob

**Bliss Sandstone**

*Tan quartzite and dark-brown hematitic and glauconitic thin-bedded sandstone*

*NONCONFORMITY*

**PRECAMBRIAN**

p€

**Precambrian rocks**

*Granite, granitic gneiss, biotite schist, migmatites, and diabase and pegmatite dikes*

Geologic contact
*Dashed where uncertain*

Normal fault
*Showing downthrown side; dashed where approximately located.*

Low angle normal fault
*Younger rocks on top of older; barbs on hanging-wall block; dashed where approximately located.*

Thrust fault
*Older rocks above younger; T on overthrust block.*

Anticline
*Showing trace of axial plane and direction of plunge.*

Syncline
*Showing trace of axial plane and direction of plunge.*

30
Strike and dip of beds

75
Strike and dip of overturned beds

Strike of vertical beds

Horizontal beds

Strike and dip of foliation

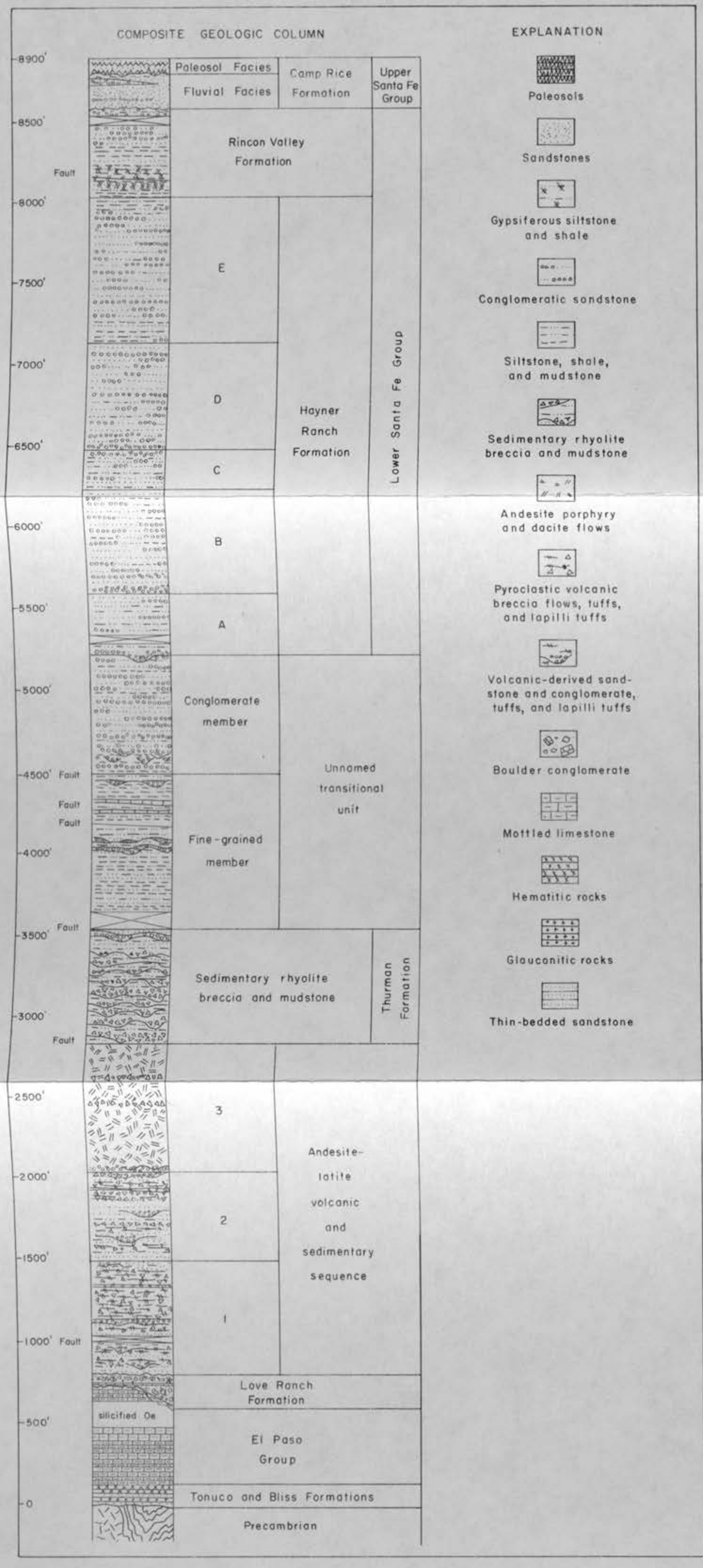
A — A'
Line of structure section

Mine; barite, fluorite, quartz

Quartz veins

Barite-fluorite veins

NMBGMR Map 482




COMPOSITE GEOLOGIC COLUMN