MEMOIR 18

Geomorphic Surfaces and Surficial Deposits in Southern New Mexico

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Abstract

Bedrock types, which served as sources for the surficial sediments, are Paleozoic limestone, dolomite, sandstone, and shale, Tertiary volcanic rocks, and monzonitic intrusives. The area is block-faulted with major faults along the mountain fronts but that in places strike across country disrupting old geomorphic surfaces.

The Dona Ana Mountains are an ellipsoidal structural dome whose geographic parameters can be described by the ellipse, $\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1$. Their major axis parallels the trend of the fault-controlled Rio Grande trench and the strike of the Robledo fault. Morphometric features conform to structural components of the dome. Displacements of as much as 200 feet along faults and axes of the dome took place in late Pleistocene time. Minor tectonic adjustments have continued into the Recent.

Geomorphic surfaces are grouped as alluvial fans, piedmonts, and aprons that adjoin the mountain fronts, basins and scarplet surfaces, and valley-border surfaces that are adjacent to the Rio Grande. Profiles of alluvial fans are described in terms of elevation and distance by $Y = 1/a + bX$ and the piedmont and aprons by $\log Y = a + bX$. Basins and adjoining areas are described as $Y = a + bX$. Radii of curvature of contours and centers of radii of these land forms have specific geometry. Sediment distribution from source areas is related to the spatial geometry.

The geomorphic surfaces range in age from historic time to post late Kansan–Illinoian. The oldest surface is dated relative to a subsurface vertebrate fauna and younger surfaces by radiocarbon. A valley-border surface and its mountain front analogue are multicyclic in origin and are x zoo to 4900 years old. The late Wisconsin Picacho surface is more than 955o years old.

Distribution of the surficial deposits' rock constituents relates to the geometry of land forms and in places is independent of the present drainage net. Clay-mineral assemblages are similar; consequently, cation-exchange capacities of fine-earth fractions are related to amount of clay in the sediment. Surficial deposits commonly are layered and separated by paleosols that are usable stratigraphically in delineating and relating bodies of sediment.

On the fans and piedmont, organic carbon and carbonate content and depth to carbonate horizon are related to the orographic-climatic regimen controlled by the rise up the mountain front. In the valley-border surface sequence, increase in redness of the soil B horizon, amount of clay in and thickness of the B horizon, and amount of carbonate in and thickness of the carbonate horizon are related to age of geomorphic surface. Complications are introduced by possible climatic changes of the pluvials and interpluvials.

The origin of carbonate horizons (ca and K horizons or caliche and calcrete) is in part pedologic, in part the result of ground-water deposition, and in part the result of surface-water deposition. In low-calcium-content sediments, the source of carbonate is eolian dust that falls on the ground surface, is dissolved and transferred downward, and precipitated in a subsurface zone.

Detailed analysis points out the discrepancies that occur and that are to be expected in the radiocarbon dates of the inorganic carbon of the carbonate in caliche.

Introduction

A co-ordinated study of the landscapes and soils of a desertic area in southern New Mexico began in 1957 and is continuing. The author's participation was full-time between August 1957 and August 196o and during short-term assignments several times a year through 1965.

Objectives of the original study were to delineate the kinds of land forms and soils in the area and to determine the nature of their origin within the physiographic history of the region. Several requirements were desired. There should be various kinds of land forms presumed to be characteristic of a desertic area. The land forms should range widely in age. They should be developed on rocks and sediments of varying mineralogic and chemical composition. Soils formed on the land forms and in the materials should vary widely in kind.

These requirements were fulfilled in an area near Las Cruces which bounds the Rio Grande in extreme southern New Mexico about 35 miles north of the international boundary and 4o miles northwest of El Paso, Texas. The study area (pls. 1 and 2) is bounded on the north by latitude 32° 32' N. and on the east by longitude 106° 33.8' W. and comprises about 410 square miles. The area includes the southern tier of sections of T. **20** S. and extends southward to and includes the northern tier of half sections in T. 24 S. It includes the eastern two rows of sections in R. 1 W. and extends eastward to and includes the western row of sections in R. 4 E. The entire area is in Dona Ana County, New Mexico, and in adjacent parts of the Bear Peak, Las Cruces, Organ Peak, and San Diego Mountain quadrangles.

The environment of the area is desertic. Shreve (1942) considers it a part of the Chihuahuan Desert, while Gardner (1951) defines it as *desert-plains grassland* and Humphrey (1958) prefers *desert grassland.* Annual rainfall in the Rio Grande Valley at New Mexico State University (elevation 3890 feet) is 8 to 9 inches, about half of which falls in July, August, and September. Forty years of records show an average temperature for July of 8o° F (Hardy, 1941). Unofficial records for some 3o years at the Boyd Ranch in the Organ Mountains to the east of Las Cruces (elevation of 6200 feet) show an annual rainfall of about 15 inches.

Vegetation is sparse and is dominated by shrubs (Gardner) such as creosote bush *(Larrea divaricata),* tarbush *(Flourensia cernua),* mesquite *(Prosopis juliflora),* and Mexican tea *(Ephedra* trifurca). Spanish bayonet *(Yucca elate)* and cacti (Opuntia *leptocaulis* and 0. *macrocentra) are* common. Grasses comprise less than one per cent cover (Gardner). Dominant types are fluff grass *(Tridens pulchellus),* burro grass *(Scleropogon brevifolius),* bush muhly *(Muhlenbergia porteri),* and black grama *(Bouteloua eriopoda).*

Physiographically, the area is part of a complex of structural basins, with or without through-flowing streams, which is a common feature along the Rio Grande in New Mexico (Bryan, 1938). Near Las Cruces the southeasterly flowing Rio Grande (fig. IA; **B.2, 0.0-D.5,** 5.0) trenches the longitudinal axis of the southern Jornada (fig. 1B; E.5, 1.o) and continguous La Mesa basins (fig. IA; B.o, 4.5) at an angle of about 45 degrees, being trenched between the Robledo Mountains (fig. rA; B.4, 1.5) on the west and the Dona Ana Mountains (fig. fA; D.o, o.5) on the east in the northwestern part of the area, and to the south cuts below the Jornada and La Mesa basins and the alluvial fans and piedmont descending westward from the Organ Mountains (fig. IB; 0.7, 1.5-H.5, 5.o). A stepped sequence of erosion surfaces rises from the river's flood plain to the mountains, basin surfaces, or alluvial fans bounding the river's trench (fig. and pl. 2).

Four miles north of Las Cruces, the internally drained Jornada basin extends northward between the Dona Ana Mountains and the San Augustin—San Andres mountains (fig. 1B; H.3, o.o-G.7, 1.5). Alluvial fans descend from the mountains and coalesce laterally into alluvial-fan piedmonts that, in turn, slope to surfaces of basins (fig. 1B; E.4, 0.2). Younger alluvial fans that coalesce laterally as alluvial-fan aprons are inset but also superimposed on the older fans and piedmont. An extensive erosion surface marked by numerous scarplets a few inches to a few feet high extends from the basin surfaces into the bounding alluvial-fan apron (fig. 1B; F.o, 1.3). Rock pediments generally are confined to the footslopes of the mountains and, with the exception of the Dona Ana Mountains area, are small in extent.

The Rio Grande Valley is tectonically controlled. Numerous block faults, some en echelon, bound the valley. Deformed sedimentary strata record a complex downdropping of a structural depression or grabens and a relative uplift of adjacent horsts (Bryan; Kottlowski, 1958, 196oa; Ruhe, 1962). Mountain fronts also are marked by complex normal, reverse, and thrust faults.

In a collaborative study such as this, the work of many individuals is involved, and the co-operation of J. W. Hawley, L. H. Gile, R. B. Grossman, and F. F. Peterson is acknowledged. Laboratory data, where indicated in the report, are from the Soil Survey Laboratory, Soil Conservation Service, Lincoln, Nebraska. To date, several preliminary notes have been published (Gile, 1961; Ruhe, 1962, 1964; Gile, Peterson, and Grossman, 1964; Hawley, 1965). This report completes the author's contributions to the over-all study. Necessarily, all analytical calculations and interpretation of data are the sole responsibility of the author.

Figure 1a

AERIAL PHOTOGRAPH MOSAIC OF STUDY AREA

Las Cruces quadrangle. Area includes a strip 21/2 miles wide across north edge of mosaic. (Location given in text by grid, such as G. 5, 2. 7)

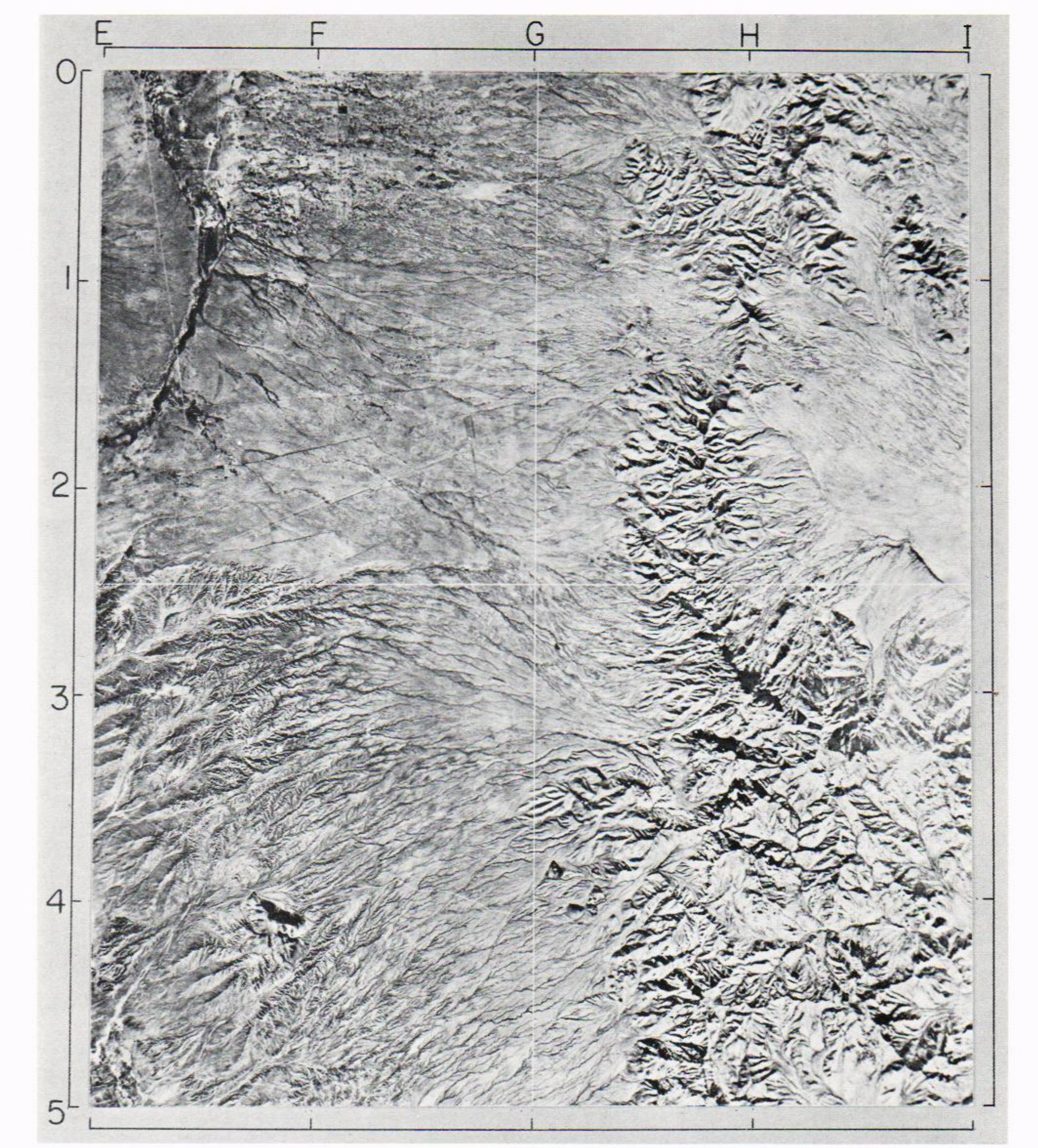


Figure 1b

AERIAL PHOTOGRAPH MOSAIC OF STUDY AREA

Organ Peak quadrangle. Area includes a strip 21/2 miles wide across north edge of mosaic. (Location given in text by grid, such as G. 5, 2. 7)

Bedrock

Bedrock crops out on the land surface in the mountainous areas, on rock pediments bounding the mountain fronts, and in the walls of canyons and arroyos. No attempt was made to place the various rock masses in a stratigraphic sequence, as this has been done adequately by a number of previous workers (Dunham, 1935; Kottlowski et al., 1956; Kottlowski, 1958, 1960a, 1960b; Bachman and Myers, 1963). Reference to these studies will furnish a necessary background. Instead, the rock masses were mapped in the field utilizing aerial photographs on a scale of 4 inches to 1 mile. Such field mapping units were transposed to quadrangle base maps of a scale of **2** inches to 1 mile. Later, the cartographic units were reduced and slightly generalized to conform to the map scale of Plate 1.

This approach to bedrock was used because the interest in it was strictly from a viewpoint of rock masses supplying materials to the unconsolidated sediments of the area. These sediments generally are indicated on geologic maps by the symbol *Qal.* A major objective of this study was to delineate components of the *Qal* and fit them into the physiographic history of the area. Bedrock is important in the sense of a source area of sediment. As most surficial sediments substantially postdate the bedrock, the ages of the bedrock are not too significant in the reconstruction of the geomorphologic history.

Distribution of rock masses and their compositions are important from the pedological point of view. They are parent materials of soils, and sediments derived from them also formed parent materials of soils.

DISTRIBUTION

The bedrock of the area can be broadly grouped as volcanic, intrusive, and sedimentary rocks. The volcanic rocks are dominantly rhyolite and an undifferentiated assemblage of andesites and latites. Two small, isolated eruptives of basalt are near Apache Canyon west of the Rio Grande and a third is in sec. 16, T. 21 S., R. 1 E. Intrusive rocks are monzonite, quartz monzonite, and syenomonzonite. Sedimentary rocks are limestone, dolomite, sandstone, siltstone, and shale.

Rhyolite bedrock occupies 17.8 square miles with two dominant areas in the southern Organ Mountains (9.33 sq. mi.) and in the Dona Ana Mountains (5.97 sq. mi.). Smaller areas are in Quartzite Mountain (1.02 sq. mi.), Robledo Mountains (0.82 sq. mi.), Picacho Mountain (0.46 sq. mi.), and Goat Mountain (0.20 sq. mi.) in the SW¼ sec. 8, T. **22** S., R. **2** E. Dunham named the mass in the Organ Mountains the *Soledad Rhyolite* and considered it Tertiary in age. Kottlowski (196oa) agreed. The Soledad Rhyolite is deeply incised by three major canyons, Ice, Soledad, and Achenback. Large alluvial fans composed of rhyolite gravel debouch from these canyons and descend westward toward the Rio Grande. A minor rhyolitic tuff crops out at La Cueva (SW¼ sec. 1, T. 23 S., R. 3 E.) and was specifically named Cueva Tuff by Dunham. The other rhyolites of the area will be informally designated by the name of the outcrop locality.

Undifferentiated volcanics crop out in four areas and occupy 7.1 square miles. The dominant area is in the Dona Ana Mountains (5.46 sq. mi.), where the rocks are mainly andesites and latites. Three minor areas are along Box Canyon (0.74 sq. mi.) near Picacho Mountain, along Fillmore Canyon (0.48 sq mi.) in the Organ Mountains, and at Hardscrabble Hill (0.42 sq. mi.) in the San Andres Mountains (secs. 13, 14, 23, 24, T. **21** S., R. 3 E.). Dunham specifically named the Orejon Andesite that occurs mainly high on the west sloping flank of the Organ Mountains along Fillmore Canyon. The other rocks will be designated informally by geographic locality.

Intrusive rocks occupy 9.47 square miles of the area and occur in the Organ—San Augustin mountains (6.2 sq. mi.) and Dona Ana Mountains (3.27 sq. mi.). In the former area, they are monzonites and quartz monzonites, and in the latter area range to syenomonzonites. They are of Tertiary age (Dunham; Kottlowski, 1960a).

Commonly, the differing rock types are responsible for differing landforms in the mountains. Near Fillmore Canyon in the Organ Mountains (fig. 2A), summits and slopes are more rounded on Soledad rhyolite. In contrast, monzonite and quartz monzonite form the jagged "Needles." The subdued, rounded slopes on the west flank of the mountains are on limestone, dolomite, and shale. Along the lower end of Fillmore Canyon, such subdued slopes are interrupted locally by the Orejon Andesite. Cueva rhyolitic tuff forms a jagged hogback outlier. In the Dona Ana Mountains monzonite and syenomonzonite project from summits and slopes as ridges (fig. 2B). Volcanic rocks usually underlie the more rounded topography.

COMPOSITION

In treating rock masses as sources of materials of sediments, it is not only necessary to know their location and distribution but also to know their composition. Consequently, the rocks were examined in the field and analyzed in the laboratory, both macro- and microscopically. For example, the rock suites of the Organ Mountains (fig. 2A) are petrologically distinctive. Soledad rhyolite has a weak red (10YR 4/2)* or gray (N 5/0) matrix with white (N 8/0) and pinkish gray (7.5YR 7/2) phenocrysts. Its texture is porphyritic with feldspar laths in a microcrystalline mosaic of quartz and feldspar. Phenocrysts are orthoclase and microcline. Commonly, the matrix shows a microflow structure oriented around the phenocrysts (fig. 3A). Quartzite Mountain rhyolite differs petrographically with a distinctive mosaic of orthoclase laths (fig. 3B).

In the field, the weak red and gray varieties of Soledad rhyolite are commonly intercalated with obsidian (rhyolite vitrophyre). The volcanic glass is black (N 2/0) with dark-

*Munsell soil color chart, dry for rocks, moist for soils.

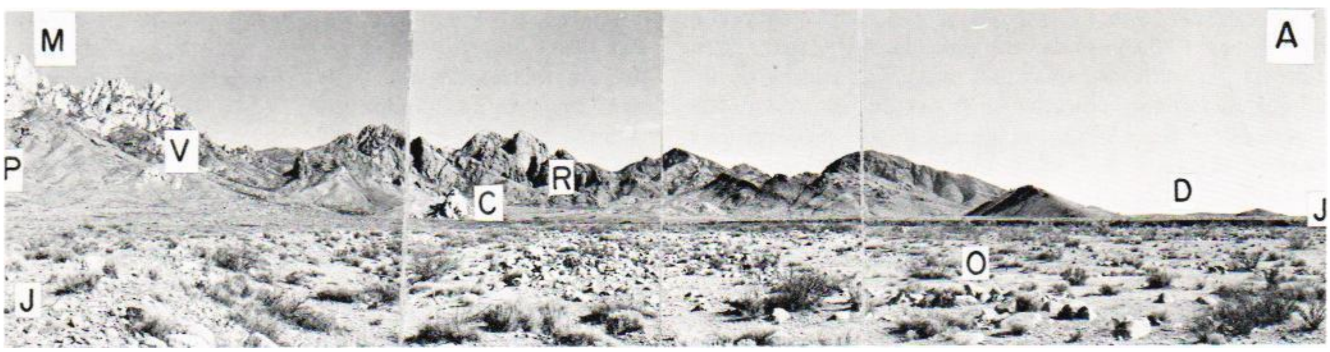
gray phenocrysts. The matrix is glassy and often has a laminar flow structure with an orientation of feldspar phenocrysts and laminae of glass. Perlitic tension cracks are very common in the glass matrix (fig. 3C).

Cueva tuff is pale yellow (2.5Y 8/4) with common white (N 8/o) specks. Feldspar and quartz phenocrysts are randomly oriented in a microcrystalline matrix but are generally elongate along one axis. The quartz phenocrysts have serrated edges, whereas the edges of the feldspars are linear and nonserrated (fig. 3D).

Orejon andesite varies in color from gray (N 6/o), speckled white (N 8/o), and very dark gray (N 3/o) to green (5G 4/0 and olive (5Y 4/4) and to blue (5B 5/I). It is porphyritic with feldspar (orthoclase, oligoclase, and andesine) phenocrysts in a microcrystalline matrix. The green and olive varieties have abundant epidote *nocrysts that give the over-all greenish hue to the rock, either in hand specimen or in outcrop (fig. 3F). Color of the blue variety appears to be the result of an abundance of blue to black opaques embedded in the matrix.

The monzonite is pinkish gray (5YR 7/2) and gray (5YR 7/1) speckled with black (5YR 2/I), very dark gray (N 3/o), or white (N 8/o). The rock is a granitoid mosaic dominantly of orthoclase with common plagioclase (oligoclase) and minor hornblende and biotite. In the quartz-monzonite variety, quartz is a minor constituent. In some specimens, plagioclase is the dominant feldspar and biotite is the major accessory mineral (fig. 3E). In contrast, the syenomonzonite of the Dona Ana Mountains is light brown (7.5YR 6/4) speckled gray (N 6/o). Orthoclase is very dominant with plagioclase in minor amounts. Biotite is the common accessory mineral.

Paleozoic limestones in the Organ Mountains are very dark gray (N 3/o) to black (N 2/0) and usually are a fine-



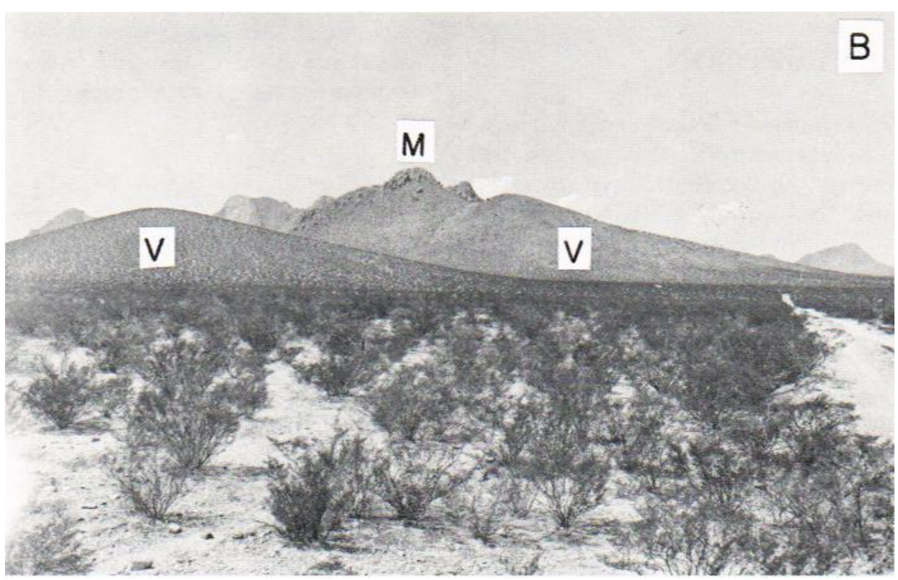


Figure 2

INFLUENCE OF ROCK TYPES ON LAND FORMS

(A) In Organ Mountains the jagged "Needles" are formed by monzonite, *M*. Sloping western flank is on Orejon Andesite, *V*, and Paleozoic limestones and shales, P. Rhyolite, R, summits are rounded. The hogback La Cueva, C, is formed of rhyolite tuff, andesite, and conglomerate. The Dona Ana surface, D, stands above the jornada surface, *J*, and the Organ surface, 0, is inset below the Jornada. (B) Jagged summit ridges of *the* Dona Ana Mountains are syenomonzonite, M, and the smoother, rounder slopes are on volcanics, V, such as andesite, lathe, and rhyolite.

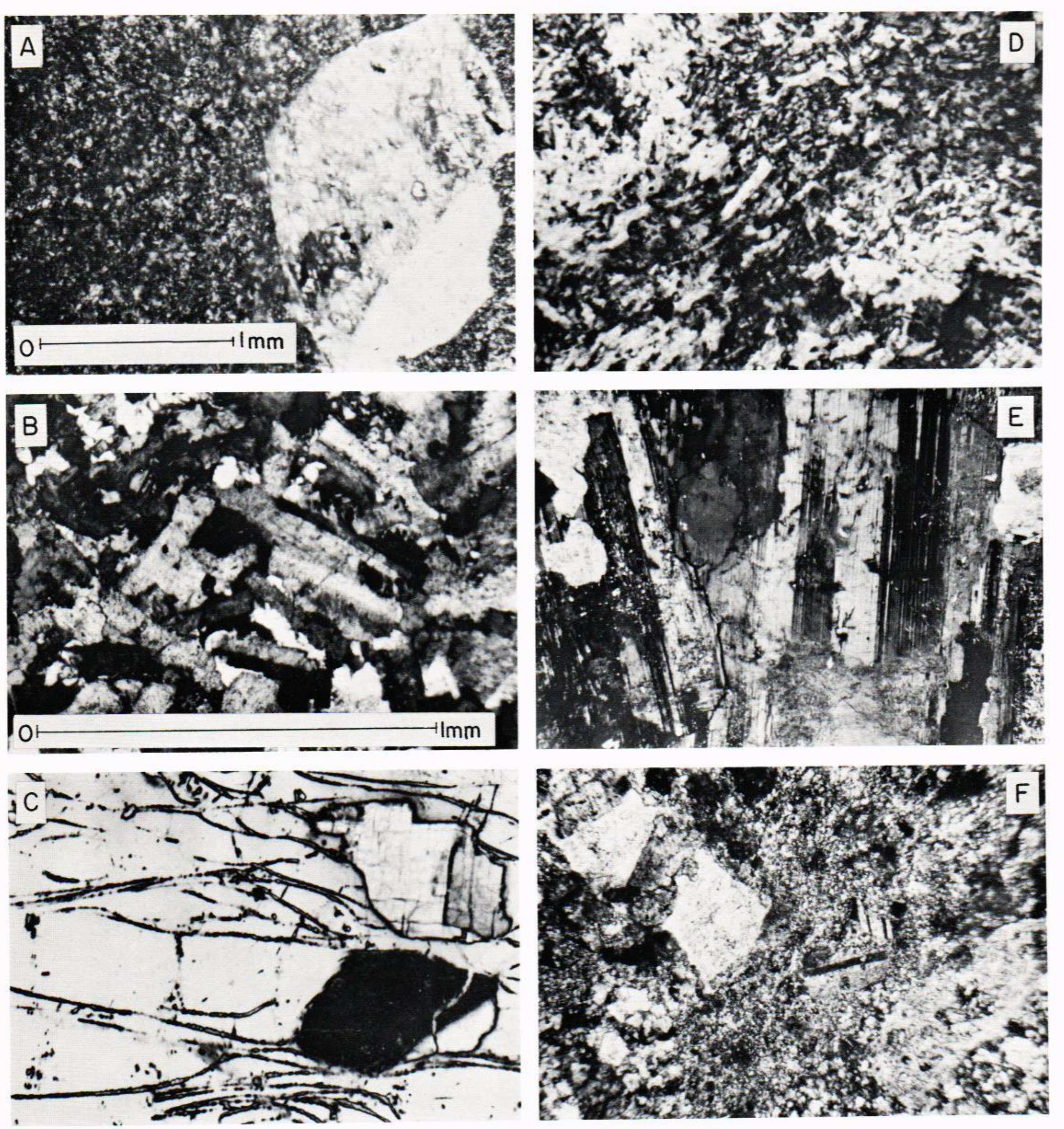


Figure 3

PHOTOMICROGRAPHS OF ROCK TYPES

(A) Soledad Rhyolite. (B) Quartzite Mountain rhyolite. (C) Soledad obsidian. (D) Cueva tuff. (E) Organ Mountain monzonite. (F) Orejon Andesite. (Scales of A, C, E and B, D, F are given in A and B, respectively) grained mosaic of calcite crystals with larger grains inset in the matrix. Cross sections of mollusk valves are common and are marked by coarse-grained calcite. Small vein fillings of calcite transect the rock. In rock outcrops, nodules of black chert weather from the face as, for example, on the slopes of Bishops Cap. In the San Andres and Dona Ana mountains, some limestones are light yellowish brown (10YR 6/4) and speckled white (10YR 8/1). In thinsection, such rocks have abundant voids which have oriented coatings of iron oxide. Light yellowish-brown or olive chert nodules occur in the limestone. It is important to note the presence of black or olive chert because both are prominent constituents in one of the unconsolidated deposits that underlies the Jomada and La Mesa basins.

Shales associated with the dark-gray and black limestones are olive (5Y 5/4), olive gray (5Y 4/2), and dark gray (N 4/o). They are fine-grained, finely laminated, and fissile parallel to the bedding. In thinsection, laminae of clay are intercalated with layers of silt-size quartz grains. Laminae are parallel and usually undulatory. Small quartz and calcite veins normally and obliquely transect the bedding.

Red beds in the San Andres Mountains are sandstones, siltstones, and shales. They are weak red (10R 4/2) with parallel laminar bedding. On a weathered face, more strongly cemented laminae commonly project, resulting in a corrugated surface. In thinsection, bedding is emphasized by denser concentrations of iron oxide in definite layers. Minor amounts of calcite may be present and usually are oriented along the bedding. The rocks may be weakly effervescent when tested with acid in the field.

These are a few examples of the 130 samples of rocks that were studied under the microscope as well as in the field and which represent the major rock types in the area. In addition, samples of some rocks beyond the area were studied. This was necessary because of the presence of erratic materials in some of the unconsolidated sediments within the study area. For example, granite of presumably Precambrian age is present on the east side of the Organ and San Andres mountains (Dunham; Kottlowski, 1960a). Major canyons, such as Bear Peak and Lohman in the San Andres Mountains, head in the granite terrain. As a result, granitic gravel is an admixture in the sediments on the west side of the mountains.

The granitoid rocks range from fine-grained aplites to coarse-grained pegmatites. Some of the feldspars are characteristically light reddish brown (5YR 6/3), pink (5YR 7/4), or pinkish white (5YR 8/2) and are orthoclase or microcline. Quartz is abundant and with the feldspars forms the granitoid fabric of the rock. Biotite is the dominant accessory mineral. This rock commonly is confused in the field with the quartz monzonite of the Organ Mountains. The granite is an important constituent in one of the unconsolated deposits in the Jomada and La Mesa basins.

Structure

It is known that the Las Cruces area has been subjected to considerable tectonic disturbance (Dunham; Bryan; Kottlowski, 1953, 1958, 196oa,b; Ruhe, 1962, 1964; Hawley). The Rio Grande Valley is structurally controlled with numerous block faults, some en echelon, bounding the valley (Bryan). Deformed sedimentary strata record a complex downdropping of a depression or graben and a relative uplift of adjacent horsts (Kottlowski, 1958). Fronts of the mountains and within the mountain masses themselves are complex normal, reverse, and thrust faults (Dunham; Kottlowski, 1960a). Relative displacement of one mass versus another has had profound effect upon erosion and subsequent deposition of sediments and the formation of land forms. Some of the major faults are shown on Plate 1.

FAULTING

The most continuous and major fault bounds the Roble-do Mountains on the east, trends southward on the east side of Picacho Mountain, and strikes S. 23° W. and then S. 35° W. for more than 16 miles. Kottlowski (1953; 1960a) recognized the fault, and it was later named the *Robledo* (Ruhe, 1962) and is now so recognized (Hawley).

There are many lines of field evidence for the Robledo fault. North of Apache Canyon and in many of the canyons that ascend from the Rio Grande flood plain to the Robledo Mountain front, beds of Paleozoic rock are ruptured, displaced, and upended at the fault location. Similarly, cemented beds in the dominantly unconsolidated fan gravels that descend toward the Rio Grande are disordered along the fault. In the north wall of the arroyo on the south side of Picacho Mountain, cemented beds in the gravel are disjointed and change attitude from essentially horizontal to nearly vertical at the fault. On the south side of the arroyo, a gully descends northward to the arroyo along the fault strike. In the west slope of the gully, volcanic rocks are exposed below a capping gravel. Only gravel is exposed on the east slope of the gully (fig. 4A). The west side is upthrown and the east side is downthrown.

Similar displacements of sediments occur along the strike of the fault to near U.S. Highway 7o. Beyond this point, thick, unconsolidated deposits blanket the area, so direct observation is precluded. However, projection of the strike coincides with the trend of a scarp that extends to the southern limit of the area and beyond (fig. IA; B.7, 4.1B.3, 5.o). The trace of the Robledo fault is discernible on the aerial photograph mosaic.

The scarp vertically displaces the La Mesa surface about zoo feet along U.S. 70. To the southwestward along the scarp, relief gradually decreases. At Norwood Ranch, it is 135 feet and at Perry Ranch, it is 75 feet. At Brook Tank, the scarp is hardly discernible in the field (Ruhe, 1962). Progressively greater relief to the northeast indicates not only that La Mesa surface is downthrown east of the Roble-do fault but that the entire downthrown block probably is tilted to the northeast.

The Robledo fault can be traced 14 miles across country by direct field evidence and an additional 22 miles on the indirect evidence of the scarp. Somehow, Dunham failed to recognize the fault origin of the scarp, considering it solely erosional. He separated his "First Erosion Surface" to the west from his "Jornada—La Mesa Surface" to the east.

West of the Rio Grande, many minor faults have strikes oblique or transverse to the Robledo fault (pl. 1, secs. I, 2, **12,** T. 23 S., R. 1 W.). Many show displacement of volcanic rocks and gravels in arroyo walls or on gully slopes. On the north wall of the arroyo at Box Canyon dam, very distinctive slickensides are preserved (fig. 4C).

The abrupt abutment of bedrock and unconsolidated gravels in arroyo walls or across gullies is a very common fault feature in the area. In the SW¼ sec. 8, T. 21 S., R. 1 E. (pl. 1) and on the right-hand (northeast) side of the gully, limestones crop out on the surface (fig. 4B). On the left-hand side, the bedrock dips steeply under unconsolidated gravels. The gully is oriented precisely along the strike of the fault.

In the SW% sec. 24, T. 23 S., R. 1 W. (pl. 1), a series of manganese veins is oriented along a strike of N. 6o° E., marking a fault. The fault extends to the land surface and has disrupted the soil which has been rotated 90 degrees. This specific soil normally has a reddish B horizon overlying a pinkish white horizon of calcium carbonate. This usual vertical sequence now extends horizontally from the manganese vein with the reddish B horizon to the north and the adjacent carbonate horizon to the south (fig. 4E).

At several other places, similar manganese veins are oriented along faults and crop out. In the SE¼ sec. 25, T. 20 S., R. x W. (pl. 1) a series of veins linearly strikes S. 86° E. for 1½ miles. The manganese cements formerly unconsolidated sands and gravels. In the SW¼ sec. 16, T. 21 S., R. 1 E., a basalt vent with associated manganese is injected in limestone. This is associated with a fault mapped by Kottlowski 1960a). In the center of sec. 2, T. 23 S., R. x W. (pl. 1), manganese cements sands lying against the flank of an east-west trending rhyolite ridge. This manganese probably is associated with the complex of faults west of Picacho Mountain. The manganese usually occurs as discrete nodules or nodular masses in the sands and gravels (fig. 5A) or it may entirely fill the interstices between grains and form a black, dense, opaque mass (fig. 5B.) In the volcanic rock, discrete nodular particles are interspersed in an unoriented lathlike fabric of plagioclase and pyroxene (fig. 5C).

Another linear concentration of manganese occurs in gravel one mile southeast of the railroad siding of Hill in the east center of sec. 4, T. 22 S., R. 1 E. The accumulation strikes S. 18° E. and crosses arroyos without directional deviation. Faulting may be involved here, but it is difficult to prove. In fact, the source vent has not been found in the gravels.

Dunham shows many faults that strike along the trend of the west slope of the Organ—San Augustin—San Andres

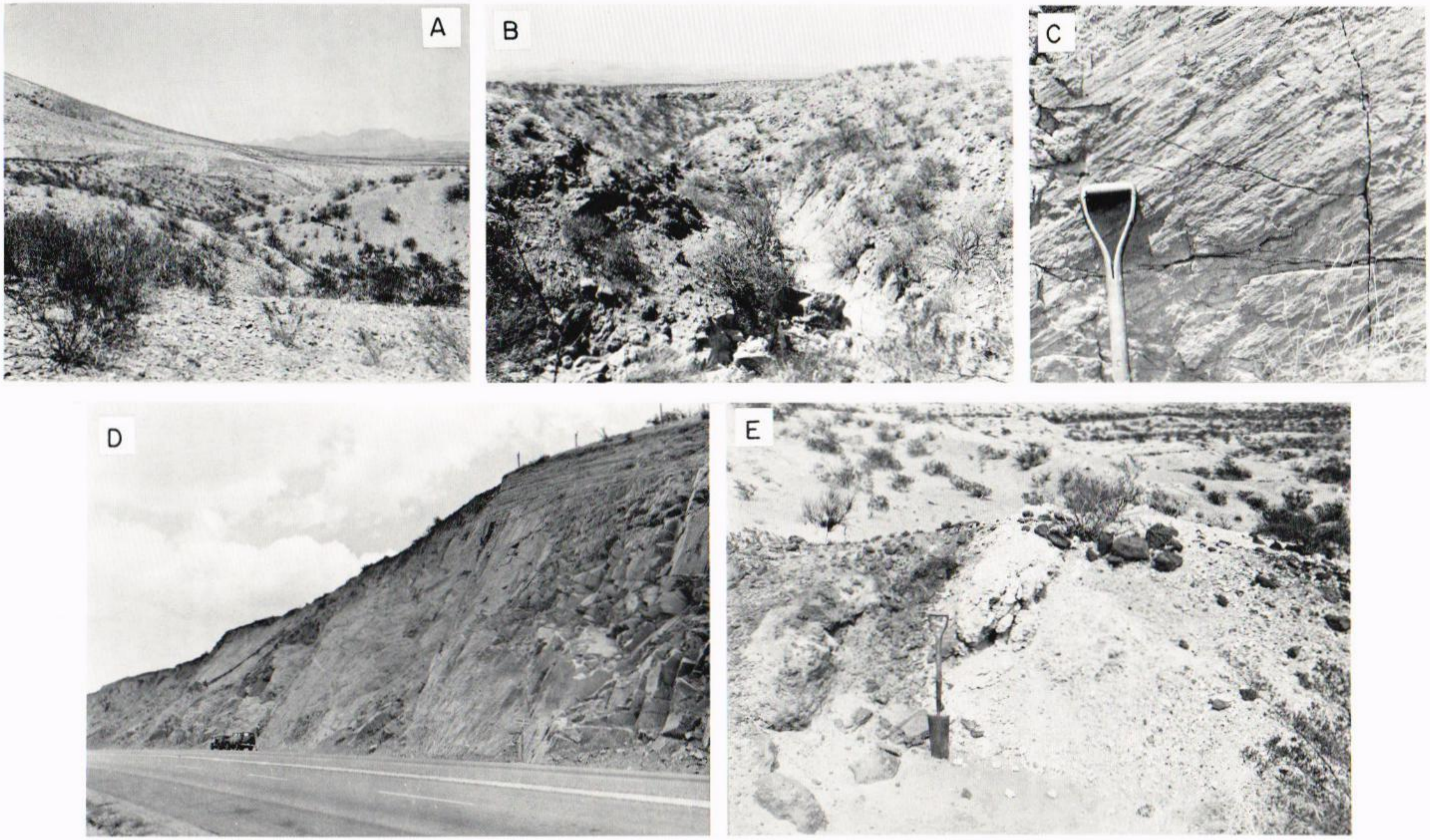


Figure 4
FAULTS

(A) Arroyo oriented along Robledo fault on south of Picacho Mountain with volcanic bedrock on west (left) side and gravel on east (right) side. (B) Arroyo oriented along fault west of Dona Ana Mountains with limestone on northeast (right) side and gravel on southwest (left) side. (C) Slickensides on rhyolite at Box Canyon dam. (D) Fault surface on monzonite along U.S. 70 in San Augustin Pass. (E) Manganese vein along fault near U.S. 7o west of Rio Grande. Soil rotated 90 degrees. Red textural B horizon abuts vein to left. Soil carbonate, K, horizon is to right.

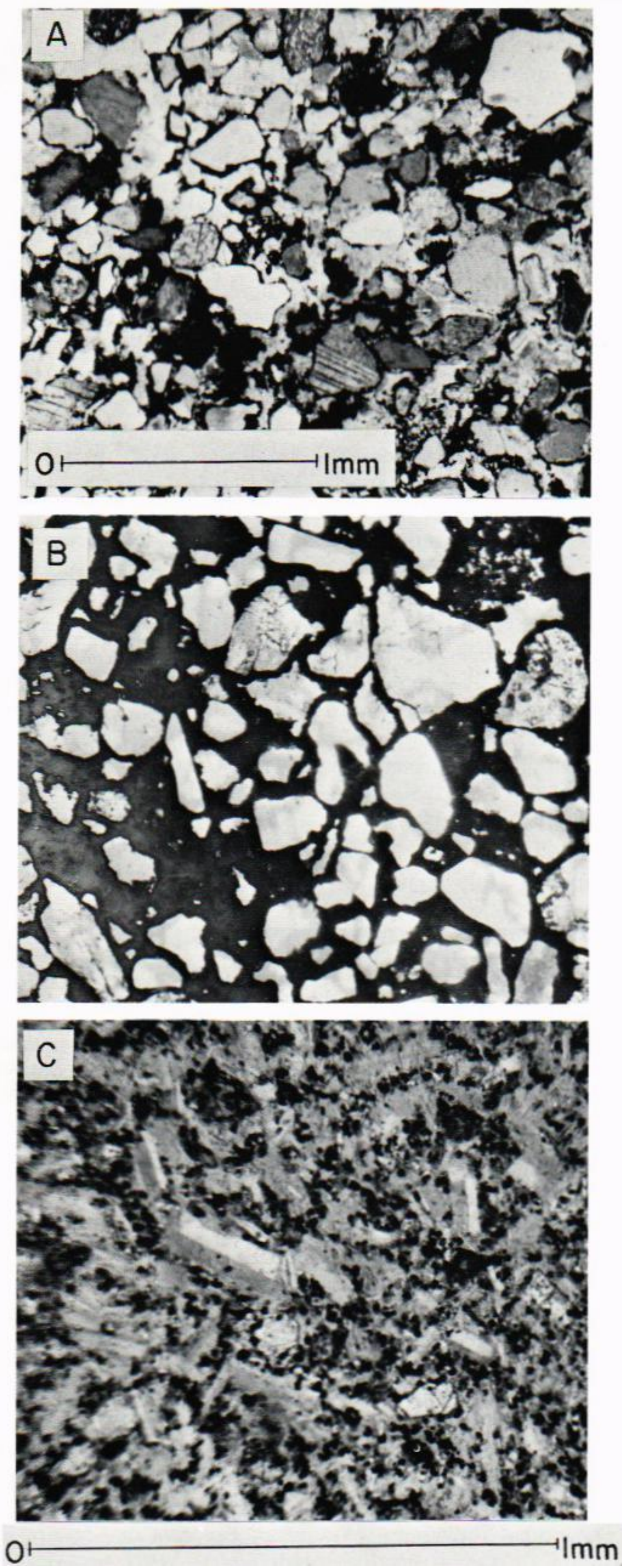


Figure 5

PHOTOMICROGRAPHS OF MANGANESE (DARK) ACCUMULATIONS

(A) as nodules in sands near La Mesa rim northwest of Dona Ana Mountains; (B) as filling voids in sands on flank of rhyolite ridge west of Picacho Mountains; (C) as nodules in basalt vent west of Dona Ana Mountains. (Scales of A and B are the same)

mountains. In addition, numerous transverse faults lie almost normal to the strike of the major fault of the front. Many of the canyons in the Organ Mountains, for example, Blair, Baylor, Fillmore, and Soledad, are oriented along these fault zones. Reiche (1938) described a pronounced fault in the alluvial-fan gravels on the east side of the Organ Mountains near the old Cox Ranch headquarters now in the White Sands Missile Range. Kottlowski (1960a) mapped this fault as well as others in the adjacent mountains. The Cox Ranch fault is distinct on aerial photographs (fig. I B; H.8, 2.4).

DOMING

Imposed on the Dona Ana Mountains is a radial drainage pattern that is elongate from northwest to southeast and is suggestive of doming. The drainage net, constructed from aerial photograph mosaics on a scale of **2** inches tot mile, is more dense on the west side than on the east side of the mountains (fig. 6, in pocket). The western flank of the mountains descends to a mean elevation of 3950 feet in the Rio Grande trench, whereas the eastern flank descends to 4300 or 432.5 feet in the Jomada basin.

Contour lines of elevations 4350 feet and higher close or almost close in elliptical patterns around the mountains. Basins on the east and north sides of the mountains are arcuate in trend and are oriented along an elliptical pattern (fig. 6). The basin deposits lie between elevations of slightly less than 4300 feet to slightly more than 4325 feet. Major physiographic features appear to be geometrically arranged.

MORPHOMETRY

It is necessary to review briefly the geometry of the ellipse, since the Dona Ana Mountains appear to be arranged in this kind of geometric pattern. An ellipse is the locus of a point that moves so that the sum of its undirected distances from two fixed points is equal to a constant. The two fixed points are the loci and the point midway between them is the center. Two co-ordinate axes, X and Y, are intersected by the ellipse, and if the X axis is selected so that the loci fall on it, the standard form of the equation of the ellipse is

$$\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1$$

The ellipse intersects the X axis at points called *vertices* and the chord drawn between them is the *major axis.* The length between the vertices is 2a, so a in the general equation is the distance from the center to the intercept of the ellipse and the X axis. The chord on the Y axis is the *minor axis* and has a length of 2.b. Consequently, *b* in the general equation is the distance from the center to the intercept on the Y axis.

A chord through either locus perpendicular to the major axis is the *latus rectum,* and its length is $\frac{2b^2}{a}$. The distance from a locus to the center is the length *c*. The fraction $\frac{c}{a}$ is the *eccentricity* of the ellipse and is denoted by *e*. Thus

$$e = \frac{c}{a} = \frac{a^2-b^2}{a}.$$

The shape of the ellipse, but not its size, is determined by its eccentricity. For example, if e = o, then c = o and the loci are coincident with the center. Hence, the ellipse is a circle and b = a.

One additional feature needs introduction. The ellipse may also be defined as the locus of a point that moves in such a «•ay that the ratio of its undirected distance from the locus to its undirected distance from a line, directrix, is equal to e, the eccentricity. To explain this, but inadvertently preceding geometric construction of the Dona Ana Mountain features, refer to Figure 7 (in pocket). In the ellipse defined by the major axis intercepts A and A' and minor axis intercepts B and B', D—D' is the directrix. Any point on the ellipse such as K or K' will satisfy the relationship $\frac{FK}{PK}$ or $\frac{FK'}{P'K'} = e$ where P and P' are points on the directrix. The points P and P' locate the directrix.

With this background, apparent elliptical geometry of the Dona Ana Mountain area may be analyzed if one has previously noted (I) the elongate radial drainage pattern, (2) the apparent elliptical patterns of contours above 435o feet, and (3) the apparent elliptical pattern of adjacent basins. Contours are tested first; the 4400-foot smoothed contour is selected for fit of an ellipse with a major axis oriented N. 4o° W. (fig. 7), which is expressed by the equation

$$\frac{X^2}{20.7} + \frac{Y^2}{6.5} = 1,$$

where a is 4.55 miles and *b is* 2.55 miles. Test of fit to contour shows an average deviation, *d*, of 0.17 mile in the relation of d = Y-Yc, where Y is the co-ordinate of the contour for various values of X and where Yc is the calculated co-ordinate for the various values of X. Statistically the standard estimate of error, Sy, is 0.21 mile with a coefficient of correlation of 0.955 at the 1 per cent level of significance. Eccentricity of the ellipse is o.828.

Using the same center of the ellipse that is located on the central ridge of the Dona Ana Mountains (fig. 7, secs. 13, 14, 23, T. 21 S., R. 1 E., cf. pl. 2), a second ellipse is fitted to the arcuate trend of the basins bounding the mountains through 198 degrees of arc. The second ellipse is expressed by the equation

$$\frac{X^2}{30.5} + \frac{Y^2}{13.5} = 1,$$

where a is 5.52 miles and *b* is 3.68 miles. Test of fit to axis of the basins shows an average deviation of o.28 mile. Statistically, the standard estimate of error is 0.31 mile with a correlation coefficient of 0.949 at the 1 per cent level of significance. Eccentricity of the second ellipse is 0.748.

The present topographic expression of the Dona Ana Mountains and the orientation of bounding basins are parts of the same geometric systems. They even have a common center.

GEOMETRY AND GEOLOGIC IMPLICATIONS

Many of the major features of landscape and bedrock conform to the geometric patterns of the ellipses. In addition, many of the features are oriented relative to the components of the ellipse that were discussed in the introduction to the geometry. All major features, with few exceptions, are confined within the larger of the ellipses.

Axes

The major axis common to both ellipses trends N. 40° W. The axis of the Rio Grande trench that is west of the Dona Ana Mountains trends N. 36° W. The trench is known to be structurally controlled. On the west side of the Rio Grande the Robledo fault bounding the Robledo Mountains strikes N. 34° W. to N. 44° W. The major axis of the Dona Ana Mountains approximately parallels known major structural trends. Consequently, it, too, is a structural axis.

The minor axis common to both ellipses follows and parallels the trend of the central ridge of the Dona Ana Mountains that is located in secs. 13, 14, 23, T. 21 S., R. I E. (fig. 7). This parallelism of a major mountain feature with a component of the over-all geometric pattern further suggests structural control.

Drainage Pattern

The drainage net conforms quite precisely to the domal landscape of the Dona Ana Mountains (cf. figs. 6 and 7). In the northwest quadrant of the ellipse (fig. 7, A"'—C—B"), 74 per cent of all drainage lines descend in directions that are between N. 4o° W. and S. 50° W., the bearings that limit the quadrant (table 1). Stream lengths were measured relative to direction. Lengths were summed and grouped by 10 degrees of arc between the limits of the quadrant. A frequency distribution for each quadrant was then calculated by the relations

$$\frac{\Sigma \text{ stream lengths per } 10^\circ \text{ arc}}{\Sigma \text{ stream lengths per quadrant}} \times 100 = \text{per cent.}$$

In the southwest quadrant, A"—C—B"', 84 per cent of all stream lengths descend in directions between the quadrant limits of S. 50° W. and S. 40° E. Similarly, in the northeast and southeast quadrants, 85 per cent of all stream lengths descend in the expected directions between the respective quadrant limits of N. 40° W. to N. 50° E. and N. 5o° E. to S. 4o° E.

Divergent directions of 15 to 25 per cent of the stream lengths in the respective quadrants are due to angular junction of tributary drainage, local influence of bedrock structure, local influence of topographic heights, and encroachment of local watersheds from one quadrant to another. However, the conformance of stream lengths in ratios of 3.o to 5.7:1.o emphasizes the elongate domal nature of the mountainous area.

TABLE 1. DIRECTIONS OF SUM OF STREAM LENGTHS ON DONA ANA MOUNTAINS DOME

Quadrant		Quadrant	
Direction	Per cent of Σ lengths	Direction	Per cent of Σ lengths
NW: N. 40° W.–S. 50° W.		*NE: N. 40° W.–N. 50° E.*	
N. 40°-50° W.	2.0	N. 40°-31° W.	—
N. 51 -60 W.	1.9	N. 30 -21 W.	1.9
N. 61 -70 W.	3.8	N. 20 -11 W.	2.4
N. 71 -80 W.	3.7	N. 10 - 0 W.	2.7
N. 81 -90 W.	6.4	N. 0 -10 E.	4.6
S. 81 -90 W.	14.9	N. 11 -20 E.	18.3
S. 71 -80 W.	12.0	N. 21 -30 E.	21.9
S. 61 -70 W.	11.2	N. 31 -40 E.	20.4
S. 50 -60 W.	18.1	N. 41 -50 E.	12.6
Subtotal	74.0	Subtotal	84.8
Others	26.0	Others	15.2
TOTAL	100.0	TOTAL	100.0
SW: S. 50° W.–S. 40° E.		*SE: N. 50° E.–40° E.*	
S. 50°-40° W.	9.1	N. 50°-60° E.	16.1
S. 40 -31 W.	11.5	N. 61 -70 E.	9.7
S. 30 -21 W.	18.0	N. 71 -80 E.	17.0
S. 20 -11 W.	4.5	N. 81 -90 E.	11.8
S. 10 - 0 W.	13.0	S. 81 -90 E.	6.0
S. 0 -10 E.	7.0	S. 71 -80 E.	14.7
S. 11 -20 E.	8.8	S. 61 -70 E.	4.5
S. 21 -30 E.	4.8	S. 51 -60 E.	4.7
S. 31 -40 E.	6.7	S. 60 -50 E.	0.5
Subtotal	83.4	Subtotal	85.0
Others	16.6	Others	15.0
TOTAL	100.0	TOTAL	100.0

Practically the entire radial drainage pattern is confined laterally between the limits of the latus rectum of the ellipse, A"–C–A"', projected through the locus, F"', also projected to the Rio Grande (cf. figs. 6 and 7). Beyond these limits, drainage-line directions are controlled by other factors. For example, in the area at the northwest corner of T. 21 S., R. 1 E., drainages descend southwesterly to the Rio Grande and almost at right angles to drainage directions within the ellipse to the southeast. This emphasizes an apparent causal control of drainage to the southeast that is expressed geometrically.

At the southeastern limit of the elliptical pattern, Dona Ana Arroyo trends S. 57° W. but extends linearly northeastward 4½ miles from the Rio Grande trench. Adjacent arroyos to the north have similar directional trends but only for distances of less than 1 mile to 1.7 miles from the trench where they ascend the Dona Ana dome and conform to the radial directional pattern. The main trend of the Dona Ana Arroyo is little affected by the radial pattern of the dome. Instead, the dome influences angular junction of tributaries to the arroyo. For example, at distances of o.3, 1.3, 2.6, 3.3, 3.6, and 4.2 miles from the Rio Grande trench, junction angles increase from 15 to 21 to 25 to 37 to 5o and to 82 degrees, respectively. The relationship of junction angle to distance is hyperbolic and is expressed by $Y' = 0.0717 - 0.0142X$ where Y' is the reciprocal of the angle and X is distance. This indicates that the linear trend of Dona Ana Arroyo is independent of the radial pattern, but that as the major axis of the elliptical dome is approached, the angle of junction of tributaries is affected by domal topography.

The independent linear trend of the arroyo is related to geometric components of the elliptical pattern. The arroyo is slightly displaced northward from the directrix, D-D', and deviates 7 degrees north of the bearing of the directrix. Further, the curvilinear trend of the ellipse fitted to the axial depression of the basins bounding the dome intercepts the head of the arroyo (fig. 7). Thus, the valley of the arroyo apparently is emplaced with its head near a structural depression, the axis of which is an apparent hinge line of a dome with its trend nearly paralleling an axis, directrix D-D', that is a loci of points which control the geometry of the upper parts of the dome. Consequently, the linear trend of the arroyo probably is structurally controlled.

Bedrock Distribution

The Dona Ana Mountains area is unique in the entire region of study in that there are appreciable areas of rock pediment (fig. 8). In the dominantly block faulted Organ, San Augustin, San Andres, and Robledo mountains, rock pediments are relatively rare. In the Dona Ana Mountains area, there are 18.25 square miles of bedrock outcrop. Approximately 55 per cent, or 10.67 square miles, is rock pediment and 45 per cent is mountain.

The rock outcrop area, whether pediment or mountain, is asymmetrically distributed relative to the geometric fit of the ellipse (cf. figs. 6, 7). About 94 per cent of all rock pediments and 62 per cent of the mountains are on the west side of the major axis (table 2). The asymmetry of pediment distribution is further emphasized by frequency distribution by quadrants. About 58 per cent of all rock pediment is in the northwest quadrant; 37 per cent is in the southwest quadrant, and only 3 and **2** per cent are in the northeast and southeast quadrants, respectively (table 2). Long protrusions of rock pediment conform directionally to the radial geometry. Such areas extend along bearings of N. 70° and 9o° W. and S. 4o° and 2o° W. Such distribution certainly is related to the domal structure of the mountainous area.

The greater distribution of rock pediment on the west side of the structural axis of the dome is directly related to a lower base level of erosion along the Rio Grande trench. However, it is independent of a specific episode of erosion. Comparison of Figures 6 and 7 with Plate **2** shows that four distinct and separable geomorphic surfaces cross the rock pediment area. The surfaces from oldest to youngest are Dona Ana, Jornada, Tortugas, and Picacho. There are two additional younger and lower surfaces, Leasburg and Fillmore, to the west of the rock pediment area and also beyond the limits of the ellipse A"–C–A"'. Therefore, the rock pediments are a complex of geomorphic surfaces and not of one episode of origin. Consequently, a successively lower base level to the west probably caused mainly by downdropping of the Rio Grande trench has resulted in greater exposure of bedrock on the west side of the dome.

The direct relationship of bedrock exposure to lower base level to the west is very systematic and can be expressed by the equation $Y = —4.4 + 194.6X$, where Y is the distance from the base level of 395o feet along the Rio Grande trench to the western edge of the rock-pediment area and X is the elevation of this edge above the base level. In contrast, this systematic relationship does not exist on the

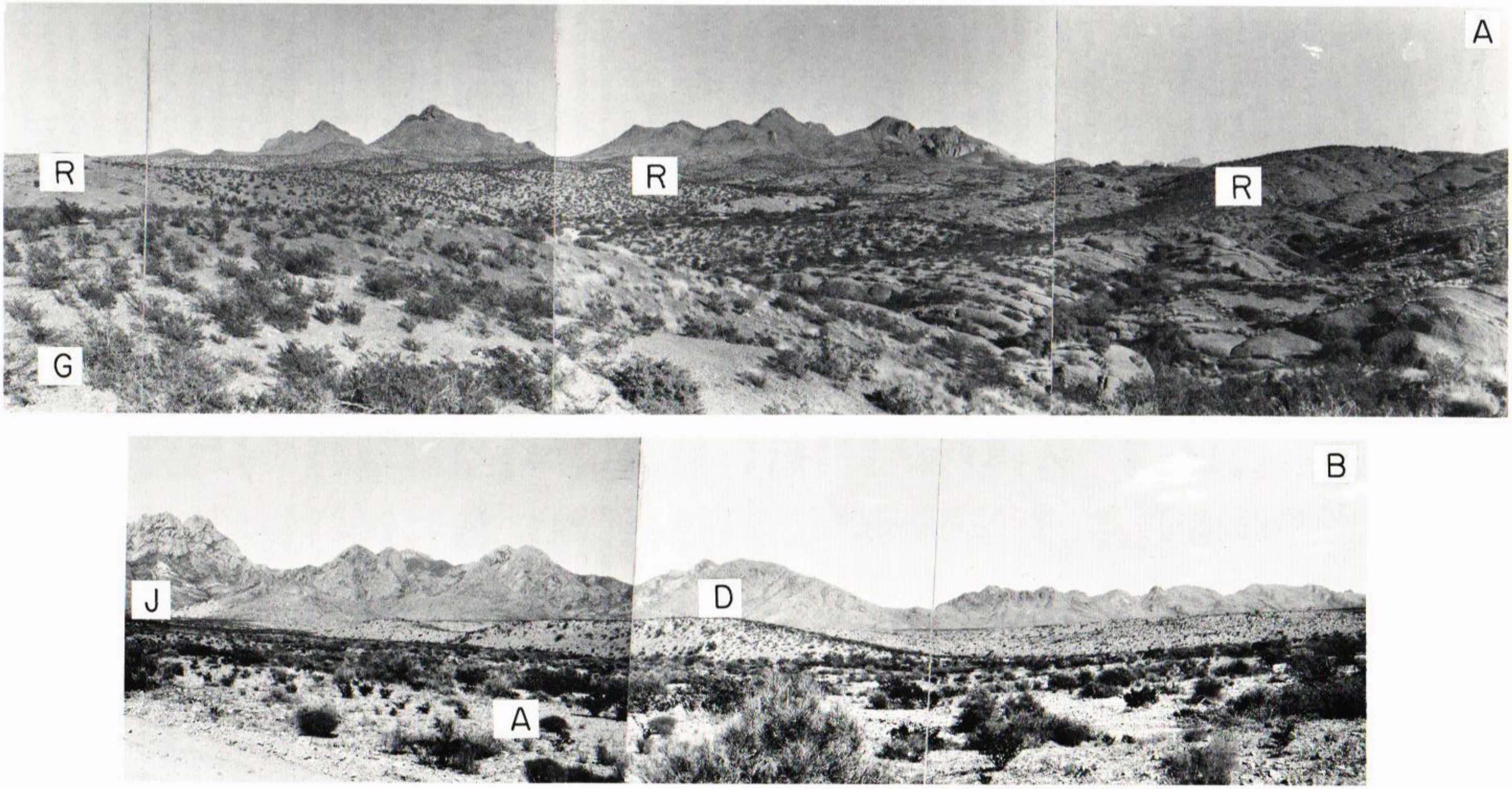


Figure 8

DONA ANA DOME AND DONA ANA SURFACE

(A) Bedrock distribution on west side of Dona Ana dome. Mountains and rock pediment, R, have exposed rock. Note that rock pediment area is multileveled, or formed by more than one pedimentation cycle. Also note roundness of slopes in this arid country. Contact with alluvial apron, G, shown. Major part of rock pediment area is Dona Ana surface. (B) Dona Ana surface, D, standing above Jornada surface, *J*, and arroyo level, *A;* west of Squaw Mountain of the Organ Mountains. Here the Dona Ana surface is a dissected remnant of an alluvial fan.

TABLE 2. BEDROCK AREAS ON DONA ANA MOUNTAINS DOME

	Rock pediments				Mountains			
Area	Square miles	Quadrant area (%)	Total pediment area (%)	Total bedrock area (%)	Square miles	Quardrant area (%)	Total mountain area (%)	Total bedrock area (%)
NW quadrant	6.16	80.5	57.7	33.7	1.49	19.5	19.6	8.1
SW quadrant	3.91	54.8	36.6	21.4	3.23	45.2	42.5	17.6
W half	10.07	68.1	94.3	55.1	4.72	31.8	62.1	25.7
NE quadrant	0.35	20.2	3.3	1.9	1.39	79.8	18.3	7.6
SE quadrant	0.25	14.4	2.3	1.3	1.47	85.6	19.3	8.0
E half	0.60	17.3	5.6	3.2	2.86	82.6	37.6	15.6

east side of the dome to the east of the structural axis. There, the common base level is approximately 4315 feet along the axis of the elliptically oriented bounding basins. In addition, there are only two geomorphic surfaces on the east flank of the dome, Jornada and Organ, which have only slight elevation change in base level. Thus, a change of base level of 365 feet on the west side of the dome in contrast to the east side is partly responsible for asymmetry of bedrock exposure on the dome. In subsequent discussion, the probability of uplift of the dome along its structural axis will be examined.

Warping of Flanking Geomorphic Surfaces

Another line of evidence for doming of the Dona Ana Mountains area is the warping of the flanking La Mesa basin surface and Tortugas and older pediment surfaces (Ruhe, 1964). The La Mesa surface is essentially flat-lying where undisturbed (pl. i; secs. 4, 5, 8, 9, 16, 17, 20, 21, T. 22 S., R. z E.; secs. 31, 32, T. 21 S., R. 2 E.). Maximum relief in these areas is less than 10 feet. Along the structural axis A"—C—A"' (fig. 7, cf. fig. 6), the La Mesa surface sharply descends from a mile southeast of *F'* northwestward along the axis for 2.2 miles. The descent is from elevation 4650 to 435o feet through the first mile at the rate of 15o feet a mile and then at 125 feet a mile. The rate of descent can be expressed hyperbolically as Y' = 0.021 o.0006X, where Y' is the reciprocal of elevation in hundreds of feet and X is the distance in miles. Certainly the La Mesa surface is not flat as in undisturbed areas. Instead, from the sharp hinge line of the basin axis in sec. 29, T. 20 S., R. E. (fig. 7), it rises southeasterly and conforms with the domal geometry along the structural axis.

In the southwest quadrant of the dome (fig. 7) there is is similar disturbance of geomorphic surfaces of younger age. In the arc of S. 0°-20° W. the Tortugas and Picacho surfaces (Ruhe, 1964) descend toward the Rio Grande trench. They also occur on the west side of the trench and descend eastward from the Robledo Mountains (pl. 2). Profiles of these surfaces can be projected to a vertical plane and their geometry analyzed (fig. 9). The Picacho surface descends from the Robledo Mountains along a curved profile that is expressed as Y' = 0.021 + 0.0011X where Y' is the reciprocal of elevation in hundreds of feet and X is the distance in miles. This surface ascends from the trench to the Dona Ana Mountains along a curved profile expressed as log Y = 1.512 + 0.017X, where Y is the elevation in hundreds of feet and X is the distance in miles. Significantly, mid points of the two projected geometric distributions fall in the same over-all geometric systems. They fit a parabolic pattern across the valley expressed by $Y = a + bX\ cX^2$ and also a hyperbolic system expressed by $Y' = a + bX\ cX^2$. This suggests that the Picacho surface has been unaffected by downdropping of the Rio Grande trench along the Robledo and associated faults. Further, the surface on the Dona Ana Mountains side of the trench has almost the same geometric inclination as the Picacho surface downvalley near Las Cruces where little disturbance of the surface can be proved. In Figure 9, note the scaled fit of the undisturbed surface (Y = a + 0.88X) to the surface in the Dona Ana Mountains area (log Y 1.512 + 0.017X). This suggests that the Picacho surface is also unaffected by any doming along the structural axis of the mountains.

Projected profiles of the Tortugas surface contrast distinctly. They descend from the Robledo Mountains along a curved profile expressed by Y' = 0.021 + 0.0013X and ascend the Dona Ana dome curvilinearly, expressed by log Y = 1.52 + 0.023X (fig. 9). The distributions do not fit an over-all geometric pattern as do those of the Picacho surface. Instead, they are parts of one arc of a parabola ($Y = a\ bX + cX^2$). Geometric conversion from the case of the Picacho distributions to that of the Tortugas distributions requires that the left-hand group of the latter be displaced downward. In other words, the Tortugas surface has been downfaulted on the west side of the Rio Grande trench, and field evidence along the Robledo fault attests to this fact.

The Tortugas surface on the Dona Ana side of the trench deviates greatly from the geometric inclination of this surface in the Las Cruces area where little disturbance of this surface could be determined in the field. In Figure 9, note the scaled fit of the least disturbed surface ($Y = a\ 0.75X\ 0.008X^2$) to the surface in the Dona Ana Mountains area (log Y = 1.52o.o23X). This suggests that the Tortugas surface, and necessarily older surfaces such as Jornada and Dona Ana, have been tilted and warped during doming along the structural axis of the Dona Ana Mountains.

Lower Basin—Sediments Distribution

One further line of evidence also helps delineate the Dona Ana dome. Sediments beneath La Mesa surface are sands, gravels, and interbedded clays, silty clays, and silts. The finer textured sediments are brightly colored red, reddish brown, olive, yellowish brown, white, and gray and extend more than 100 feet in depth (Rube, 1962). Such beds are exposed along but well below the rim of La Mesa surface in sec. 5, T. **21** S., R. 1 E. (figs. 6 and 7). They also crop out in an arcuate pattern in sec. 1, T. **22 S.,** R. I E., and secs. 5, 6, 7, 8, T. **22** S., R. **2** E. In the latter area, their pattern conforms concisely to the elliptical pattern of the dome. In

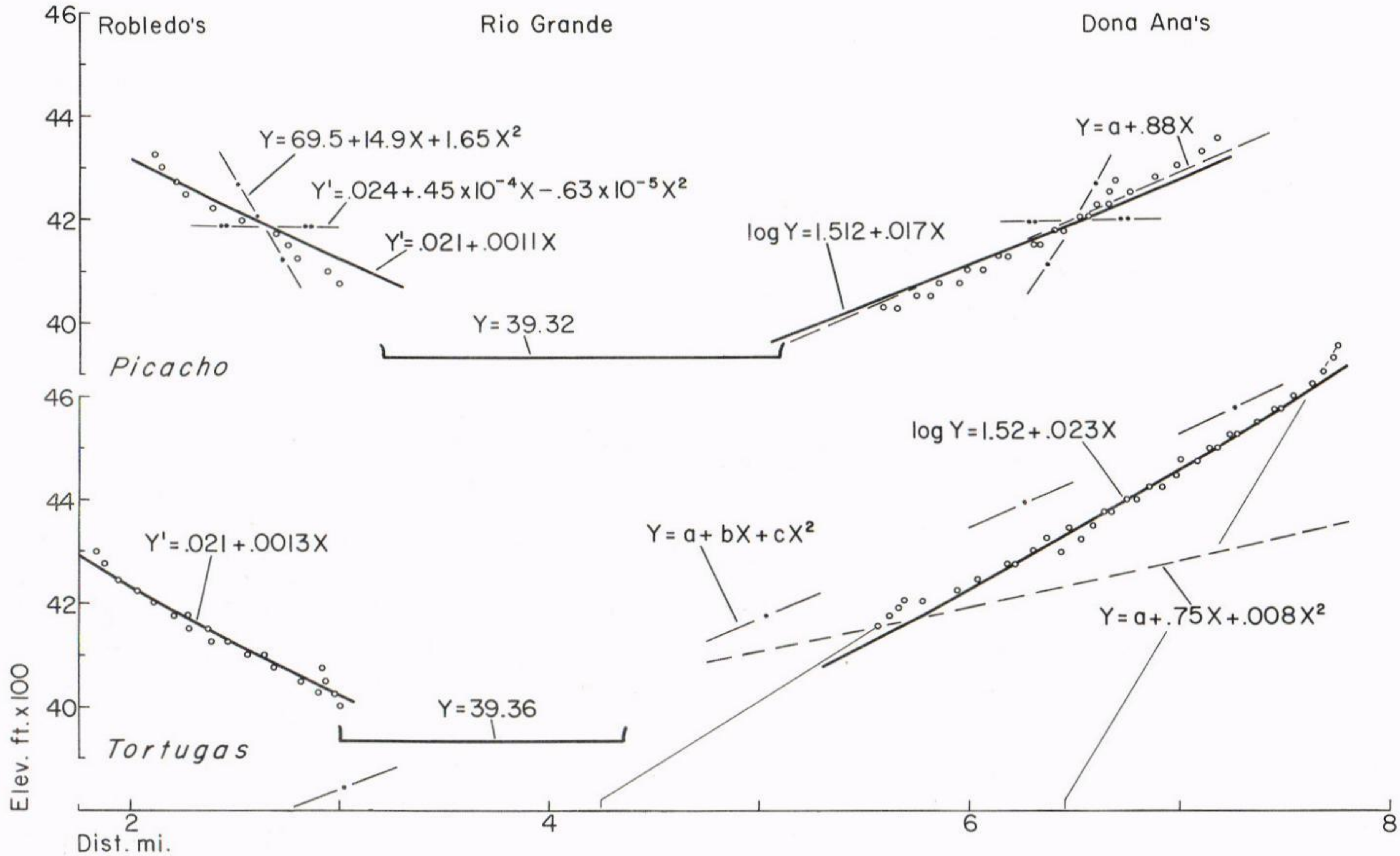


Figure 9

GEOMETRY OF PROJECTED PROFILES OF THE PICACHO AND TORTUCAS SURFACES

across the Rio Grande from the Robledo Mountains to the Dona Ana Mountains. Attempted fits of over-all geometric systems shown by bar-dot patterns. Attempted fits of scaled more stable profiles shown by broken line.

fact, the calculated fit of ellipses brackets the outcrop pattern (fig. 7). The outer limit of the pattern almost coincides with the projected hinge line marked by the axis of basins. Doming inward from this hinge line permitted dissection by the radially disposed streams well below the level of the La Mesa surface.

AGE OF STRUCTURES

The ages of faulting and doming may be determined with reference to bedrock, unconsolidated sediments, and geomorphic surfaces. The youngest deformed rocks are the Tertiary volcanics and monzonites; hence, major tectonic displacements postdate the Tertiary (pl. 1). In the area south of Picacho Mountain and on the west side of the Rio Grande, the Tortugas surface and its associated unconsolidated gravels are downthrown east of the Robledo fault (Ruhe, 1962). However, the next younger Picacho surface crosses the Robledo fault in many places without any change in gradient, indicating that the last large displacement along the Robledo fault was post-Tortugas pre-Picacho in age.

In the previous discussion of warping of geomorphic surfaces on the west flank of the Dona Ana dome, it was pointed out that the Picacho surface was not only relatively unaffected by downdropping of the Rio Grande trench but was relatively undeformed by doming along the structural axis of the Dona Ana Mountains. In contrast, the Tortugas surface was downfaulted along the Rio Grande trench and was tilted and warped during doming along the Dona Ana structural axis. As in the case of faulting, major structural deformation by doming also was post-Tortugas pre-Picacho in age, indicating a contemporaneity within the whole structural system of the area.

This does not negate later tectonic adjustments. In the vicinity of Las Cruces, profiles of Tortugas, Picacho, and the next younger Fillmore surfaces have inflections in slope gradients that probably indicate warping of surfaces due to adjustments along normal faults bounding the valley (Rube, 1964). As the Fillmore surface is Recent in age, less than 2620 ± 200 years by radiocarbon dating, such minor tectonic adjustments have continued to very recent time.

Along the elliptical basin axis east of the Dona Ana Mountains, four basin surfaces with associated sediments are successively inset from oldest to youngest (pl. 2). The younger two are Recent in age, as an associated surface and sediment to the east is less than 1100 to 4600 years old by radiocarbon dating (Ruhe, 1964). Exact orientation of the basin insets along this structural axis suggests continued tectonic adjustment along this hinge line to very recent time.

Reiche considered the fault on the east side of the Organ Mountains to be Recent and noted a striking color contrast between the pre- and postfaulting alluvia. The sediment forming the scarps and extending upslope behind them has a pronounced reddish-brown soil on its surface. In individual and coalescing fans built below and against the scarp, the sediments are light gray in color and lack a pronounced soil on their surfaces. Such respective features among others differentiate the Jornada from the Organ surface on the west side of the Organ Mountains (Ruhe, 1964). The Organ surface and its sediments are Recent, as they are radiocarbon-dated at less than II oo to 4600 years old. Thus, there have also been very late tectonic adjustments in and near the block-faulted mountains in the area.

Geomorphic Surfaces

All the major geomorphic surfaces can be grouped three-fold: (1) alluvial fans, piedmonts, and aprons; (a) basins and scarplet surfaces; and (3) valley-border surfaces (Ruhe, 1964). These groups are definable physiographically and are set apart from each other in space. A member of one group may be juxtaposed with a member of another group so that relative space and time relationships may be determined. However, a member or members of one group may be isolated in space from but be contemporaneous in time with a member or members of another group.

The alluvial fans, piedmonts, and aprons descend from mountain masses to enclosed basins or termini scarps where valley-border surfaces are set below them. Locally, the alluvial fans may extend headward to rock-pediment erosion surfaces along the bounding mountain front. Basins occupy axial positions of depressions and generally grade to alluvial fans that ascend to peripheral higher land masses. Valley-border surfaces occur in a stepped sequence along the Rio Grande and ascend to termini scarps marking piedmonts, basins, or adjacent mountain fronts.

Two additional units are delineable and occupy appreciable parts of the area. They are the Rio Grande flood plain and the mountain slopes and summits. Little detailed study was made of these, in the main, undifferentiated units.

The geomorphic surfaces of the area have been discussed, and the names assigned remain unchanged except for a refinement of the Fort Selden complex (Ruhe, 1962, 1964; Hawley). This unit was undivided in 1962, recognized with four members in 1964, but regrouped into two members in 1965. The Fort Selden complex will be discussed herein as composed of the Fillmore and Leasburg members. Distribution of the surfaces is shown on Plate 2, and the area occupied by each surface is given in Table 3. Listing is by physiographic grouping.

Frequency distribution by area shows the great dominance of the Jornada surface (fig. 10. In the alluvial fan, piedmont, and apron group, the mid-Pleistocene Jornada surface dominates the Recent Organ surface. The Dona Ana surface has minor distribution. All basin and scarplet surfaces from very Recent to late Pleistocene, Lake Tank 0 and 1, White-bottom, Lake Tank 2, are quite minor. The mid-Pleistocene La Mesa has moderate distribution. In the valley-border group and in increasing age, Fillmore, Leasburg, Picacho, and Tortugas, the Leasburg surface is a minor feature. Approximately 39 per cent of the area is occupied by surfaces of Recent age, 13 per cent by surfaces of late Pleistocene age, and 35 per cent by surfaces of mid-Pleistocene age.

ALLUVIAL FANS, PIEDMONTS, AND APRONS

Three geomorphic surfaces are recognizable within this group, which in increasing are are the Organ, Jornada, and Doña Ana surfaces. The Jornada is the major surface and serves as a datum to which the Organ and Dona Ana surfaces can be related phvsiographically. Sediments underlying the Organ surface also can be related stratigraphically to the Jornada sediments.

JORNADA SURFACE

Alluvial fans debouch from canyons in the Organ, San Augustin, and San Andres mountains westward toward the Rio Grande or into the Jornada Basin and descend successively lower slope gradients to imperceptible mergence with basins or basin remnants. The individual fans coalesce laterally to form alluvial-fan piedmonts and also to form one major geomorphic surface that extends northward along mountain fronts to San Marcial, New Mexico. This surface long has been known as the *Jornada surface* (Lee, 1907; Dunham; Kelley and Silver, 1952; Kottlowski, 1953; Ruhe, 1962, 1964).

TABLE 3. AREAL DISTRIBUTION OF GEOMORPHIC SURFACES

SURFACE		Area (sq. mi.)	Total area (per cent)
Undifferentiated			
Rio Grande flood plain		50.79	12.4
Mountain summits and slopes		52.52	12.8
Alluvial fans, piedmont, and aprons			
Organ		53.40	13.0
Jornada		107.84	26.3
Dona Ana		5.04	1.2
Basins and scarplet surfaces			
Lake Tank 0		1.15	0.3
Lake Tank 1		3.21	0.8
Whitebottom		9.22	2.3
Lake Tank 2		7.74	1.9
La Mesa		16.35	4.0
Valley-border erosion surfaces			
Fort Selden	Fillmore	41.50	10.1
	Tortugas	4.50	1.1
Picacho		29.10	7.1
Tortugas		26.94	6.6

Morphometry of Landscape

The Jornada surface is mainly a constructional surface formed by alluvial fans that debouch from canyons in mountains. Downslope, the alluvial fans coalesce laterally and comprise a broad piedmont. Along the Organ—San Augustin—San Andres mountain front, large alluvial fans descend westward from Achenback, Soledad, Ice, Fillmore, Clark and Brown, Lohman, and Bear Peak canyons (pl. 2). Some of these fans occupy 6 to 8 square miles. From the mouths of smaller canyons, such as Baylor and Blair, small alluvial fans descend westward and occupy one or less square mile. The difference in size of alluvial fans can be appreciated by visual comparison of the Blair Canyon fan and the Finley Canyon fan, which is located at the south end of the Organ Mountains to the south and east of Pena Blanca (fig. u).

In the past few years, the morphometry of alluvial fans has been quantitatively described in various ways. Ruhe (1964) used profiles of radii expressed in feet per mile and radii of curvature of specific contours. Mammerickx (1964) compared slope angle and slope length of pediments associated with fans. Denny (1965) related fan area to source area above fan apex and slope in feet per mile to drainage area. Melton (1965) used fan gradient versus basin area and drainage-basin relative relief: Recently, Troeh (1965) developed three-dimensional paraboloids of revolution to describe alluvial fans and pediments. A choice of any of these methods is dictated by what morphological property or properties of the land form are meant to be demonstrated. Projected profiles are useful in relating one surface to another and in estimating former base levels to which a constructional or erosional surface descended. Analysis of radii of curvature of contours is useful in determining centers of symmetry of sediment dispersion, geographic displacement of such centers through time of construction of a land form, and the distinguishing of one land form from another.

In projecting profiles, points of elevation are transposed laterally to a vertical plane (fig. 12). Points of intercept on the vertical plane form a distribution to which X and Y axes may be fitted. The abscissa is scaled in units of distance and the ordinate is scaled in units of elevation. A curve is *calculated* for the distribution of points and is fitted. In the simple case that is illustrated, contour lines are parallel, so one point of elevation is transposed laterally for each contour and the population yields a specific curve. Commonly, a number of adjacent and parallel traverses when projected form a family of curves that are very closely spaced. By standard curve fitting techniques, one regression line may be calculated for the

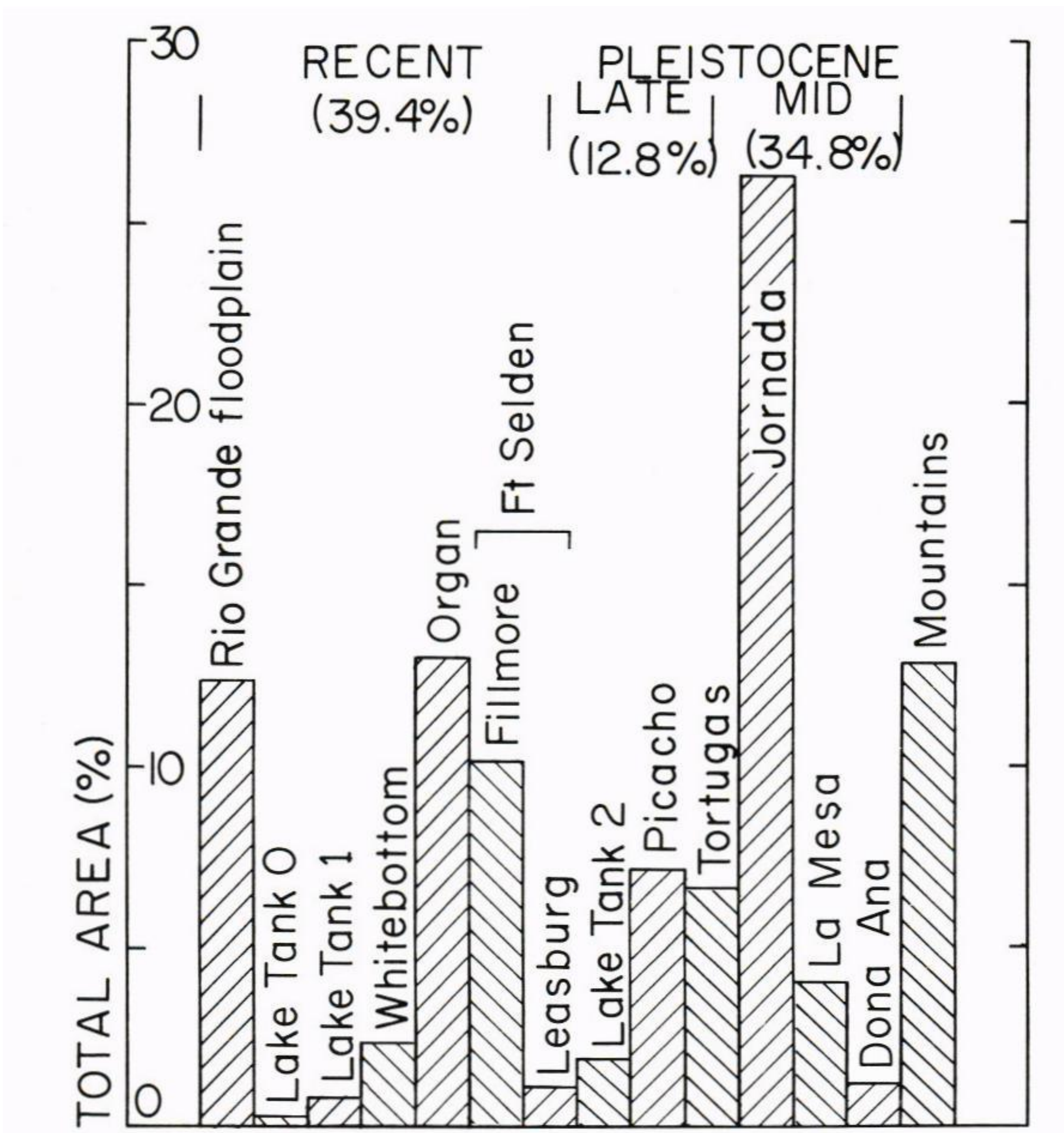


Figure 10

FREQUENCY DISTRIBUTION OF AREAS OF GEOMORPHIC SURFACES AND GROUPING FROM RECENT TO MID-PLEISTOCENE AGE

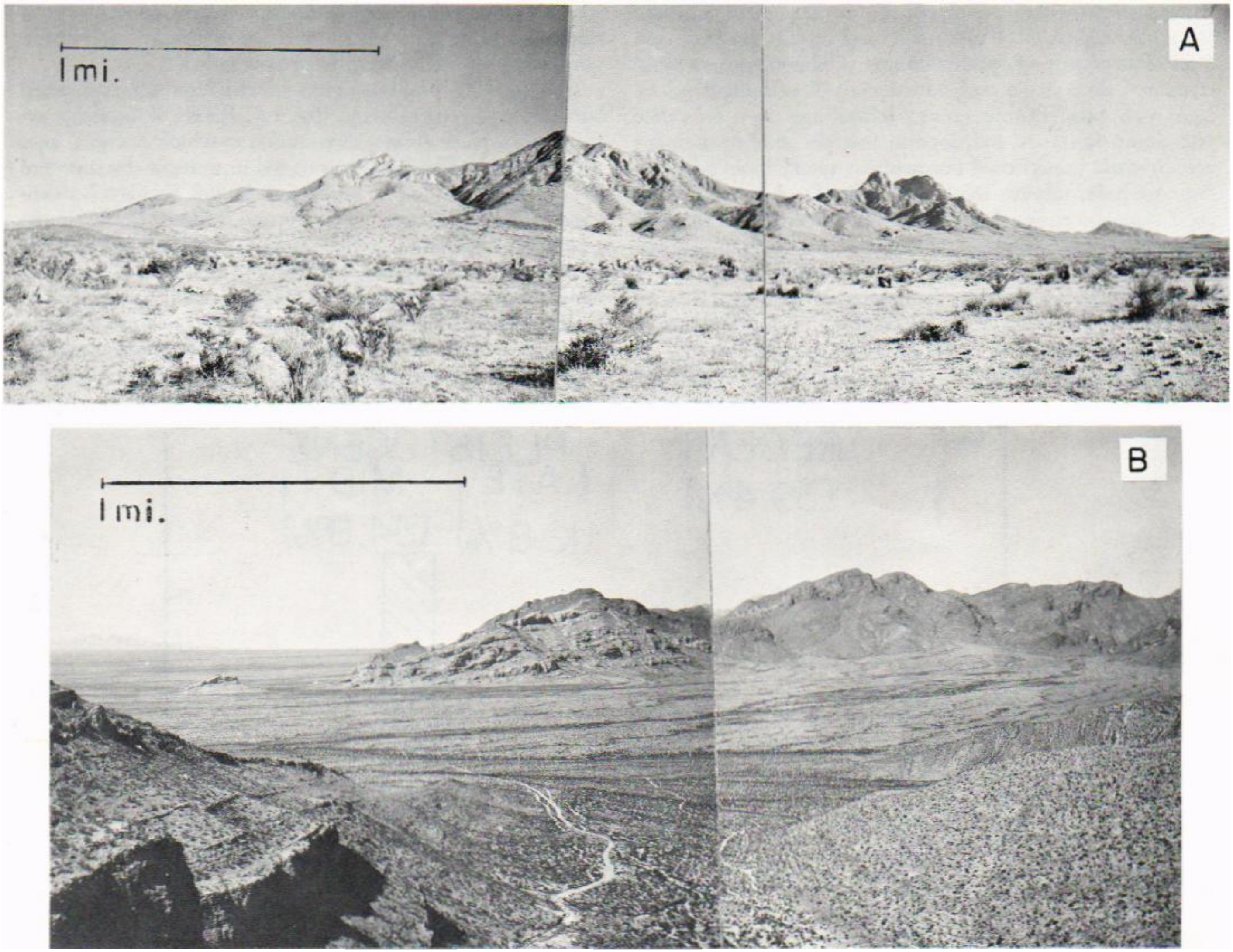


Figure II

CONTRAST OF SIZE OF ALLUVIAL FANS

(A) Blair Canyon fan on Organ Mountain front. Empire—Baylor canyon fan is to right, south. (B) Finley Canyon fan at south end of Organ Mountains. Pena Blanca is outlier to left. (Photo from Bishops Cap by F. F. Peterson)

family, and a standard estimate of error may include most of the points of distribution. Thus, an area of a specific length, width, and relief can be reduced to a two-dimensional plot for analytical purposes.

Alluvial fans and piedmonts along the Organ—San Augustin—San Andres mountain front can be conveniently grouped in four families of curves (pl. z). The groups are from the south limit of the area to Squaw Mountain (profiles I to 4), Ice and Fillmore canyons (profiles 5 and 6), Middle Spring to Organ village (profiles 7 to 9), and Clark and Brown Canyon to Bear Peak Canyon (profiles to to 13). All the profiles of these areas are composed of two longitudinally merging curves. Above 4800 feet elevation, the profiles are best fitted by a hyperbolic function Y' = a -I-- bX, where Y' is the reciprocal of elevation in feet and X is the distance in miles along each traverse. From 4300 to 4800 feet, the curves are expressed by the equation log Y = a bX, where Y is elevation in feet and X is distance in miles (table 4).

Two points are significant concerning these profiles. In the area above 4800 feet, the slope constant b in the equations is very similar, o.00iz and 0.0014 (table 4), for two areas and groups about a mean value of 0.0013 for all equations. The mountain sources of the alluvial fans stand 6000 to 7000 feet in elevation throughout these areas. The slope constant for one equation of area is an extreme value of 0.0019. The mountain sources stand 7000 to 9000 feet in elevation. The slope constant for the equation of the remaining area is the other extreme value of o.0008. The mountain sources stand at 5000 to 6000 feet in elevation. Thus, the initial relief of the source controls the resultant geometric curvature of the constructional surface built below it.

Where the curvature of the surface changes from a hyperbolic to a logarithmic function at 4800 feet, contour lines change from concentrically curvate above to essentially linear and parallel below. This is the zone of mergence and lateral coalescence of individual alluvial fans and cones forming the broad piedmont that extends downslope to a general elevation of 4300 feet (Ruhe, 1964).

TABLE 4. LONGITUDINAL CURVATURE OF ALLUVIAL FANS AND PIEDMONT

AREA	GEOMETRY	NO. ‡
South limit to Squaw Mountain	$Y' = 0.33 - 0.0014X$*	85
	$\log Y = 1.52 + 0.017X$†	84
Ice and Fillmore canyons	$Y' = 0.032 - 0.0012X$	66
	$\log Y = 1.58 + 0.011X$	49
Middle Spring to Organ village	$Y' = 0.037 - 0.0019X$	97
	$\log Y = 1.59 + 0.011X$	78
Clark and Brown Canyon to Bear Peak Canyon	$Y' = 0.028 - 0.0008X$	89
	$\log Y = 1.49 + 0.023X$	38

* Above 4800 feet; function is $Y = \dfrac{1}{a + bX}$

† 4300 to 4800 feet

‡ Number of samples

A second change and longitudinal mergence of profiles takes place at an elevation of 4300 feet, which generally marks the terminal scarp of the Jornada surface above the valley-border surfaces. Below this elevation, projected profiles become linear and are expressed by the equation Y = a + bX, where Y is elevation in feet and X is distance in miles. For example, a remnant of La Mesa surface extends from sec. 5, T. 24 S., R. 3 E. along a bearing of S. 2o° W. to section 18 of the same township. *(See* Tortugas Mountain and San Miguel quadrangle sheets, 7.5 minute series.) The curvilinear piedmont surface (log Y1.52 + 0.017X, table 4) merges with a toe-slope surface descending to La Mesa. Its profile is expressed by Y = 41.5 + 0.42X.

Consequently, physiographic components are defined by geometric systems from the base level of a basin to the distant mountain range and in order are (1) mergence zone with basin defined by Y = a + bX below 4300 feet; (2) piedmont defined by log Y = a + bX from 4300 to 4800 feet; and (3) alluvial fans defined by $Y = \dfrac{I}{a + bX}$ above 4800 feet to the mountains. The change in the specific case from La Mesa surface near Mossman Ranch to the Organ Mountains is Y = 41.5 + o.42X to log Y = 1.52 + 0.017X and to Y' = 0.033 — o.00 14X. Calculated geometric projection of this complex geomorphic surface to the present Rio Grande shows that the base level at this axial position during Jornada time was at an elevation of 4120 feet, or 220 to 240 feet above the present flood plain in the Las Cruces and in the southern part of the area (pl. 2). These values differ from a previous estimate (Ruhe, 1962) by 8 to 15 per cent and are probably more reasonable. The previous estimate was made from a graphic reconstruction.

The surface of an alluvial cone or fan usually is an irregular variant of the geometric form *quadric cone.* As such, it may be anaylzed three-dimensionally (Troeh) or in the usual way by determining the geometry of a surface through study of curves of sections of the surface formed by the intersection of a family of parallel horizontal planes with the surface of the form. The curvature of contours and the centers of radii of curvature are geometric features that are useful in analysis. The curves and centers may be constructed and located by circumscribing arcs by inspection, or by construction of perpendiculars to two tangents of an arc.

Small alluvial cones debouching from Blair and Empire canyons (fig. I I) are examples of analysis. Arcs of curvature of contours are fitted, and centers of radii of curvature are located (fig. 13). These canyons, as previously noted, are oriented along faults transverse to the main fault on the west front of the Organ Mountains. They also are the source areas of sediments that constructed the alluvial cones. The Blair Canyon cone rises from an elevation of 4900 feet to an apex or locus of distribution of sediments at 5450 feet. The Empire Canyon cone rises from an elevation of 485o feet to an apex of 555o feet. Contours are rather regularly and symmetrically patterned concentrically about the apex.

Each center of radius of curvature is a center of symmetry for a contour of the constructional surface. On both cones the centers of radii precess in a systematic manner (fig. 13). The center of the outermost contour is at the apex of the cone or mouth of the canyon. As contours are displaced upward on the cone, centers of radii are displaced downward along an axial radius (9-8-7 on the Blair cone and 14-13-12 on the Empire cone). Then, as contours are continually displaced upward, the direction of displacement of centers of radii is reversed, moving upward again to the apex (6 to on Blair cone, I1 to I on Empire cone). Displacement in the reverse direction also is along the axial radius, and the location of the final center is very near the first center. This suggests that as the center of symmetry systematically shifts, so must the locus of dispersion of sediments shift in constructing the alluvial cone.

As the sediments near the apex **I-2-2'** on Blair cone and to 5 on Empire cone) certainly are the youngest of the cone, the precession of centers of symmetry suggests a time-sedimentation sequence in building the cone. In earlier phases, sediment is carried to greater distances from the canyon mouths, and in later phases, sediment is deposited on earlier phase material but at successively shorter distances from the source. The cone is built back and up on itself to the canyon mouth.

The orientation of the displaced centers of radii of curvature along an axial radius indicates little displacement along the Blair and Empire faults during or subsequent to cone building. In a case that will be examined later, displacement laterally from an axis is related to faulting.

Rock Pediment

Of the 107.84 square miles of Jornada surface in the area, 6.5 per cent, or 7.02 square miles, is rock pediment near the Dona Ana Mountains (pls. 1 and 2). There, this erosion surface cuts indiscriminately across varying kinds of rock,

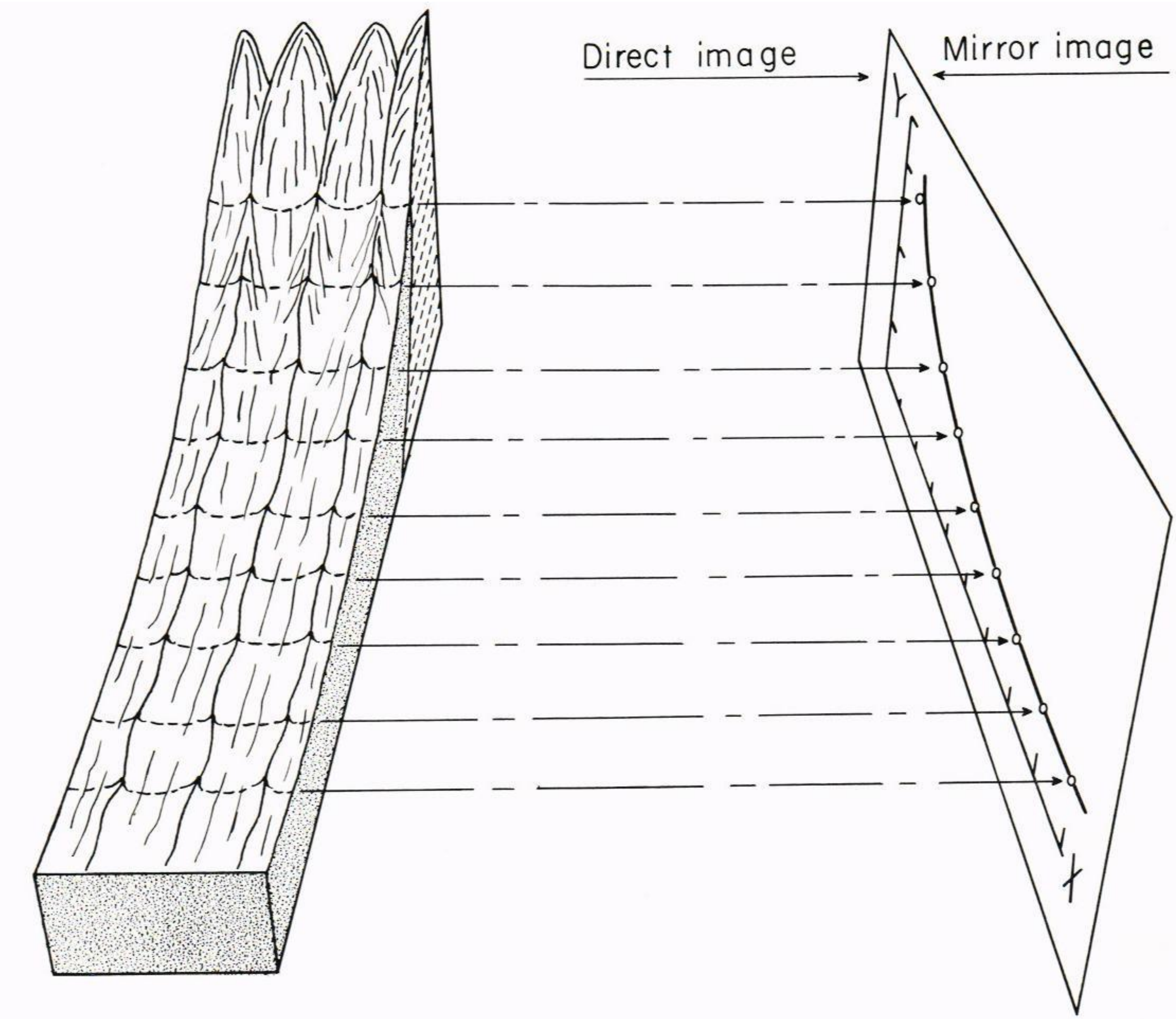


Figure 12

METHOD OF PROJECTING PROFILES TO A PLANE FOR CONSTRUCTION OF A FAMILY OF CURVES

such as monzonite, rhvolite, andesite, latite, and limestone. No distinct changes in gradient or other morphometric property of the surface occur at contacts between rock types. Close inspection and comparison of the distribution of the Jornada surface with the distribution of gravel and bedrock (pls. 1 and 2) show that the surface crosses these varying kinds of material without distinct change. In some places, the surface is on bedrock and at other places on gravel for equidistances from the major axis of the Dona Ana dome along symmetrical radii (fig. 7). Further inspection shows that although other surfaces such as Tortugas and Dona Ana are below and above the Jornada in the area, geomorphic contacts between surfaces also are independent of contacts between rock and material types (fig. 8). These lines of evidence show that although the Jornada is dominantly constructional in the area of study, that is, built by deposition of sediments, it locally may be an erosion surface that is cut across bedrock.

The downslope and upslope juxtaposition of gravel and rock pediment has raised questions concerning the effect of structural deformation in the formation of pediments (Tuan, 1962). Tuan's study in the Santa Catalina Mountains in Arizona showed a rock pediment 3.6 miles wide sloping from the mountain front at 167 feet a mile. An alluvial apron then descends at 235 feet a mile through a distance of 6.6 miles. Such a distinct change in surface slope from rock pediment to alluvial apron is not present on the Dona Ana mountain front. Along Wagner and Cleofas canyons (pl. r), a rock pediment descends at 175 feet a mile. The surface of the alluvial apron continues without break in gradient through a distance of 1 mile to 1.5 miles. Projected ascendant profiles of these surfaces are expressed by Y = 40.4

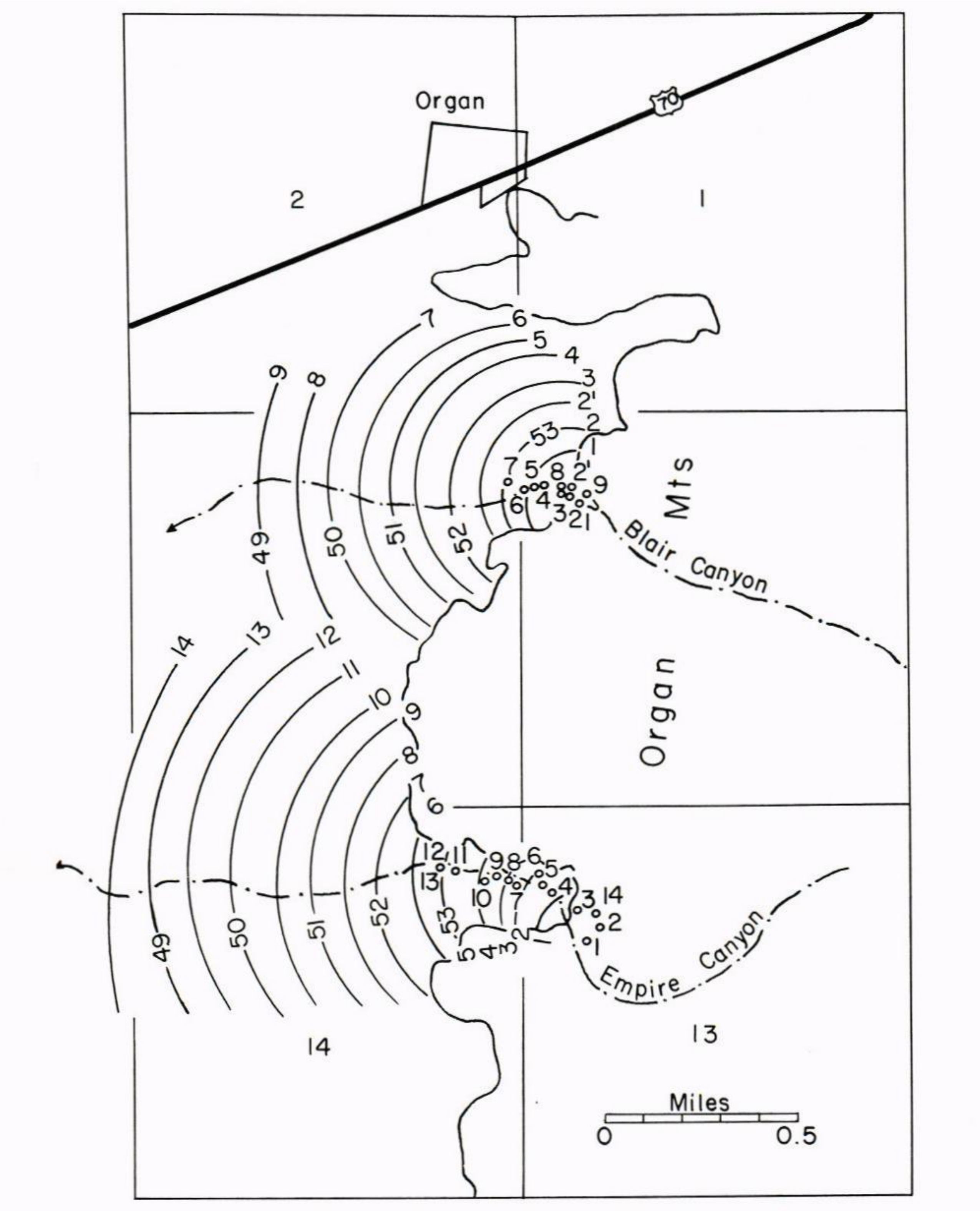


Figure 13

GEOMETRY OF BLAIR AND EMPIRE CANYON ALLUVIAL FANS ON THE WEST FLANK OF THE ORGAN MOUNTAINS SHOWING FITTED CURVATURE OF CONTOURS AND CENTERS OF RADII OF CURVATURE

+ 1.75X, where Y is elevation in feet and X is distance in miles, and the standard error of estimate (Sy) is 13.3 feet at a coefficient of correlation of 0.99 that is significant at the z per cent level. The width of the area of projected profile sample is 1.5 miles.

The bedrock surface beneath the gravel of the alluvial apron is exposed in the walls of Wagner and Cleofas canyons, so this surface may be measured and reconstructed downslope from the rock pediment-alluvial apron contact. The buried bedrock surface slopes more steeply at 205 feet a mile. Projection of this surface upslope yields an estimate of the amount of rock planation at varying distances above the pediment-apron contact. At 0.4, o.8, and 1.2 miles, minimum rock planation is 12, 25, and 38 feet, respectively (fig. 14).

The estimate is based on the assumption that the reconstructed surface had a linear slope like the present land surface gradient. If the gravel mantling bedrock above the pediment-apron contact had been as thick as the gravel presently mantling bedrock below the contact, the planation values would be doubled.

The geometry of the rock pediment relative to the adjacent alluvial apron suggests a cause of planation like that in the mechanism proposed by Tuan. Relative uplift caused stripping of the alluvial cover from the upper parts of the tilted surface. Previously, the possible tilting and warping of the younger Tortugas surface were shown for the same area (fig. 9). Such disturbance was mainly post-Tortugas pre-Picacho in age. As the Jornada surface is older than the Tortugas, it undoubtedly was also affected. However, the presence of bare, unweathered rock at the pediment surface suggests that movement during later time may also be involved. In any case, the near fit of the Jornada pediment profile, buried and projected, with that of the Jornada alluvial apron shows that the present rock-pediment surface is an approximation of the original and may be considered essentially as an exhumed surface somewhat modified by subsequent planation and dissection.

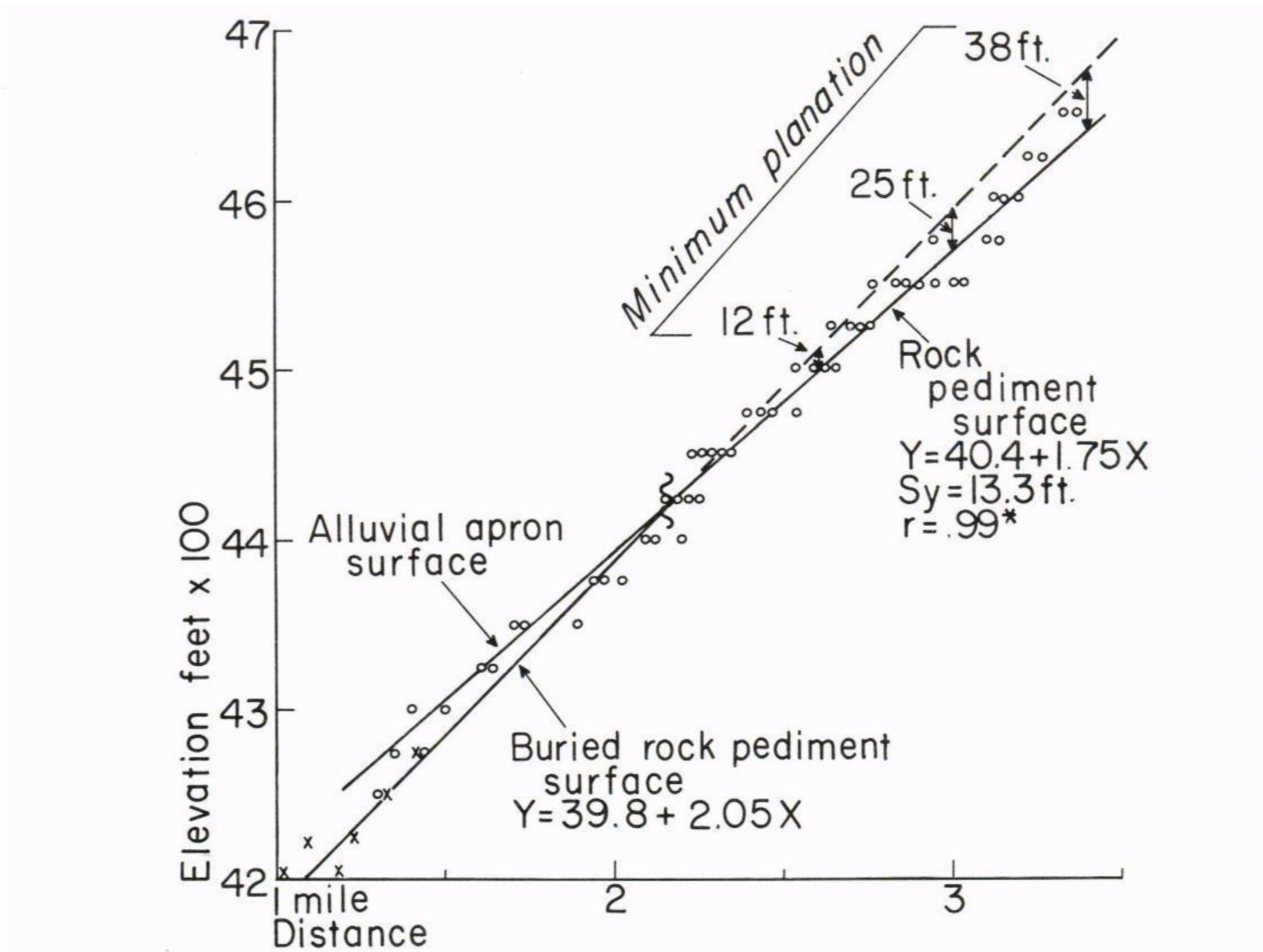


Figure 14

GEOMETRY OF PROJECTED PROFILES OF ROCK PEDIMENT AND ALLUVIAL APRON OF THE JORNADA SURFACE ON THE WEST OF THE DOÑA ANA MOUNTAINS

Profile of planation surface on bedrock beneath gravels of alluvial apron also shown.

Relation to Other Surfaces

The Jornada surface can be used as a physiographic datum throughout the area, and, as such, all other surfaces or sequences of surfaces can be related to it. In the alluvial fan, piedmont, and apron group, one surface, the *Dona Ana*, stands distinctly above the Jornada and consequently must be older. Another surface, the *Organ*, is inset below and also lies above the Jornada and must be younger. The inset part of the Organ surface is in the alluvial fan landscape, whereas the overlay is downslope in the piedmont area. The axis of shift from inset to overlay coincides with the change in geometry of curvature of the Jornada surface from $Y = \frac{1}{a + bX}$ to $\log Y = a + bX$.

The Jornada surface is also related to the basin and scarplet surface group. It descends, as previously pointed out, to the La Mesa surface and sediments associated with it are distributed across La Mesa. Hence Jornada is younger than La Mesa. The Jornada surface also descends from the Dona Ana and San Augustin mountains to the *Lake Tank* 2 surface, but sediments associated with the latter overlie the Jornada. Thus, the Lake Tank 2 surface must be younger.

The valley-border surface group occurs as a sequence of stepped levels below a terminal scarp of the Jornada surface. Hence, all these erosion surfaces are younger than the Jornada. Specific details of the relationships of all members of the various groups are discussed as each associate is introduced.

Dona Ana Surface

The Dona Ana surface has relatively small areal distribution and occupies about 5 square miles or 1.2 per cent of the area (table 3). The most extensive remnants are west of Squaw Mountain in the Organ Mountains and high on the west flank of the Dona Ana dome (pl. 2; fig. 1B, G.1, 3.5). Near Squaw Mountain, the surface is a high, level, dissected alluvial fan and stands well above the adjacent Jornada surface (fig. 8B). In the Dona Ana mountain area the surface is a rock pediment that stands one level above the Jornada rock pediment and alluvial apron. The Dona Ana alluvial-fan and rock-pediment surfaces occupy 1.5 and 2.85 square miles, respectively.

The projected profile of the Dona Ana surface near Squaw Mountain has the curvature that is typical of an alluvial fan, $Y = \frac{1}{a + bX}$, where Y is elevation in feet and X is distance in miles. From its western terminal scarp to its eastern edge that stands above Ice Canyon (pl. 2), the surface rises as expressed by $Y = \frac{1}{0.0257 - 0.00133X}$. The datum Jornada surface is adjacent and rises eastward to the mountain front along Ice Canyon; its projected profile is expressed by $Y = \frac{1}{0.0244 - 0.0096X}$. The geometric contrast is evident. The Dona Ana surface rises at a greater rate of increase per unit of distance. Thus, at its western terminal scarp, the Dona Ana surface stands only 15 feet above the adjacent Jornada surface, but at distances of 0.5, I .0, 2.0, and 2.5 miles eastward, the relief increases to 6o, 12o, 18o, and 2 x o feet, respectively. The differences in curvature and rates of change of slope may be related either to descent to different base levels or to differential tectonic disturbance after surface formation.

In the Dona Ana mountain area, the Dona Ana rock pediment also stands one level above the Jornada rock pediment. The lower surface rises with distinct changes in gradient to the upper surface. Projected profiles of both surfaces have unusual geometry which can be expressed by the general equation $Y = a + b_1X\ b_2Xn$ (fig. 15). This differs from previously described erosional and constructional surfaces, and curve fitting by least squares is extremely complex. Consequently, the surfaces are described by mathematical scaling and direct determination of algebraic form components (Jensen, 1964).

Whereas the previous erosional and constructional forms were simple linear, logarithmic, parabolic, and hyperbolic forms, the rock pediment surfaces have mergent linear and exponential forms in short distances. Rates of change of elevation are related to the twelfth power of units of distance. Such gradients are excessive in comparison to gradients previously analyzed. For example, the rates of change on both the Jornada and Dona Ana rock pediments are 2.5 times an ordinary parabolic curvature of other surfaces in the area. The excessive change in geometry is related to tilting and warping of these surfaces high on the western flank of the Dona Ana dome. The surfaces occur at higher elevations and nearer the major axis of the dome (pl. 2; fig. 7), and undoubtedly they have been more disturbed tectonically than other surfaces that are lower on the flanks and at farther distances from the structural axis.

ORGAN SURFACE

In areal distribution the Organ surface is second in dominance and occupies 53.4 square miles or 13 per cent of the total area (table 3; fig. to). The surface is composed of a series of isolated alluvial fans that in their upper parts are inset below the Jornada surface and in their lower parts are built on the Jornada surface. Such fans are along the west front of the Organ Mountains from the southern limit of the area northward to Ice and Fillmore canyons (pl. 2). Northward along the Organ—San Augustin—San Andres mountain front, the Organ fans coalesce laterally into broad alluvial aprons that extend westward as much as 7.5 miles from the mountains. Similar fans and aprons are on the east and north sides of the Dona Ana Mountains.

In addition, where older surfaces have been tectonically warped or ruptured, Organ fans and aprons formed. On the west side of the Rio Grande, La Mesa surface is upthrown and downthrown along the Robledo fault (pl. **2;** fig. IA, B.5, 4.2 to B.3, 5.o). Organ fans head in arroyos on the scarp, descend to the downthrown block, and coalesce laterally along the base of the scarp for more than 3 miles. The Organ surface also is inset and overlies La Mesa surface where the latter is upwarped on the north flank of the Dona Ana dome (pl. 2; secs. 31, 32, T. 21 S., R. I E.)

Inset and Overlay

The inset and overlay of the Organ surface relative to older surfaces are best illustrated by an isolated alluvial fan that descends from Ice and Fillmore canyons in the Organ Mountains (fig. 16). Here, inset of the Organ surface below the bounding and adjacent Jornada surface is distinct (fig. 2A). These relations can be detected from distributions of contours on reasonably accurate topographic maps if the country is known. *(See* Organ Peak and Tortugas Mountain quadrangles, 7.5 minute series.) If contours are smoothed, arcs may be fitted to them and centers of radii located (fig. 16). Two geometric systems are evident. One has larger radii and lesser curvature of arc conforming to the Jornada surface. As previously discussed for the Blair and Empire canyon fans, centers of radii or loci of sediment dispersion, which built the alluvial fan, precess. However, on this Jornada fan they do not displace along one axial radius as they did previously. Instead, they originate in the vicinity of Fillmore Canyon and then are successively displaced in a parabolic path westward and southeastward up Ice Canyon. A major fault, along which Fillmore Canyon is emplaced, is crossed. Such precession and crossing of a fault

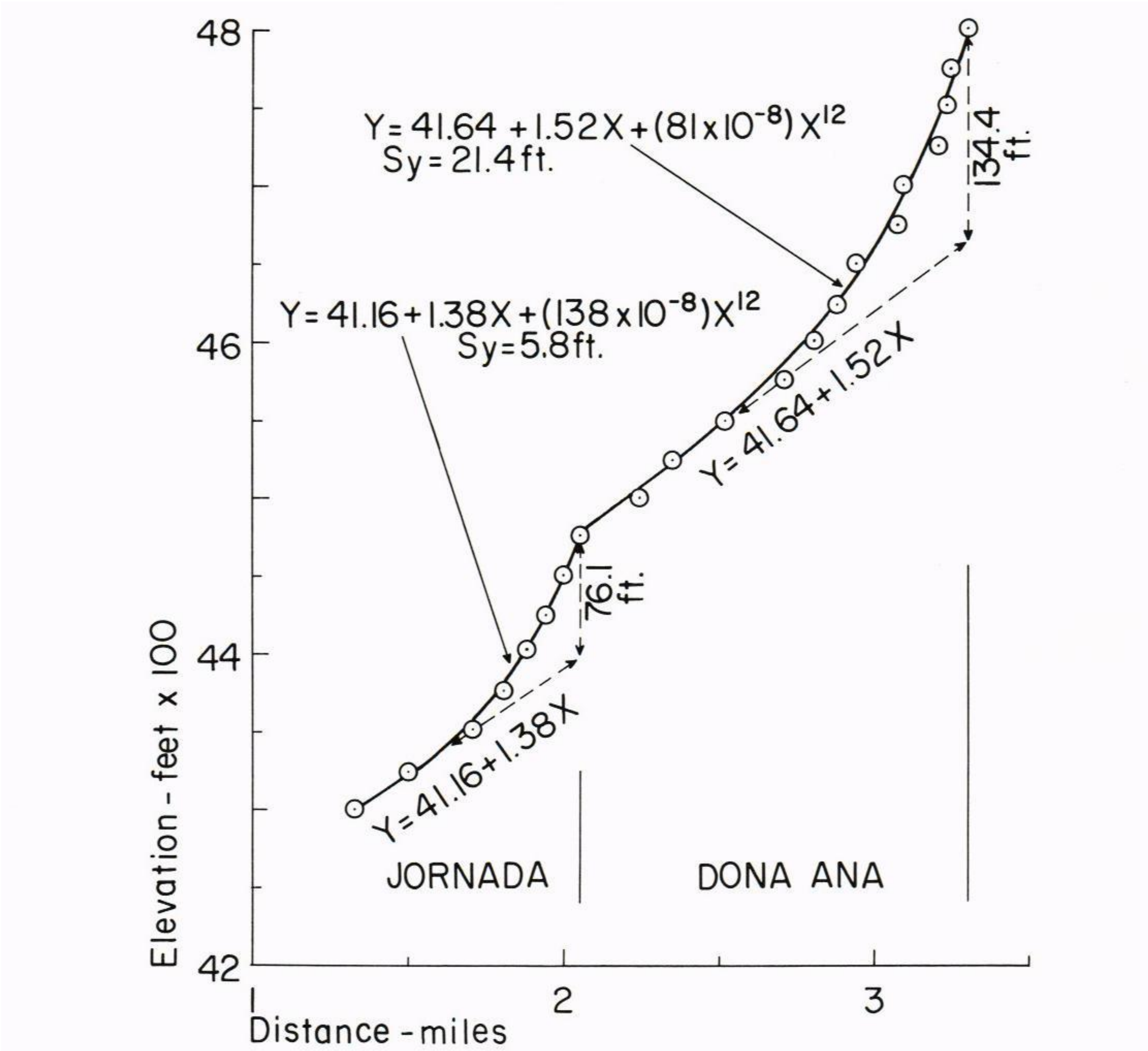


Figure 15

GEOMETRY OF PROJECTED PROFILES OF THE JORNADA AND DONA ANA ROCK PEDIMENT SURFACES ON THE WEST FLANK OF THE DONA ANA MOUNTAINS

Surfaces described by mechanical scaling and direct determination of algebraic form components as shown by construction lines.

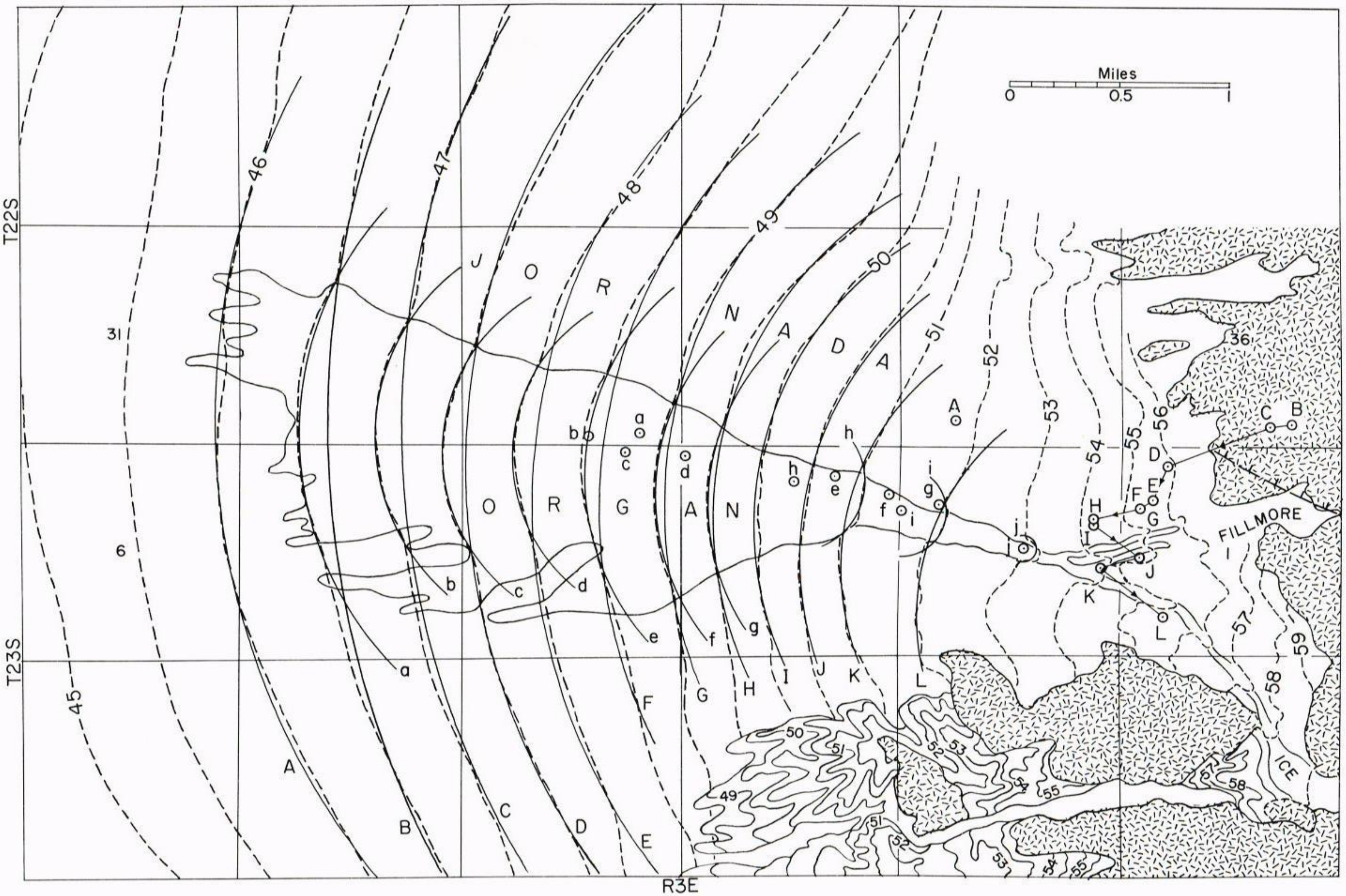


Figure 16

Geometry of Organ and Jornada alluvial fans debouching from Ice and Fillmore canyons in the Organ Mountains

showing arcs fitted to smoothed contours and centers of radii of curvature. Note precession of centers from Fillmore to Ice Canyon on Jornada surface. Closely spaced contours at bottom of map show the Dona Ana surface.

suggest that during the upward building of the Jornada fan, displacement occurred on the south side of the fault, causing a shift of sediment source to the southward. Although the main sediment may have come originally from Fillmore Canyon, the source shifted in later phase fan-building to Ice Canyon. As a result, the spatial geometry of the fan in its upper part is asymmetrically oriented toward Ice Canyon.

The second geometric system within the contours is shown as a pronounced westward bulge below 4950 feet and an eastward bulge above 510o feet (fig. 16). These distortions of contour lines conform to the mapped limits of the Organ surface. Westward convexity is the overlay component and eastward convexity marks the inset component of the Organ versus the Jornada surface.

Circumscribed arcs and located centers of radii differ from the Jornada system. Curvature is greater and radii are shorter. The convex westward contours show the effect of deposition of Organ sediments on the Jornada surface. The convex eastward contours show Organ erosion below the Jomada surface. In arroyo walls, there are many exposures of relatively unweathered Organ sediments overlying a buried soil (Rube, 1964). When the sediments and buried soil are traced laterally, the sediments feather out and the buried soil becomes the surface soil of the adjacent Jornada landscape.

The zone between 5000 and 5050 feet shows little distortion between the two geometric systems. One arc can be circumscribed to satisfy the Jornada and the Organ surfaces. This is the apparent area of balance between dominant deposition downslope and dominant erosion upslope.

Displacement of centers of radii also differs in the Organ and the Jornada systems. There was parabolic precession of the Jornada centers, but the Organ centers are displaced downward and upward along one axial radius, indicating little if any lateral tectonic disturbance during the Organ episode. Geographic emplacement of the Organ fan was inherited from the asymmetrical shift of sediment distribution during construction of the Jomada surface.

Projected profiles of the two surfaces have different curvatures, and the profiles cross in the balance area between 5000 and 505o feet in elevation. The Organ surface can be described as $Y = \frac{1}{0.0238 - 0.00091X}$ and the adjacent Jornada surface as $Y = \frac{1}{0.0241 - 0.00096X}$, where Y is elevation in feet and X is distance in miles.

The contrast in geometry of the surfaces is easily converted to three dimensions so that an estimate can be made of the volume of Organ sediments deposited on the Jomada surface below the balance zone and the volume of Jomada sediments eroded above the balance zone. The volume of Organ sediments is 9257 acre-feet, and the volume of Jornada sediments eroded is 48o acre-feet. The former value is minimal because projection of the Jornada surface contours (fig. r 6) does not take into account possible scouring of the Jornada surface below the Organ sediments. The latter value is only 5.2 per cent of the former, so obviously other source areas were eroded to account for some 95 per cent of the Organ sediments. This material had to come mainly from the slopes in the Organ Mountains along Ice and Fillmore canyons.

Age

The Organ surface is in physiographic contact mainly with the Jornada surface, and as it is inset and overlies the latter, it is younger. It is in direct contact with the Whitebottom scarplet surface which forms a series of stepped levels cut in Organ sediments. Consequently, the Organ surface is older than the Whitebottom. There is no direct contact of the Organ with other surfaces of the basin or valley-border surface groups where relative age may be determined diagnostically.

Fortunately, three radiocarbon dates from Organ sediments date the surface reasonably accurately. Near Gardner Springs and along the arroyo heading to the spring, three sites are located in the NW¼, sec. 2, T. z, S.; R. 3 E. Site I was Soo feet west of Bear Peak Canyon road; site z was 300 feet east of the road; and site 3 was in a branching arroyo 200 feet south of site 2. Charcoal at site r in a sandy loam sediment at a depth of zo to 32 inches is 2120 ± 100 years old (I-290).* Charcoal at site z in sandy loam sediment at a depth of 90 to 98 inches is 464o ± 18o years old (I-291).

Sites r and 2 are 800 feet apart, and the ground surface between them has several minor scarps like those of the Whitebottom surface. This suggests that cut and possible fill cycles may separate the two radiocarbon horizons. If these were relatively minor geomorphic events that did not seriously interrupt the sedimentation continuity, rate of sediment deposition may be calculated between the radiocarbon horizons. The rate is 1 foot per 445 years. Even with the possible interruptions, this rate is in good agreement with that of a valley-border group analogue that will be discussed later.

Charcoal at site 3 at a depth of 55 inches is 1130 ± 90 years old (I-292) and is in a distinct arroyo fill 6o feet wide and 7 feet thick. The fill, as exposed in the arroyo wall, is inset in the sediments containing the other two radiocarbon horizons. Consequently, the Organ surface and sediments are multicyclic in origin.

If the same rate of deposition between sites r and 2. continued to the ground surface, the age of the surface would be about 1375 years. This age is not precluded by the date at site 3. The Organ surface at sites r and 2, whose possible age is 1375 years, was subsequently cut by an arroyo channel that was filled about 25 per cent 1130 years ago; the remaining 75 per cent filled later.

Thus, the Organ surface was constructed in Recent time, and part of it is a few thousand years old and part of it certainly dates from the last millenium. Contemporaneity of the Organ surface and sediments with the Fillmore surface and sediments of the valley-border surface group is discussed later.

* "I" is Isotopes, Inc., kith their sample number.

BASINS AND SCARPLET SURFACES

Four basin surfaces are along the curvate axial depression between the Dona Ana and San Augustin—San Andres mountains (pl. 2). Each is readily mappable physiographically, and each has distinctive sediments associated with it.

LA MESA SURFACE

This surface occupies the largest area of all the basin surfaces, 16.35 square miles or 4 per cent of the total area of study. The largest remnants are west of the Rio Grande south of Picacho Mountain, at the north and south ends of the axial depression east of the Dona Ana Mountains, and at the north end of the structural axis of the Dona Ana dome (pl. 2). A small remnant is near the southern limit of the area south of Tortugas Mountain.

Remnants of La Mesa surface at the south and north ends of the axial depression stand as much as to feet above the adjacent deposits. In the South Well area (sec. 33, T. 20 S., R. 2 E.) the margin of the surface is scalloped by cusp-shaped embayments of lower surfaces and deposits. Sandy loam and loam sediment grade downward into "mixed rounded gravels." These gravels are widespread in the area, contain erratic cobbles and pebbles, and are dominantly rounded in contrast to the angularity of most surficial sediments. They also contain the vertebrates *Equus* and Cuvieronius, which indicate that the beds are no older than late Kansan and no younger than Illinoian (Ruhe, 1964), As La Mesa surface is formed above these beds, it is younger and must be post late Kansan—Illinoian.

It has been pointed out that the La Mesa surface is upthrown and downthrown along the Robledo fault west of the Rio Grande and is warped and tilted in the area northwest of the structural axis of the Dona Ana dome.

LAKE TANK SURFACES

Three constructional basin surfaces are designated herein as o, I, and 2 but were previously named the *Lake Tank*, *Organ—VtJIlitebottoln*, and *Jornada*, respectively (Ruhe, 1964). The reason for redesignation is that more detailed subsurface study suggests a slight refinement of placement of the surfaces and their associated deposits in the geomorphic and stratigraphic sequences of the area. No attempt will be made here to spell out the detailed relationships, as it would pre-empt work of others that probably will be published elsewhere. However, the three Lake Tank surfaces and their associated sediments maintain their relations one to the others and to the La Mesa surface as Ruhe (1964) described. Certainly, the Like Tank o surface is Recent and historical and the Lake Tank I surface is, in part, also Recent and historical.

All the Lake Tank surfaces are relatively minor in areal distribution. Lake Tank I occupies 1.15 square miles or o.3 per cent of the total area, and the second and third surfaces are 3.21 square miles (o.8 per cent) and 7.74 square miles (1.9 per cent), respectively (table 3; fig. i o).

Most of Lake Tank o surface is occupied infrequently by Isaacks Lake and is a playa (fig. 17). After heavy runoff or thaw, water may stand several feet deep on this surface for a few weeks or a few months. Between 1957 and 1965, water was impounded three times in the lowest part of the basin surface covering an area about 0.5 mile long and o.25 mile wide. Several peripheral strand lines attest to larger lake coverage in the past (fig. 17).

Sediments associated with this surface have more than 6o per cent less than 2 microns clay. After water dissipates, the clays are massive and exhibit little structure. Upon drying, a coarse, angular, blocky structure forms with blocks 3 to 6 inches in over-all dimension. Grooves, striae, and slickensides form on the faces of the blocks. The ground surface breaks up into systems of polygonal desiccation cracks; that is, typical mud cracks (fig. i8A). As drying continues, the cracks widen from 3 to more than 6 inches and deepen to more than 3 feet (fig. i8B). The polygonal columns stand as mounds, making the ground surface very irregular and rough. It is difficult to walk or ride across the surface. Commonly, the wheel of a vehicle may drop into a wide crack. All these evidences indicate that the clay is a self-churning mass because of expansion and contraction of the clays that are brought about by wetting and drying. Consequently, a horizonated soil is prevented from forming on the Lake Tank o surface, and properties within the zone of the soil are dependent upon the time in the churning cycle that the soil is observed.

Sediments of the Lake Tank o surface are inset on those of the Lake Tank 2 surface (fig. 17A, B) and also abut and are inset against those of the Lake Tank r surface (pl. 2). Lake Tank o surface is younger than the other two. Shallow drainageways filled with red and reddish-brown sandy loam and loam sediments ascend from higher strand lines of the Lake Tank o surface eastward on the Jornada surface (pl. 2; fig. 1B, E.6, o.2; fig. 17A). These drainageways are contemporaneous and show modification of the Jornada surface in recent time.

The Lake Tank I surface is extremely flat (pl. 2), and its associated sediments are dominantly silts and silty clays. The deposits overlie a paleosol which, when traced westward—that is, along the line between secs. 15 and 21 T. 21 S., 11. 2 E.—rises to the ground surface where it becomes the soil on the Lake Tank 2 surface. Lake Tank surface is younger than Lake Tank *2*. Lake Tank I surface merges laterally and imperceptibly with the Organ surface in sec. 35, T. 20 S., R. 2 E. (pl. 2), and silts and silty clays of the Organ sediments also merge with silts and silty clays of Lake Tank 1 sediments. Thus, the sediments arc in part contemporaneous, so the surfaces must he. However, a complication is introduced by the associated \\'hitebottom surface (pl. 2).

The Lake Tank 2 surface was previously designated as the *Jornada Basin surface* (Rube, 1964) and was related to the Jornada surface mainly on the basis of soil stratigraphy. However, the sediments on the Lake Tank 2 surface "may" overlie the true Jornada surface and hence may be younger.

WHITEBOTTOM SURFACE

This surface is marked on the landscape by a series of scarplets a few inches to a few feet high which ascends eastward from the Lake Tank I surface toward the San Andres 'Mountains (pl. *2*, fig. 18C). Areal distribution patterns of the scarplets indicate that they are confined to

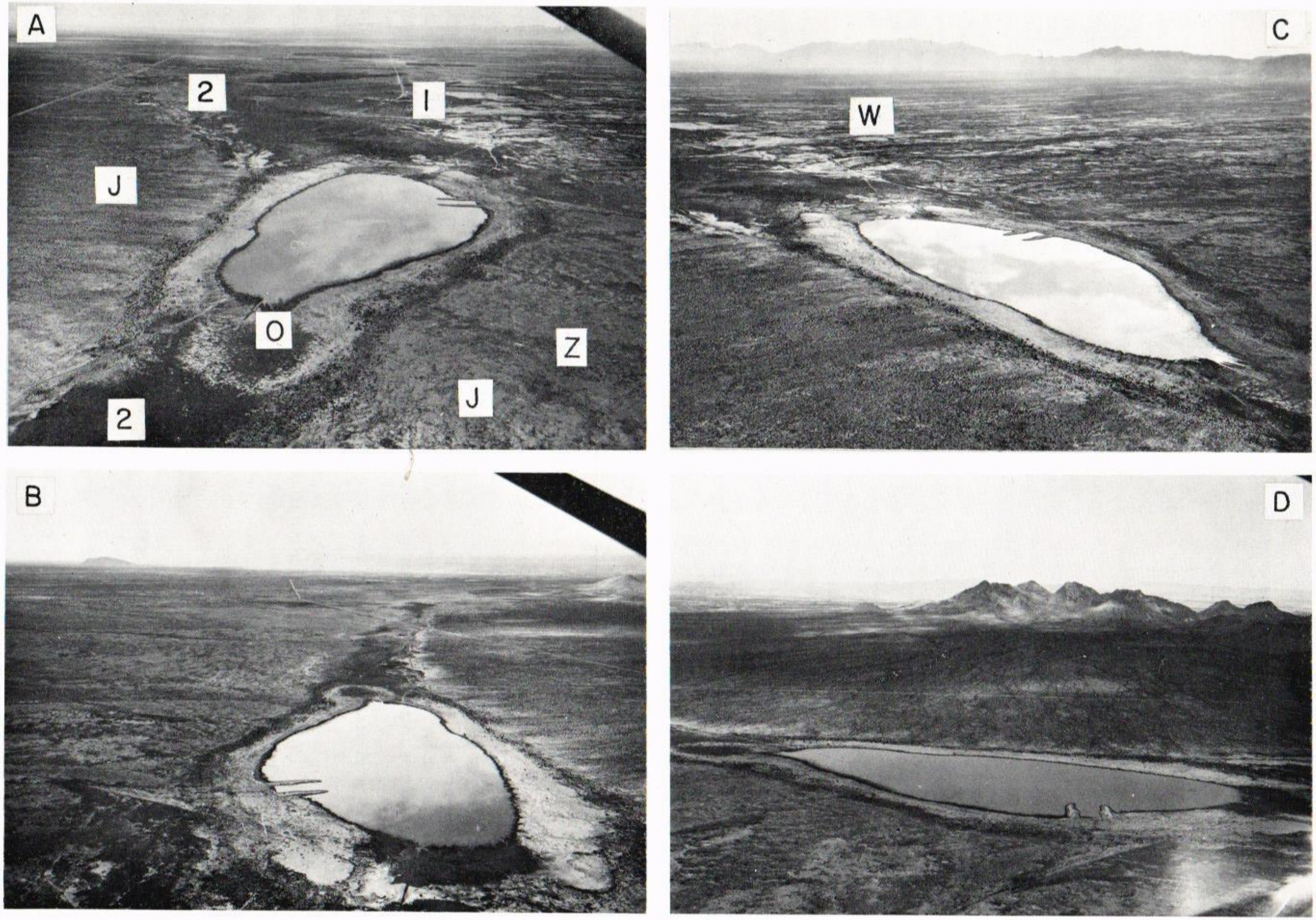


Figure 17

INTERMITTENT ISAACKS LAKE ON LAKE TANK 0 SURFACE

(A) To north, (B) to south, (C) to northeast, and (D) to west. Note bounding strand lines around lake. Symbols: o, Lake Tank o surface; 1, Lake Tank r surface; a, Lake Tank **a** surface; J, Jornada surface; W, Whitebottom surface; Z, alluvium in drainageways on Jornada surface. (Airphotos by J. W. Hawley)

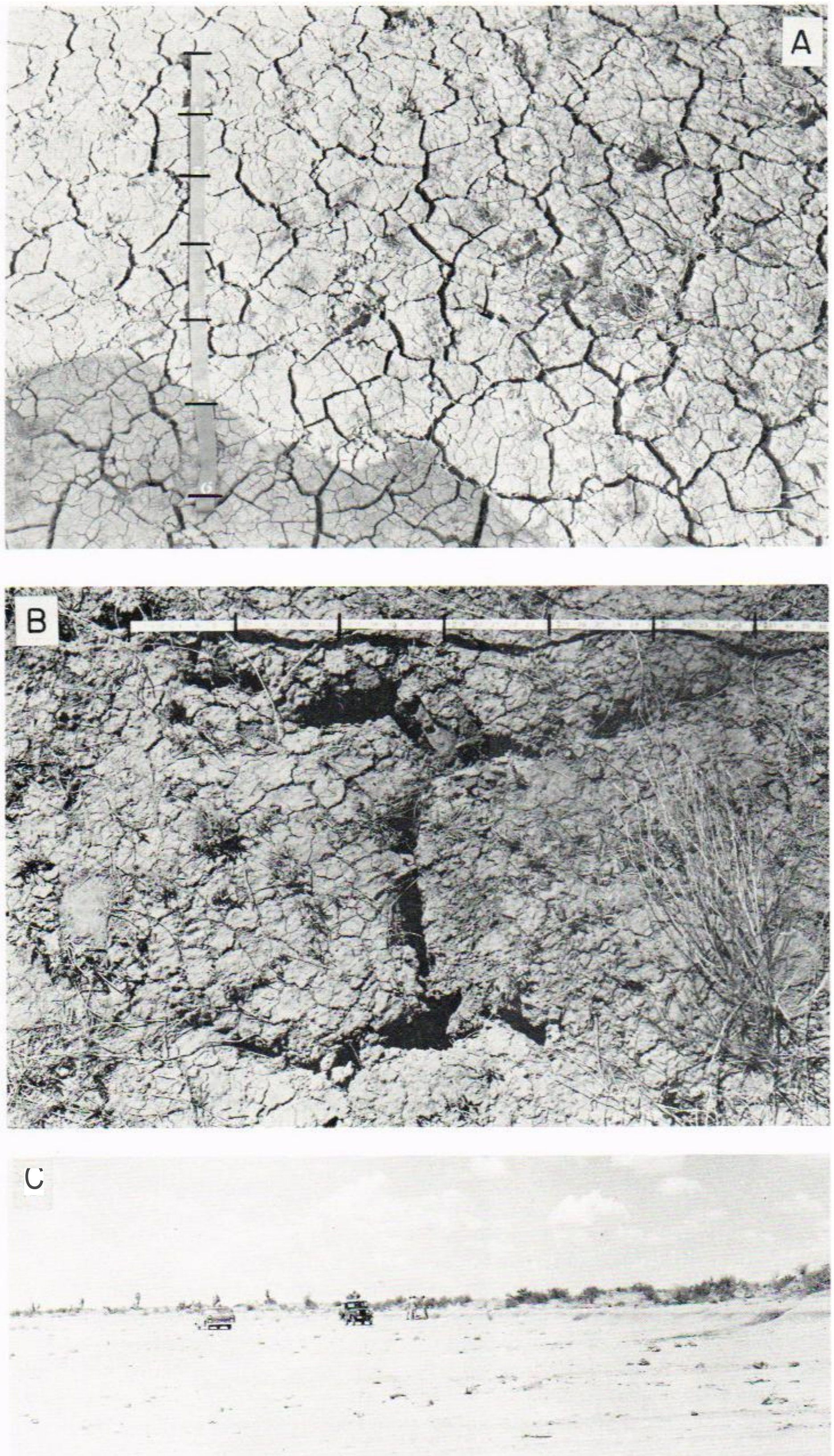


Figure 18

DESICCATION FEATURES ON LAKE TANK 0 SURFACE

(A) Mud cracks following disappearance of Isaacks Lake. (Scale in *feet)* (B) Polygons and cracks several months later. (Scale 0.5 foot) (C) Scarplet on Whitebottom surface.

watersheds on a pre-existing surface. Two to four miles east of the basin, the scarplets are in long, narrow belts suggestive of distribution along drainageways. Within two miles of the basin margin, the patterns coalesce laterally to form a broad belt that parallels the long axis of the Lake Tank I basin. The Whitebottom surface occupies 9.22 square miles or 2.3 per cent of the area (table 3).

At all places, the scarplets are cut below the Organ surface and are restricted to silts and silty clays of Organ sediments (pl. I). They do not occur in Organ sands and gravels. Consequently, there is a specific control of their formation by kind of sediment. In some places, the scarplets are rounded in profile although scalloped by rills (fig. 18C). In other places, they have vertical faces and are fronted by blocks and mounds of silty sediment that certainly have fallen from the scarplet face.

In the belt near the Lake Tank 1 basin, the base of the scarplets and the erosion surface that extends westward are emplaced on a paleosol which has a reddish-brown, clayey B horizon. Not only is the paleosol exhumed by Whitebottom erosion, but it also controls the depth to which erosion has progressed in this area. The paleosol when traced westward passes under the Lake Tank basinal sediments and may be the buried soil that rises to the ground surface on the Lake Tank 2 sediments. Depth of Whitebottom erosion is not universally controlled by the paleosol. To the eastward, as the Organ silts thicken, the base of the Whitebottom scarplets is in silts.

There are numerous scarplets on the Whitebottom surface. For example, in the line of sections from 35, T. 21 S., R. 2 E., through 32, T. 21 S., R. 3 E., at least 54 scarplets occur as risers between treads as in a shallow. staircase rising from 4310 to 4550 feet in elevation in 4 miles (pl. 2). Only those scarps that could be cartographically handled at a scale of 2 inches tot mile are shown. There are others. Among those mapped, continuous lengths of scarp-lets range from less than o.i mile to slightly more than 1.3 miles.

There is a vegetation association with the scarplet landscape but it is not necessarily restrictive. Burro grass with scattered tarbush, creosote bush, desert holly, and sparse snakeweed is present on the silts above the scarp. Commonly, an elongate dune is adjacent to and parallels the scarp on the higher tread and is usually marked by the presence of yucca (fig. 18C). On the tread below the scarplet riser, burro grass and tarbush are also present on thin silts and silty clays that mantle the buried soil in the belt adjacent to the Lake Tank I basin and also in the belt where the lower tread is on thicker silts and silty clays.

On other parts of the Organ surface in the general area, black grama grass, fluffgrass with scattered sand dropseed, creosote bush, mesquite, snakeweed, and yucca afford reasonable cover. The sediments, however, are gravelly, loamy sands. Scarplets are not present even though original landscape geometry is very similar to the areas of silts and silty clays. Thus, the distinct relationship between scarplets and the kind of material in which they are formed must be considered in any geomorphic mechanism explaining their formation.

Hadley and Rolfe (1955) have explained similar scarplets as eroding seepage steps where shallow subsurface flow crops out on a hill slope and saturates the surficial mantle. The wetting action loosens the soil and makes it available for removal by surface flow. The seepage face migrates upslope as seepage loosens material and surface flow transports the soil downslope. In cases like these, the height of the seepage face is generally controlled by the thickness of the surficial mantle.

This apparently is not the explanation for the origin of the Whitebottom scarplets. Within limits and with some exceptions, permeability increases with the increase in size of particles of a material, and the particle-size distribution provides a general guide to the water-transmitting properties of the material (Lauritzen, 1955). The converse, in general, is also true. With decrease in size of particles, infiltration decreases and, consequently, runoff increases. The silty clays that have scarplets have a particle-size distribution of o.1 per cent gravel, 19.4 per cent sand, 45.5 per cent silt, and 32.3 per cent clay. The gravelly, sandy loam sediments that do not have scarplets have 24.0 per cent gravel, 55.3 per cent sand, 13.9 per cent silt, and 6.9 per cent clay. These values are weighted means of 6 horizons and 5 horizons to depths of 4 feet respectively.' Thus, infiltration would be less and runoff would be greater on the silty clays than on the gravelly, sandy loam sediments. One would expect greater seepage and possible scarplet formation in the latter, but scarplets are lacking.

On the silty clays pronounced runoff has been observed during rainstorms, and networks of rills are common on the lower treads of scarplets (fig. 19). The long axis of each small rill watershed is oriented down gradient toward the Lake Tank 1 basin. The "micro" drainage basins evolve in areas as small as 100 x 100 feet. Rills initially incise the silty clay only several inches. Valley-flanking micro pediments (Frye, 1954) form along the main rill and its dendritic-pattemed tributaries (fig. 19), and several cycles of micropediments may develop. These result in the over-all lowering of ***the*** interfluves between the various orders of rills in the microwatershed. A broader multicyclic erosion surface evolves on the interfluves, and a scarplet only a few inches high forms at the peripheral divide (fig. 19). A number of subparallel and adjacent rill systems form a continuous but sinuous scarplet across country. With continued erosion within the rill systems, a scarplet several feet high may form (fig. 18C), and seepage along the face may cause sapping and collapse of blocks whose debris may then be removed by running water. However, seepage and sapping are an aftereffect and subsequent cause. Rilling by runoff initiates the scarp.

An initial requirement for rilling is the removal or reduction of grass cover by whatever cause, whether it be grazing by stock or destruction by drought. The barren or sparsely covered surface is then rilled. Scarplet retreat is maintained by rilling and sapping at the scarplet base since declivity increases as the scarplet height increases. Eroded debris is transported across the lower tread, and much of it has accumulated in the Lake Tank I basin (pls. I and 2). Hence, those sediments and their surface are, in part, of Whitebottom age.

* Calculated from data of the Soil Survey Laboratory, Soil Conservation Service, Lincoln, Nebraska, hereafter referred to as SSL-LN.

VALLEY-BORDER SURFACES

A number of geomorphic levels are in stepped sequence in a belt paralleling and ajacent to the Rio Grande flood plain (fig. 20) These surfaces from lowest to highest and correspondingly youngest to oldest are the *Fort Selden* (comprised of the *Fillmore* and *Leasburg* members), Pica*cho,* and *Tortugas.* The sequence of surfaces may rise to bounding mountain slopes, as along the east side of the Robledo Mountains, to a terminal scarp of the Jornada surface, or to a terminal rim of the La Mesa surface (pl. 2). Originally, the members of the Fort Selden surface complex were not separated (Ruhe, 1962). Then four members were recognized (Ruhe, 1964) but further study required the combination of two pairs for consistency in cartography (Hawley). The Fillmore member, Picacho, and Tortugas surfaces occupy appreciable areas of 41.5, 29.1, and 26.94 square miles, or 10.1, 7.1, and 6.6 per cent of the total area, respectively (table 3). The Leasburg member is a minor surface occupying only 4.5 square miles or 1.1 per cent of the total.

MORPHOMETRY

Some of the surfaces within the valley-border sequence have been termed *terraces.* For example, Kottlowski (1953) used the term *Picacho terrace.* With the exception of a small area of the Leasburg surface near the ruins of Fort Selden, few if any of the surfaces paralleling the Rio Grande are terraces. This is particularly true if the term

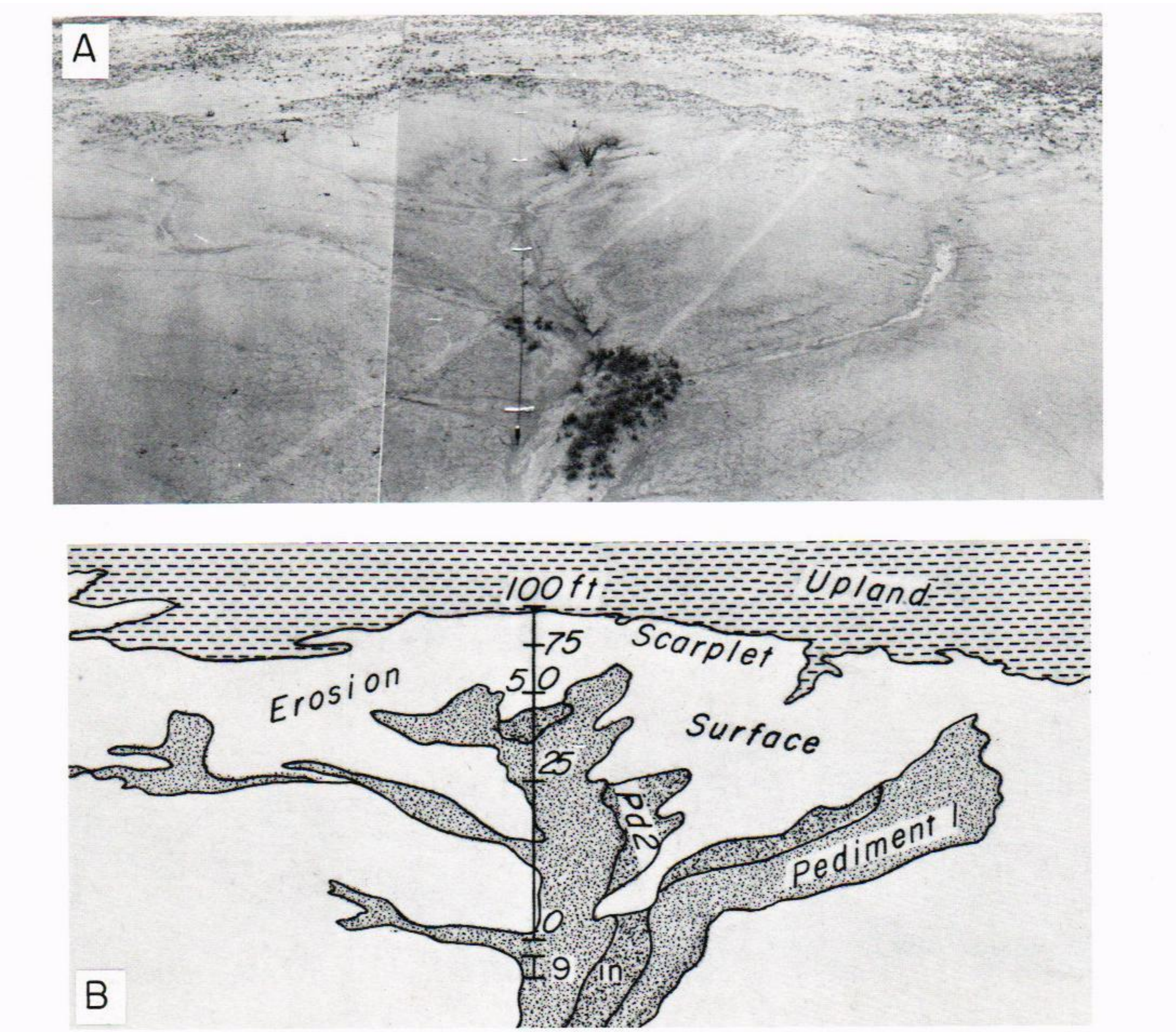


Figure 19

ORIGIN OF SCARPLET ON WHITEBOTTOM SURFACE BY BILLING

(A) Photograph. (B) Explanatory diagram of photograph. (Scale along tape in z5-foot units; vertical scale is 9 inches) *terraces* is restricted to levels of unconsolidated materials contained between recognizable valley walls (Tator, 1953). A difficulty in the Rio Grande Valley is recognizing its walls. As Ruhe (1962, 1964) pointed out, the valley is at least biwalled. The inner wall is formed at the edges of the flood plain by the terminal scarps of surfaces of the stepped sequence. The outer wall is the terminal scarp of the Jornada surface, the terminal rim of the La Mesa surface, or the mountain slopes to which the surfaces of the stepped sequence ascend. Then, too, the terminal scarps between surfaces of the stepped sequence may also be considered valley walls, so the valley, then, is multiwalled.

From the Rio Grande flood plain to the outer valley wall, the stepped sequence of surfaces ascends like a staircase. Each surface, Fillmore, Leasburg, Picacho, and Tortugas, is a sloping tread separated from adjacent treads by risers, that is, scarps. A specific surface rises to different elevations at varying distances from the flood plain (table 5). For example, the Fillmore member of the Fort Selden complex rises from 3900 to 4325 feet and occupies 14.57 square miles or 35.1 per cent of its total area within this elevation range. At other places, the Fillmore member ascends from 3925 to 4300 feet and occupies 17.46 square miles or 42 per cent of its total area. in addition, the surface rises from

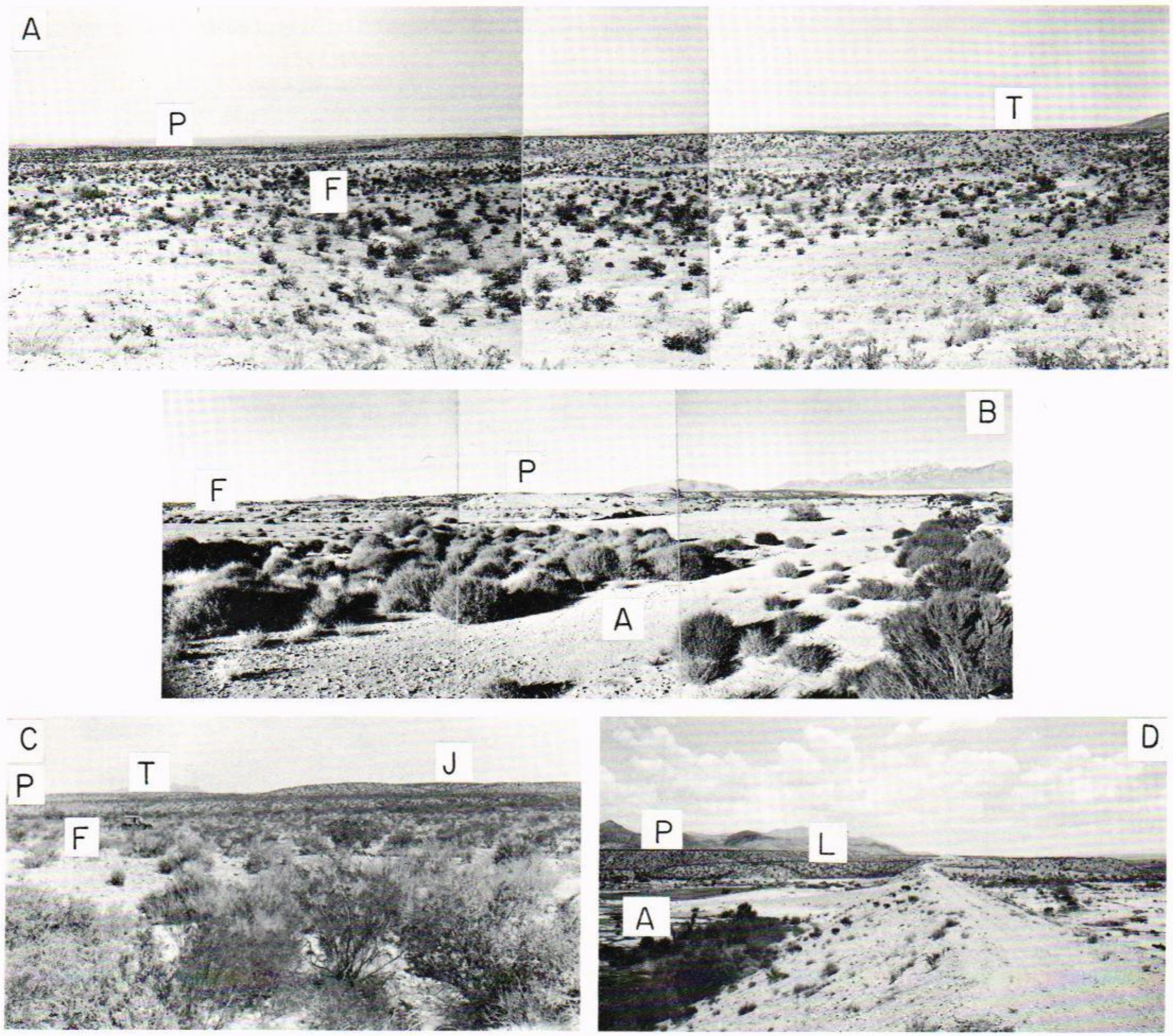


Figure 20

GEOMORPHIC SURFACES IN STEPPED SEQUENCE ALONG RIO GRANDE

(A) Fillmore, *F*, Picacho, *P*, and Tortugas, T, surfaces west of Tortugas Mountain. (B) Arroyo level, A, Fillmore, and Picacho surfaces along Fillmore Arroyo southwest of Tortugas Mountain. (C) Fillmore, Picacho, Tortugas, and Jornada, *J*, surfaces north of Tortugas Mountain. (D) Leasburg, L, and Picacho surfaces at north end of Apache Canyon dam.

395o to 4200 and from 4075 to 4450 feet in other parts of the area. The elevations 3900, 3925, 395o, and 4075 feet mark the terminal scarp of the Fillmore surface; its arithmetic mean elevation is 3939 feet, which is 43 feet above the arithmetic mean elevation of the Rio Grande flood plain. The progressive rise in elevation of the terminal scarp is from south to north along the valley and coincides with the ascent of the Rio Grande flood plain from 3876 feet in the south to 3962 feet in the north.

The other surfaces of the stepped sequence have similar area-altitude distributions, but their specific values differ (table 5). Arithmetic mean elevations of termini scarps are 3961, 4026, and 4136 feet for the Leasburg, Picacho, and Tortugas surfaces, respectively, and the respective scarps are 65, 13o, and 240 feet above the flood plain. Arithmetic mean elevation of the terminal scarp of the Jornada surface is 4300 feet, which is 404 feet above the flood plain. The tread of any surface of the sequence may abut this scarp, but commonly the Tortugas surface is in its proper place below it (pl. 2).

Ascendance of the surfaces from the flood plain to the outer valley wall is shown in projected profiles (fig. 21). In the area near Las Cruces from Alameda Arroyo to the south limit of the area and on the east side of the valley, the Fillmore surface rises as expressed by $Y = 24.94 + x.65X$, where Y is elevation in feet and X is distance in miles. The Picacho surface also rises linearly as expressed by $Y = 34.07 + 0.88\ X$. The Tortugas surface is curvilinear in profile and rises eastward as expressed by $Y = 35.25 + 0.75X$ o.008X^2. The Jomada surface is curvilinear and is expressed by $\log Y = 1.524 + 0.017X$. A lower surface

TABLE 5. TERMINI SCARPS OF SURFACES OF THE VALLEY–BORDER SEQUENCE

surface	elevation range (feet)	area (sq. mi.)	surface area (%)	elevation of scarp* (feet)	above flood plain (feet)
Fort Selden					
	3900-4325	14.57	35.1		
	3925-4300	17.46	42.0		
Fillmore	3950-4200	3.73	8.9	3939	43
	4075-4450	5.73	13.8		
	3925-4100	0.98	22.0		
	3950-4050	0.80	18.0		
Leasburg	3975-4275	2.45	54.9	3961	65
	4000-4100	0.22	4.9		
	3925-4375	7.37	25.3		
	3950-4275	1.31	4.4		
	4000-4375	6.08	20.9		
Picacho	4025-4400	7.15	24.5	4026	130
	4050-4350	2.97	10.2		
	4250-4725	4.23	14.5		
	3975-4475	2.64	9.8		
	4100-4550	9.65	35.8		
Tortugas	4150-4475	9.18	34.0	4136	240
	4250-4775	4.90	18.2		
	4300-4875	0.57	2.1		
	4200-4675	4.95	4.6†		
Jornada†	4300-4750	56.47	52.8	4300	404
	4400-4775	4.86	4.5		

* Arithmetic mean elevation of top of scarp
† Not carried to mountains; does not total 100 per cent

may abut the terminal scarp of the next higher surface or may pass around a protruding nose along an interfluve and extend to and beyond the terminal scarp of the Jornada surface.

Valleyward projection of the geometry of these surfaces permits estimation of previous base levels compared to the present flood plain of the Rio Grande. The values are 9 to 12 feet, 71 to 79 feet, and 147 feet above the flood plain for Fillmore, Picacho, and Tortugas, respectively. These estimates differ from those made by the graphic reconstruction which were 25, 135, and 35o feet (Rube, 1962). Previously herein, it was shown that the Jornada surface when projected is 220 to 240 feet above the flood plain.

Ascendance of these surfaces away from the Rio Grande precludes their being terraces of that stream. Instead, each surface is a complex feature with many components. The Tortugas surface from the south limit of the area northward to Dona Ana Arroyo abuts the terminal scarps of Jornada and La Mesa and is cut into the mixed rounded gravels containing the vertebrate fauna older than the La Mesa surface (pls. 1, 2). In this area, the Tortugas is an erosion surface whose remnants occupy axial summits of interfluve divides. Its curvate nature indicates that it was controlled by an ancestral Rio Grande base level at an elevation of 147 feet above the present flood plain. Reconstruction of the surface indicates that it probably was a valley-flanking pediment.

On the west flank of the Dona Ana dome, this surface is in part rock pediment and in part alluvial apron. On the east slope of the Robledo Mountains and around Picacho Mountain, the surface is constructional and is alluvial fans and cones. Where constructional, the surface is associated with angular gravels that are locally derived upslope from adjacent bedrock. South of Picacho Mountain to the south limit of the area, the Tortugas surface is a remnantal valley-flanking pediment along interfluve divides on mixed rounded gravels. Locally in any area, the Tortugas passes around the terminal scarp of the Jomada surface extending upslope and paralleling arroyos. Here, the surface is a valley-flanking pediment that descended to an ancestral higher stand of the arroyo which in turn descended to the higher, ancestral Rio Grande.

On the east side of the valley, the Picacho surface also is is a pediment flanking the Rio Grande Valley from the south limit of the area to Dona Ana Arroyo. It is cut below the levels of the Tortugas and Jornada surfaces and into the mixed rounded gravels within a few miles of the valley and also is cut into the angular gravels associated with the Jornada piedmont. The Picacho surface passes around termini scarps of the older surfaces, which are noses along interfluve axes, and passes upslope paralleling arroyos. Here the surface is a valley-flanking pediment that stands above lower surfaces but descends toward the arroyos. Farther up-slope, the surface is a terrace paralleling the arroyos.

On the south and west flanks of the Doña Ana dome, the Picacho surface is dominantly an alluvial apron. On the east slope of the Roblado Mountains and around Picacho Mountain, the type area of the Picacho surface (Dunham), it is a constructional alluvial fan. Southward on the west side of the valley, the surface is a pediment cut into the mixed rounded gravels and associated sands (pls. 1 and 2).

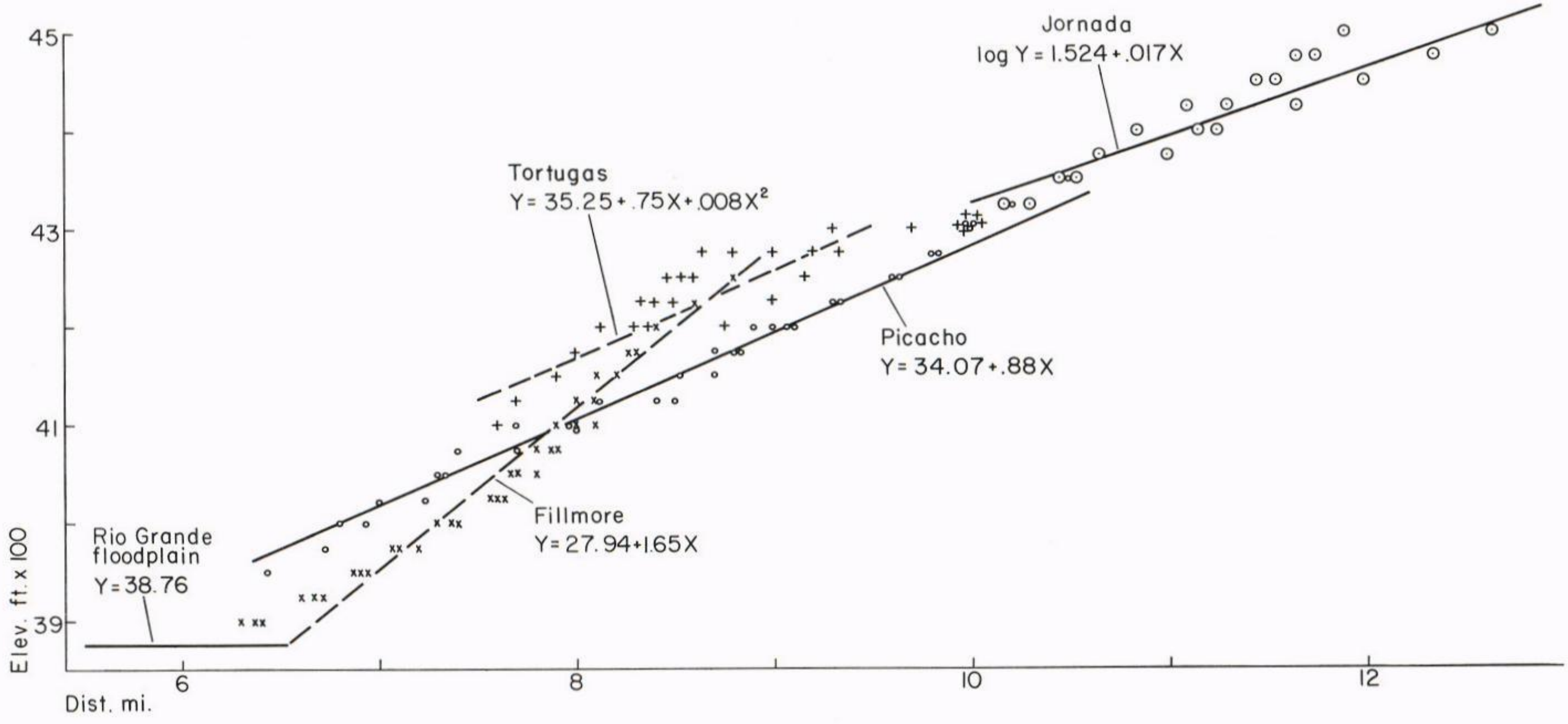


Figure 21

GEOMETRY OF PROJECTED PROFILES OF VALLEY-BORDER SURFACES ON EAST SIDE OF RIO GRANDE IN VICINITY OF LAS CRUCES

The Fillmore member of the Fort Selden complex is formed mainly on the sands associated with the mixed rounded gravels (pls. 1 and 2). Its main distribution is south of Dona Ana Arroyo and south of Picacho Mountain on the east and west sides of the Rio Grande, respectively. This surface has components very similar to those of the Picacho. In addition, the surface has constructional features of alluvial fans that coalesce laterally along the margin of the Rio Grande flood plain. These fans were built by arroyos that descended to a Recent level of the flood plain. Presently, terminal scarps are scallops or cusps that were cut along historical channels of the river.

The Leasburg member of the Fort Selden complex is of minor extent and occurs mainly north of Dona Ana Arroyo and north of Picacho Mountain on both sides of the river. At places, it may be a pediment flanking the Rio Grande or a possible alluvial bench or terrace. Locally, it extends along arroyos upslope from the valley but is difficult to delineate consistently.

Various combinations of surfaces are in the area. On the east side of the valley and north to U.S. 7o, the landscape steps are Fillmore, Picacho, Tortugas, and Jornada. Northward to Goat Mountain, Jornada is replaced by La Mesa. On the west flank of the Dona Ana dome, the entire sequence excluding La Mesa is present and is Fillmore, Leasburg, Picacho, Tortugas, Jornada, Dona Ana, and mountain slopes. On the east side of the Robledo Mountains and Picacho Mountain, Jomada drops from the arrangement and Tortugas or Picacho abuts mountain slopes. Southward, Leasburg is absent and La Mesa is again present above Tortugas. Such complexities in combinations can be determined only through controlled field mapping.

AGES OF SURFACES

All the valley-border surfaces are younger than La Mesa and Jornada as they are cut below the latter two. They are post late Kansan—Illinoian.

The Fillmore surface may be dated reasonably accurately by radiocarbon. In the north bank of Fillmore Arroyo at a distance 1500 feet southwest of the power line in unsectioned Dona Ana Bend Colony, T. 24 S., R. 2 E., charcoal was extracted from loamy-sand sediment at depths of 46 to 54 inches. The sample site was a buried hearth. It was lenticular in cross section, 3o inches long and 8 inches thick and extended 24 inches into the face of the bank. Numerous stones at the base of the lenticle had charred upper surfaces and rested on reddish loam that presumably had been fired. Charcoal from the hearth is 262o ± 200 years old (Rubin and Alexander, 1960; W-819). The Fill-more surface 46 inches above the C14 horizon is younger.

One mile west of Shalem Colony in the NW¼ sec. 20, T. 22 S., R. 1 E., and 70 to 85 feet west of the bank of the Rio Grande, two charcoal horizons were found in the vertical arroyo bank. Four sedimentary units were distinct from the surface downward: (1) a gravel 1.5 to 2 feet thick, (2) a gravelly loam 5 to 6.5 feet thick, (3) a gravel 2 feet thick, and (4) a gravelly sand at least *5* feet thick to the base of the cut (fig. 22A). An upper charcoal lens was found in unit 2 at a depth of 38 to 41 inches (fig. 22B). The lens was 23 inches long and 3 inches thick and contained charcoal fragments one half to one inch in diameter. The containing loam sediment was brown (7.5YR 5/4), but beneath the charcoal lens the sediment contained gray (10YR 5/I) ash. A layer i inch thick was reddish brown (5YR 5/4), indicating that the sediment had been fired. This, too, was a hearth site, and the charcoal is 285o ± 120 years old (I-294). As the Fillmore surface is 38 inches above the charcoal horizon, it is younger.

The second charcoal horizon was 12 feet eastward and at the contact between units 2 and 3 at a depth of 92 to 95 inches. Here, a lens was 24 inches long and 3 inches thick and contained charcoal fragments a quarter inch in diameter that were mixed in gray (10YR 6/1) ash. A subjacent layer of sediment 1 inch thick was reddish brown (5YR 5/4), indicating that the sediment had been fired beneath a hearth site. Sedimentary unit z directly overlies the lower hearth. The charcoal is 4910 ± 225 years old (1-293).

The lower and upper hearth dates permit calculation of the rate of deposition of unit 2, which is 1 foot per 434 years. This is in excellent agreement with the rate calculated for the Organ sediments at I foot per 445 years. If similar rates continued to the ground surface, the age of the Fillmore surface at the Fillmore Arroyo site would be 86o years and at the Shalem Colony site, 1310 years. However, the latter is complicated by a change in the kind of sediment, sandy loam to gravel, from unit 2 to unit 1 (fig. 22B).

The Picacho surface can be minimally dated by radiocarbon (Ruhe, 1965). In the SE¼ sec. 19, T. 23 S., R. 3 E., a soil on this surface has a prominent, indurated subsurface carbonate horizon. Within the upper inch of this horizon, *organic* carbon sealed in the carbonate is 9550 ± 300 years old (I-616). The organic carbon is in a soil B horizon of illuvial silicate clay which was subsequently engulfed by calcium carbonate. The 9550-year date represents the latest at which accumulation of organic carbon could have begun and this is the *minimum* age of the B horizon. The date also represents the minimum age for stabilization of the Picacho surface and the beginning of soil formation on it. The Picacho surface must be as old as late Wisconsin.

The Picacho surface may be much older than the minimum age. An analogous soil-landscape relation in southern Iowa illustrates a possible magnitude of discrepancy (Ruhe, 1966). In the Edina soil formed in loess, the radiocarbon ages of the AI, A2, and 82 horizons are 410, 840, and 1545 years, respectively. The base of the loess is 16,500 years old and the ground surface where it was traced under younger Pleistocene deposits is 14,000 years old. Thus, the discrepancies between the radiocarbon age of organic carbon in soil horizons and the age of the ground surface below which the soil formed are 13,590, 13,160, and 12,455 years, respectively. The magnitude is 12,500 to 13,500 years. Radiocarbon dates of soil-organic carbon reflect only the equilibrium status of the organic-carbon system when arrested in time either by sampling, burial under younger sediments, or engulfment by other additives in the soil, such as happened on the Picacho surface.

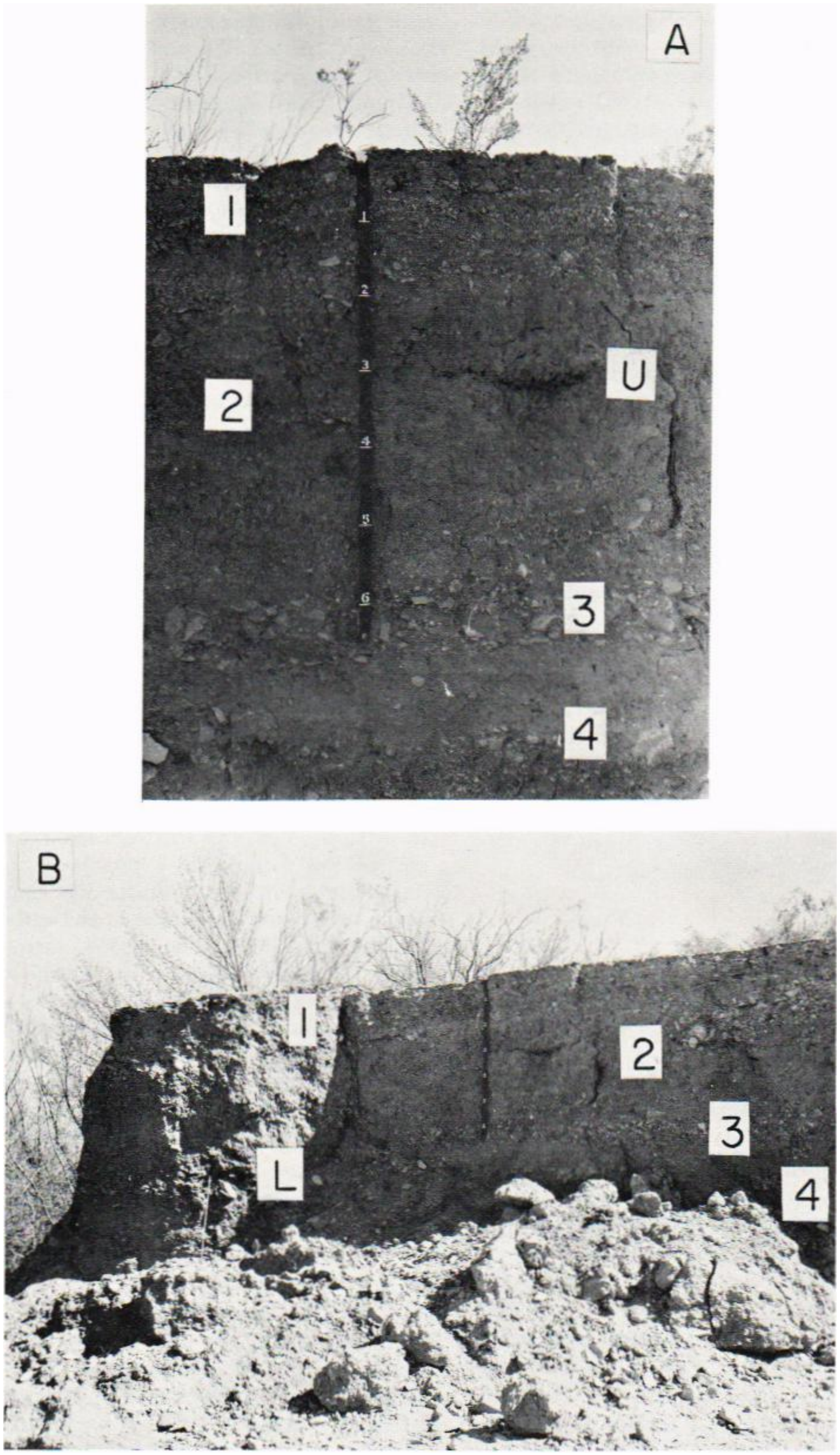


Figure 22

SHALEM COLONY RADIOCARBON SITE

(A) Detail of upper hearth, *U*, showing containment in sandy loam, unit 2. (B) Panorama of cut showing relation of upper hearth to lower hearth, L, and the four sedimentary units. Ages are *U*, 2850 ± 120 years and L, 4910 225 years.

However, these chronological benchmarks can be used to calculate magnitudes of erosion and deposition in time. On the east side of the Rio Grande and northward to Dona Ana Arroyo (pl. I), the Fillmore surface occupies 16.1 square miles and the arroyo channels comprise 2.3 square miles. The Fillmore is inset below the Picacho surface an arithmetic mean depth of 14.6 feet, and the arroyos are incised to an arithmetic mean depth of 4.8 feet below the Fillmore. Lack of numerous measurements of thickness of the Fillmore and arroyo fills prevents quantification of the maximum cutting of each below its adjacent higher neighbor, so the values are minimal. The volume of sediment removed during Fillmore erosion is 140,950 acre-feet and during arroyo cutting below the Fillmore is 928o acre-feet.

Since Fillmore erosion began after 9500 years (date on Picacho surface) and backfilling to an 8-foot depth (lower Shalem Colony date) was completed at 4900 years, the elapsed time is 460o years. At several places where measurements were possible, the 8-foot depth marks the level where 63 per cent of the Fillmore sediments had been deposited. Consequently, some 339,910 acre-feet were removed during the elapsed time at a rate of 730 acre-feet a century. As the calculated age of the Fillmore surface at Fillmore Arroyo is 86o years, the rate of erosion during arroyo cutting is 8o acre-feet a century. The rate during Fillmore time is more than nine times greater than the rate during immediate prehistoric and historic times. Yet, considerable emphasis has been placed on modern arroyo cutting without placing its magnitude within the proper perspective of the over-all problem of erosion (Ruhe and Daniels, 1965).

In summary, the Fillmore, Leasburg, Picacho, and Tortugas surfaces must be fitted below one end member, the Jornado surface, which is post late Kansan—Illinoian; the Fillmore itself is the other end member at less than 262o years or Recent. The Picacho within the sequence is more than 9500 years or late Wisconsin. The Leasburg is between Fillmore and Picacho and so must be more than 490o (lower Fillmore date) to more than 9500 years or Recent to late Wisconsin in age. The Tortugas is between Picacho and Jornada and so must be more than 9500 years, or prior to late Wisconsin to post late Kansan—Illinoian.

CORRELATION OF SURFACES

The surfaces within the area may be placed within a correlation framework that is based in part on relative positions and in part on absolute chronology. The contemporaneity of the Fillmore and Organ surfaces and sediments is evident. Radiocarbon dates of the former are 2620 ± 200, 2850 ± 120, and 4910 ± 225 years and of the latter, are 113o ± 9o, 2120 ± 110, and 4640 ± 180 years. The Organ cycles are mountain-front analogues of the valley-border cycles of the Fillmore. Correlation of surfaces within the area is shown in Table 6.

Correlation of the surfaces in the Las Cruces area with those along the Rio Grande Valley to the south and to the north have been proposed (Ruhe, 1964). These other areas include those near El Paso, Texas (Kottlowski, 1958), and near San Acacia (Denny, 1941), Albuquerque—Belen (Wright, 1946), and Tesuque (Miller and Wendorf, 1958), New Mexico. These correlations have been confirmed more recently (Hawley; Kottlowski, Cooley, and Ruhe, 1965).

TABLE 6. CORRELATION OF GEOMORPHIC SURFACES WITHIN AREA

SURFACE	GROUP	AGE
Rio Grande	Flood plain	Recent–historical
Arroyos	Channel	Recent–historical
Lake Tank 0	Basin	Recent–historical
Whitebottom	Erosion surface	Recent–historical
Lake Tank 1	Basin	Recent–historical
Organ	Fan, apron	Recent (less than 1100 to more than 4600 years)
Fillmore	Valley-border surface	Recent (less than 2600 to more than 4900 years)
Leasburg	Valley-border surface	Late Wisconsin–Recent (more than 4900 to less than 9550 years)
Picacho	Valley-border surface	Late Wisconsin (more than 9550 years)
Lake Tank 2	Basin	Late Wisconsin
Tortugas	Valley-border surface	Pre-late Wisconsin
Jornada	Fan, piedmont, pediment	Post late Kansan–Illinoian
La Mesa	Basin	Post late Kansan–Illinoian
Dona Ana	Fan, pediment	Older, contemporaneous, or younger than La Mesa

Surficial Deposits

Bodies of sediments were separated on the basis of texture and composition, and their distributions were delineated and mapped (pl. 1). In some places there is a distinct association of kind of sediment with geomorphic surface, but this does not preclude a wide variation in texture and composition on a specific geomorphic surface (pl. 2). The main effort of study was directed toward those deposits that are at or near the surface and whose vertical dimensions were controlled by the heights of arroyo walls. A number of observations were also made of greater thicknesses of sediment along the terminal rim of the La Mesa surface.

In the main, interest will be directed toward those sediments that are younger than the mixed rounded gravels containing the vertebrate fauna of late Kansan—Illinoian age. These rounded gravels have been treated in some detail elsewhere (Ruhe, 1962, 1964).

TEXTURE

In general, the sediments of the alluvial fans, aprons, and piedmont are gravels, although there are exceptions. For example, an alluvial fan that forms part of the Jornada fan that debouches from Fillmore Canyon has boulders as large as 25 feet in diameter; many of them are 10 to 15 feet in diameter (fig. 23A). The boulders are monzonite from the "Needles" of the Organ Mountains and had to be transported 1½ miles from their source. Usually, transport of such large boulders is attributed to debris flow even though rocks as large as 3 to 4 feet in diameter are known to be transported in channels of high mountain streams (Miller, 1958).

In extreme contrast to this coarseness of texture are the silty clay sediments of the Organ surface that are derived from limestone, sandstone, and shale (pl. 1). They have only a trace of gravel; less than 3 per cent very coarse, coarse, and medium sand; 4 to 5 per cent fine sand; 13 to 14 per cent very fine sand; 45 to 54 per cent silt; and 26 to 36 per cent clay (fig. 23B).

Gravel textures are related to lithologic composition of the fan sediments. In 298 particle-size analyses plotted on a triangular graph whose corners are gravel (more than 2 mm in diameter), sand (2.o to 0.062 mm), and silt plus clay (less than 0.062 mm), data groups depend upon the kind of rock that constitutes the gravel (fig. 24). Of 69 samples of rhyolite gravel, 81 per cent of the samples have a textural composition of 4o to 8o per cent gravel, 10 to 45 per cent sand, and less than 20 per cent silt and clay. Of 83 samples of monzonite gravel, 86 per cent of the samples have a textural composition of 5 to 40 per cent gravel, 35 to 8o per cent sand, and 15 to 35 per cent silt and clay. The distinct textural differences between the rhyolite and monzonite gravels reflect a greater resistance of the rhyolite to reduction in size during sediment transport and greater resistance to weathering and also give rise to distinct differences in soils formed in these gravels.

Between the areas of rhyolite and monzonite gravels is a broad zone of a mixture of the two but with additions of andesite and some limestone (pl. I). Texturally, these gravels (fig. 24A) encompass the ranges of the rhyolite and monzonite groups.

Gravels derived from sedimentary rocks such as limestone, sandstone, and shale have a wide textural range. They, too, overlap parts of the ranges of the rhyolite and monzonite groups. The gravels derived from volcanic rocks such as andesites and latites in the Doña Ana Mountains have a very similar textural range (fig. 24P, V).

Of 20 samples of mixed rounded gravel, 75 per cent group in a textural composition of 25 to 5o per cent gravel, 5o to 75 per cent sand, and less than 15 per cent silt and clay. They separate distinctly in texture from the other kinds of gravel (fig. 24) and are also distinctive in degree of rounding of individual pebbles and cobbles (fig. 23D). Edges as well as faces of particles are rounded. In contrast, other gravels in the area which are derived from mountain sources are angular (fig. 23C). The mixed rounded gravels are generally associated with the Tortugas surface (pls. and 2). Commonly, in the valley-border area, gravels associated with surfaces below the Tortugas are mixtures of the mixed rounded gravels that were exhumed during Tortugas pedimentation and angular gravels that were derived from the Jornada piedmont, fans, or mountains. These angular gravels were carried along arroyos through the mixed rounded gravels and resulted in the angular-rounded mixture (pl. 1, Gy; pl. 2).

Sands in the valley-border area that are associated with post-Tortugas surfaces have a distinctive textural range; less than 5 per cent gravel, 85 to 95 per cent sand, and less than 15 per cent silt and clay (fig. 245).

Basin sediments have a wide textural range, being less than 5 per cent gravel, 5 to 8o per cent sand, and 20 to 95 per cent silt and clay. La Mesa basin sediments represent one extreme and are dominantly sandy loams and loamy sands. Lake Tank o sediments are the other extreme, being dominantly clays (fig. 24). In places, texture of sediment and specific geomorphic surface are distinctly associated (fig. 25D).

This does not hold true for the rhyolite gravel. Dense, aphanitic Soledad rhyolite breaks out of rock outcrops in coarse angular blocks and apparently undergoes little if any comminution in transport in a first cycle of sedimentation, in subsequent cycles, or in weathering after deposition. The rhyolite gravel of the Jornada fan is fresh and angular at distances of 0.35 to 5.1 miles from the mountain front. Median diameters are greater than 20 mm throughout this distance, and apparently there is no systematic decrease of size with distance as indicated by the haphazard arrangement of cumulative frequency distributions of particle sizes (fig. 25A).

Rhvolite gravel in the Organ fan, later cycle relative to the Jornada, has characteristics similar to the earlier cycle sediments. Both sets of samples, 1 to 3, are at comparable distances from the mountain front.

Although the gravel of the Jomada fan should have been subjected to weathering for a much longer time after depo-

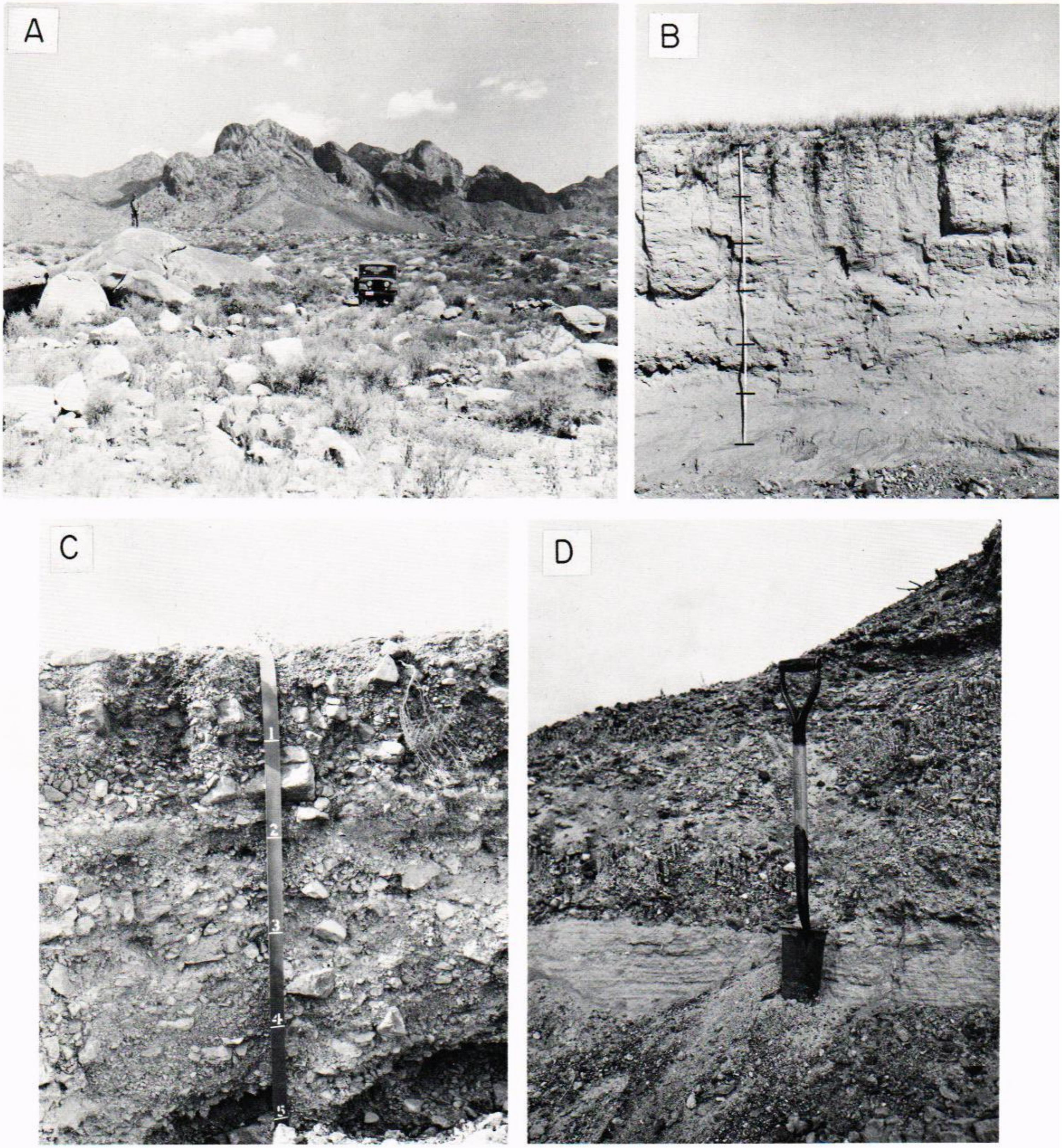


Figure 23

VARIABILITY OF SURFICIAL DEPOSITS ASSOCIATED WITH SURFACES

(A) Monzonite boulders on Jornada fan near Fillmore Canyon. (B) Silty clays of Organ sediments derived from sedimentary rocks of San Andres Mountains. (Scale in feet) (C) Angular Soledad Rhyolite gravel underlying Jornada surface. (Scale in feet) (D) Mixed rounded gravels that underlie La Mesa surface. (From pit west of Tortugas Mountain)

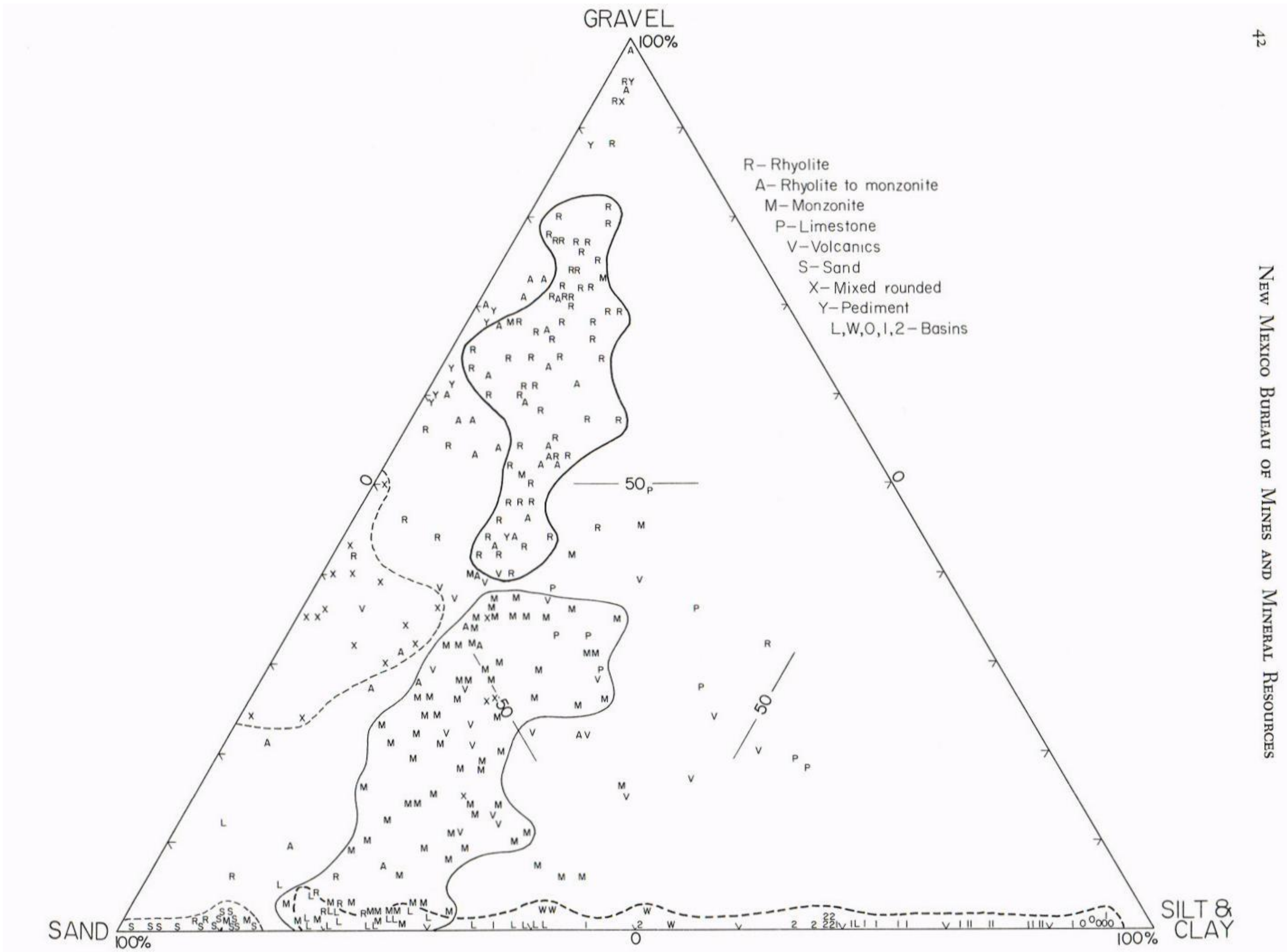


Figure 24

VARIATIONS IN TEXTURES OF SURFICIAL DEPOSITS

Note distinct groupings of rhyolite, monzonite, and mixed rounded gravels.

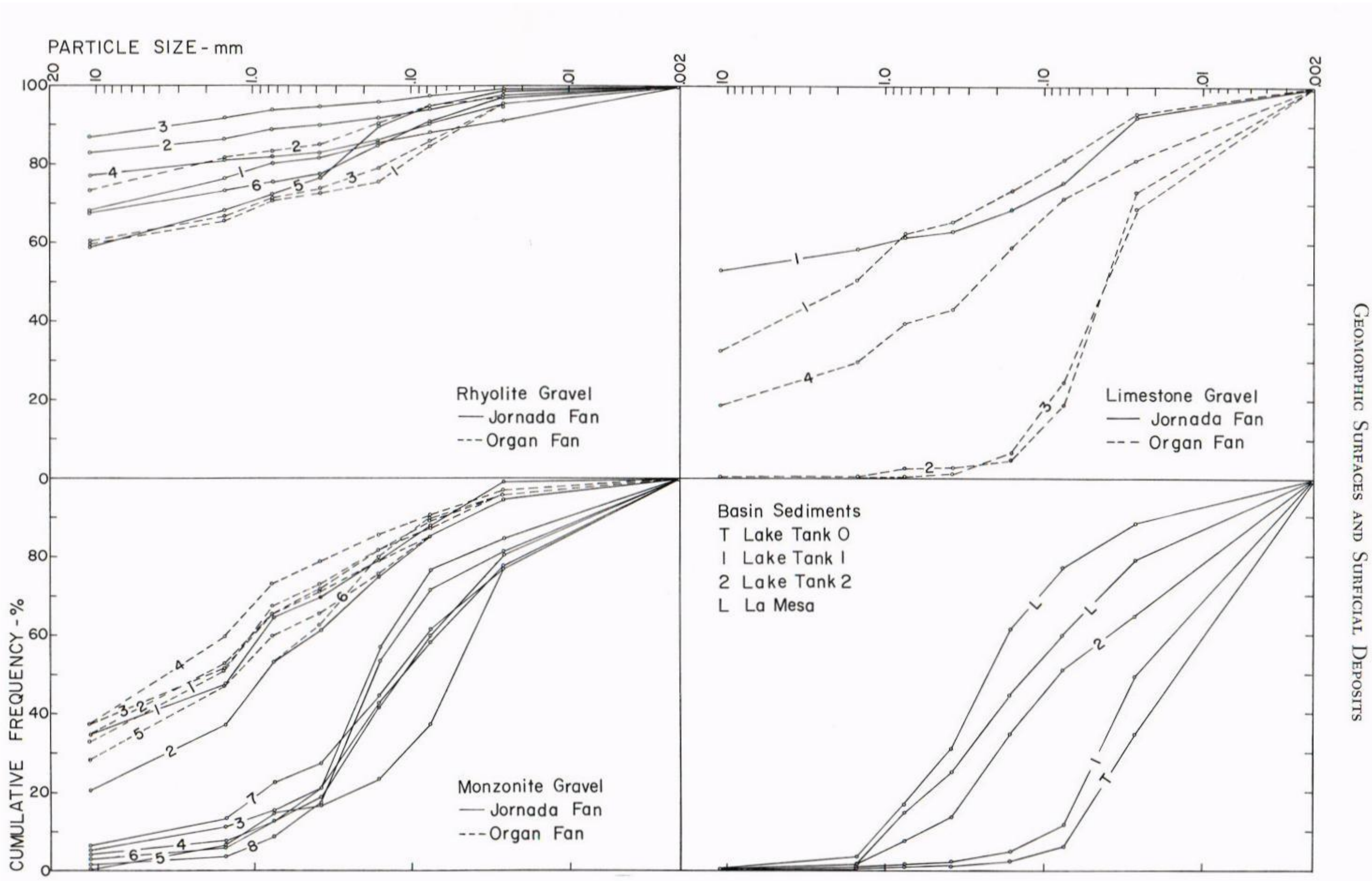


Figure 25

CUMULATIVE FREQUENCY PARTICLE-SIZE DISTRIBUTIONS OF SURFICIAL SEDIMENTS ASSOCIATED WITH GEOMORPHIC SURFACES sition than Organ gravel, post late Kansan–Illinoian versus less than 1100 to more than 460o years, freshness and angularity of particles, and comparable particle-size distributions show little difference between the gravels. Soledad rhyolite resists reduction in size by weathering as well as during transport to considerable distances from the mountain source.

Monzonite gravel differs. Although granitoid monzonite breaks out of rock outcrops in large blocks (fig. 23A), the boulders round in short distances of transport and break down into fine gravel. With prolonged weathering, particles are subjected to further size reduction. In the Organ fan apron that heads against the mountain front at San Augustin Pass, NE¼ sec. 6, T. 22, S., R. 4 E., median diameter of particles is 1.7 mm within a quarter mile of the source area (table 7). In Jomada fan sediment median diameter is 1.35 mm within a half mile of the source. In both sediments, there is a systematic decrease in size related to distance from the source. In Organ sediments, the decrease is linear, as expressed by Y = 1.942 — 0.195X, and in Jornada sediments the decrease is curvilinear as expressed by Y = 2.248 — 1.245 log X, where Y is median particle size in millimeters and X is distance in miles. In Organ sediments, the distribution is essentially a size sorting of raw sediment in alluvial transport downslope. Little weathering may have affected the particles, as soils on the Organ surface show little development. The distribution in Jornada sediments is complicated by weathering, since soils on this surface have well-developed textural B horizons. Cumulative frequency curves of each sediment group are in separate sets (fig. 25B).

There is definite comminution of particles in later cycle reworking of sediment in the limestone gravel of the Jornada and Organ fans. In Jornada sediment, median diameter is more than 20 mm, but during reworking of this sediment during construction of the Organ fan, median diameter decreased to 1.5 mm at a comparable distance from the mountains. With increase in distance downslope toward the basins (pl. 2), Organ sediments are finer textured and are silt loams and silty clay loams with silt dominant, clay abundant, very fine sand common, and slight amounts of fine to very coarse sand (fig. 23B).

COMPOSITION

The composition of surficial deposits was determined by pebble counts of many hundreds of samples, of which more than 25o sites are located from the valley-border area to the bounding eastern mountain front (fig. 26). By knowing the nature of bedrock and outcrop areas, particles in the sediments are relatable to sources, and sediment-distribution patterns can be determined.

South of Fillmore Canyon, gravel in the Jornada fans and piedmont and in the Organ fan apron is entirely rhyolite. Northward, rhyolite content systematically decreases to less than 5 per cent. Isopleths of rhyolite content sweep northward about a focus at the mouth of Fillmore Canyon and cross the present drainage divide between the Rio Grande and the internally drained basin of the Jornada. Pebbles and cobbles of Soledad rhyolite and Cueva rhyolitic tuff are in the basin at least 11/2 miles north of the divide and more than 9 miles from the mountain source. As demonstrated by Ruhe (1962), such sediment distribution, not only northwestward but also southwestward, precluded existence .of the Rio Grande or any through-flowing stream system in Jornada time.

Westward from the northern Organ and southern San Augustin mountains, composition of fan gravel is more than 90 per cent monzonite. This content systematically decreases to less than 5 per cent as isopleths sweep northward about a focus at the mouth of Clark and Brown Canyon and also sweep southward about the focus at Fillmore Canyon (fig. 26). This systematic pattern is approximately centered astride the drainage divide. The coupling of monzonite and rhvolite sediment distribution demonstrates that much of the arroyo net from Alameda Arroyo southward was emplaced after Jornada time when the Rio Grande incised its ancestral trench. Arroyo-length directions descending to the valley are discordant to directions of radii of sediment dispersion.

Between the monzonite and rhyolite gravel areas is a zone of coalescence that is roughly triangular in shape, with one apex at Fillmore Canyon. As rhyolite decreases northward and monzonite decreases southward, the composition is further complicated by admixtures of Orejon

TABLE 7. MEDIAN PARTICLE SIZE RELATIVE TO DISTANCE FROM MOUNTAIN FRONT IN MONZONITE GRAVEL OF JORNADA AND ORGAN FANS

	Jornada		Organ	
Sample*	Distance (miles)	Median diameter (millimeters)	Distance (miles)	Median diameter (millimeters)
1	0.50	1.35	0.25	1.70
2	2.00	0.85	0.60	2.00
3	3.75	0.05	1.50	1.35
4	3.90	0.11	2.65	1.90
5	4.65	0.11	3.60	1.25
6	5.00	0.17	4.90	0.82
7	5.75	0.12		
8	6.00	0.18		

* Calculated from data of SSL-LN

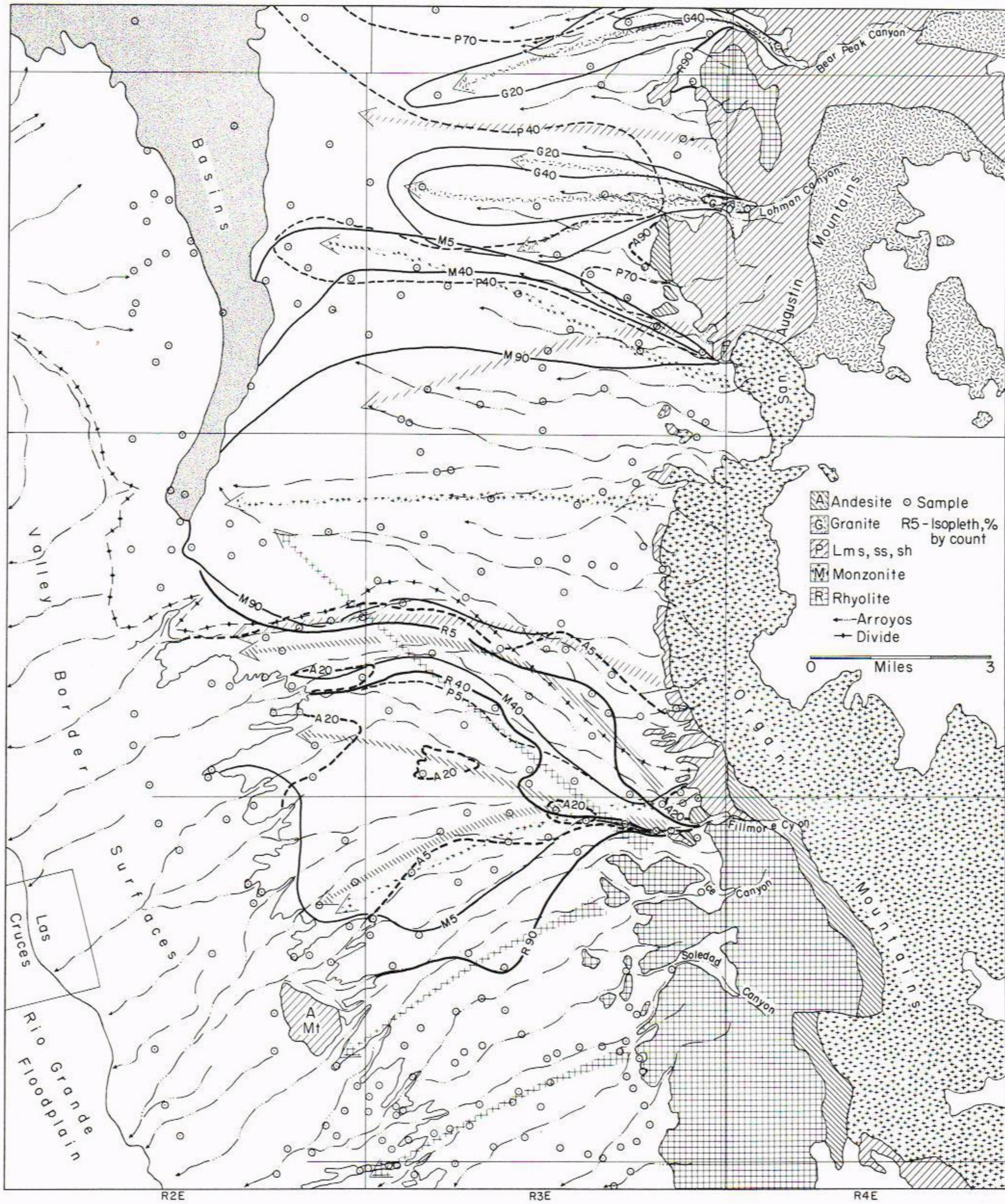


Figure 26

COMPOSITION OF SURFICIAL DEPOSITS ASSOCIATED WITH JORNADA AND ORGAN SURFACES

Isopleths show per cent by count of rock type. Shaded arrows show distribution from a mountain source. Note that some distribution patterns cross present drainage divides and directions of drainage nets.

andesite and Paleozoic limestone derived from rock in the Organ Mountains in the critical Fillmore Canyon area (fig. 26). In greater detail (Rohe, 1964), the effect of the younger Organ fan sediments (pl. 2) is apparent. Salients and re-entrants in the isopleths reflect the higher andesite content of the younger sediments.

Westward from the Paleozoic sedimentary rock area in the San Augustin Mountains, gravel is mainly limestone, shale, and sandstone. A coalescence zone to monzonite sediments is quite narrow, as monzonite isopleths sweep northward and limestone isopleths sweep southward from a focus near the mouth of Clark and Brown Canyon.

Local complexities are the dominance of andesite gravel in the fan below the andesite in Hardscrabble Hill and rhyolite gravel adjacent to the west of Quartzite Mountain (fig. 26; pl. 2). In addition, the extension of Bear Peak and Lohman canyons into granite on the east side of the San Augustin Mountains has resulted in appreciable granite in the gravel west of these canyon mouths. This occurrence of granite particles solves one of the problems of the erratic granite cobbles with pink feldspars in the sediments, including the mixed rounded gravels, in the Jornada and La Mesa basins.

All these complex patterns of sediment distribution conform to the previously discussed geometric patterns of alluvial fans coalescing laterally downslope into broad piedmonts. In addition, the radial distribution of lithologic kinds of gravels relative to bedrock source on the Dona Ana dome should be noted (pl. 1; figs. 6, 7).

Knowledge of the composition of the angular gravels is important in determining sources of sediment on the younger erosion surfaces in the valley-border area. As pointed out, these gravels have been transported through arroyo systems and mixed with the mixed rounded gravels. An average percentage by count of the latter in the Las Cruces area is quartz, 25; rhyolite, 22; andesite and latite, 14; quartzite, 11; chert, 9; granite, 7; monzonite, 3; basalt, z; and limestone, less than 1. An overlay of angular admixtures on the rounded gravels is readily determinable and can be mapped (pl. 1, Gy). For example, in the SE¼NW¼ sec. 36, T. 23 S., R. 2 E., in an arroyo wall below the Picacho surface, 7 feet of reddish-brown gravel dominated by red and gray angular rhyolite overlie 5 feet of brown, well-bedded, cross-bedded sands with intercalated mixed rounded gravel. An indurated carbonate horizon extends from the surface to a depth of 2 feet 7 inches. The composition in percentage by count of the upper unit is rhyolite, 87.7; quartz, 5.3; granite, 2.6; quartzite, 1.3; chert, 1.3; andesite, 1.0; and monzonite, o.6. The rhyolite is dominantly angular and subangular. Composition of the lower unit in percentage by count is quartz, 36.9; sandstone, 21.5; granite, 12.o; chert, 10.0; quartzite, 7.7; andesite, 4.6; monzonite, 3.8; and rhyolite, 3.1. The particles are dominantly rounded and subrounded. At this section the contact between the two units marks the Picacho erosion surface or pediment cut into mixed rounded gravel. The upper unit, 7 feet thick, is the alluvial sediment deposited on the erosion surface, and the ground surface is the constructional Picacho surface built by the deposition of Picacho gravels. These gravels are dominantly (88 per cent) angular particles transported along the throughway along the north branch of ancestral Fillmore Arroyo; during transport, they picked up a minor amount (12 per cent) of constituents of the mixed rounded gravel from the local area. Such relations are common in the valley-border area on the east side of the Rio Grande northward to Dona Ana Arroyo.

Composition of the fine-textured basin sediments was determined by X-ray diffraction analysis of selected samples. Analytical runs were made on paired subsamples. One contained carbonate and the other had carbonate removed by pretreatment using the acetate buffer method (Grossman and Millet, 1961). This treatment presumably hardly alters other minerals during removal of the carbonate (Jackson, 1956).

Untreated La Mesa basin sediment is composed dominantly of calcite, quartz, and feldspar in that order of abundance (table 8). Since the clay is a minor constituent in these sandy loam sediments, the clay-mineral suite is minor, as is iron-oxide, hematite. X-ray diffraction patterns show a pronounced peak at x o A superimposed on a broad plateau that extends from 12 to 17 A with an additional domal peak from 14 to 17 A apexing, at 15.5 A. Removing the carbonate and rerunning the sample, a peak at 10.5 A is superimposed on a broad dome that extends to 14 A. A

TABLE 8. X-RAY DIFFRACTION ANALYSIS OF LA MESA SEDIMENTS

d Spacing (Å)	Mineral*	With carbonate	Without carbonate	d Spacing (Å)	Mineral*	With carbonate	Without carbonate
2.28	C	24.0 (1)†	1.0 (2)	3.48	F	4.5 (2)†	———
2.46	Q	23.0 (1)	1.0 (2)	3.70	F	4.0 (1)	2.0 (2)
2.49	C	15.5 (1)	———	3.86	C	12.0 (1)	———
2.54	Q	———	3.5 (2)	4.26	Q	39.0 (1)	4.0 (2)
2.59	Cl	5.5 (1)	———	4.45	Cl	1.5 (3)	3.5 (2)
2.69	H	———	1.5 (2)	5.40	Cl	1.5 (2)	1.5 (2)
2.76	C	1.5 (2)	———	6.50	Cl	3.0 (2)	3.5 (2)
2.84	C	3.0 (2)	———	10.6	2:1	12.0 (2)	30.0 (2)
2.98	F	8.5 (1)	———	11.9	2:1	9.0 (3)	17.5 (2)
3.03	C	87.0+(1)	———	14.9	2:1	9.5 (3)	3.5 (2)
3.18	F	19.5 (1)	5.5 (3)	15.5	2:1	9.5 (3)	———
3.24	F	18.0 (1)	4.5 (3)	16.0	2:1	8.5 (3)	———
3.35	Q	80.0 (1)	20.0 (1)				

* C, calcite; Q, quartz; Cl, clay; H, hematite; F, feldspar; 2:1, interlayered montmorillonite, vermiculite, mica.

† Peak height and shape where (1) is sharp, (2) domal, and (3) plateau

second dome extending from 14 to **22** A apexes at 16 A. After heating to 500° C, a sharp peak remains at **10.2** A with a slight dome at 16 A (table 9E). The clay minerals are mica and interlayered montmorillonite-vermiculite. No kaolinite was identified, as there was no determinable peak at 7.13 A even after several runs of subsamples. Samples of other sediments show the same general kind of clay-mineral assemblage (table 9) but with one exception. A kaolinite peak is present in all other patterns.

The similarity of composition of clay mineral assemblages of these basin sediments is evident in their cation-exchange capacities. Amounts of exchangeable ions vary with the kind of clay mineral, the amount of clay, and the amount of organic matter (Robinson, 1949; Thompson, 1952; Coleman and Mehlich, 1957). The kinds of clay minerals are similar in all sediments, but the amount of clay ranges systematically from to to more than 6o per cent. Cation-exchange capacities (C.E.C.) are related to amount of clay as expressed by $Y = 35.94 - 0.337 (7o-X) - 1.9 \times 10^{-10} (70-X)^6$, where Y is C.E.C. in milliequivalents (M.E.) per 100 gm and X is the amount of less than 2 micron clay (fig. 27A). The standard error of estimate (Sy) is ± 2.53 M.E. for too gm. A test of C.E.C. versus amount of organic matter showed no significant relationship. In all samples organic carbon is less than o.3 per cent.

The specific association of C.E.C. to amount of clay in this system of basin sediments, where clay-mineral assemblages are similar and organic matter little affects exchange capacity, permits prediction of clay minerals in other sediments in the area. The basins are common depositories of finer textured sediments derived from rhyolite, monzonite, sedimentary rocks, and volcanic terrain (pl. i). Thus, plots of C.E.C. versus amount of clay of samples of the other sediments should show a relationship like that of the basin sediments. The data plot reasonably well within the limits of error determined for the basin sediments (fig. 27B). Consequently, clay-mineral suites of the other sediments must be like those of the basin sediments. The samples of monzonite-gravel sediments group rather consistently on the negative side of the distribution, suggesting that greater amounts of kaolinite may be present.

LAYERING

A striking feature of the surficial deposits is their layering. Gravels of the Jornada alluvial fans and piedmont thin from the Organ Mountains westward toward the Rio Grande and the Jomada Basin. For example, a well in the SW¼ sec. 27, T. 23 S., R. 3 E., penetrated more than 185 feet of rhyolite gravel without any apparent major stratigraphic break at depth; that is, the presence of intercalated paleosols. This well is one mile west of the mountain front of Soledad Rhyolite. The rhyolite gravel thins to 1 foot in the terminal scarp of the Jornada surface in the center of sec. 25, T. 23 S., R. **2** E. This site is 4¾ miles west of the well. Here, the rhyolite gravel is partly cemented by calcium carbonate and overlies a truncated paleosol in sandy loam sediments. The paleosol has a reddish-brown (5YR 4/4) sandy loam, coarse subangular blocky B horizon 33 inches thick which grades downward into light reddish-brown sandy loam, massive C horizon. Interiors of peds in the B horizon are leached of carbonates, although carbonate coatings are on ped faces. The carbonate, when traced upward, ascends along joints and fractures to the carbonate zone in the overlying gravel. Thus, the buried B horizon has been secondarily enriched by carbonate of a younger weathering cycle. Below 5 feet in the paleosol C horizon, the sandy loam is calcareous and contains secondary carbonate.

A second buried soil with a reddish-brown B horizon is near a depth of 10 feet below the base of the rhyolite

TABLE 9. X-RAY DIFFRACTION ANALYSIS OF CLAY MINERALS

	TREATMENT		
SAMPLE	UNTREATED	GLYCOL	HEATED
		10.2-7.5-1	10.2-19.5-1
	10.3-20.0-3*		
	10.7-19.0-3		
	12.8-15.5-3		
	14.9-11.0-3		
A		16.1-6.5-3	
			16.4-3.0-2
	16.9-8.0-3		
		19.6-4.5-3	
	20.1-3.5-2		
		22.1-1.5-3	
	10.2-9.5-3	10.2-5.5-2	10.2-10.5-1
	11.0-9.0-3		
	12.8-7.5-3		
			15.5-5.0-2
B	16.1-10.0-3		
		16.7-5.52	
			17.6-3.5-2
		20.1-1.5-2	
	21.0-2.0-2		21.0-1.5-2
		10.2-6.0-2	10.2-18.0-1
	10.5-8.5-3		
		12.8-8-1.5-2	
	14.2-11.0-3		
C	15.7-10.0-3		15.7-2.5-2
		17.6-12.0-3	
			18.4-1.5-2
	20.5-3.5-3	20.5-9.0-3	
		10.2-3.0-2	10.2-16:0-1
	10.8-20.0-3		
	12.8-20.0-3		
D		16.4-8.0-2	16.4-1.5-2
	16.9-7.0-2		
	20.1-2.0-2		
			10.1-5.0-2
		10.5-25.5-1	
	10.6-30.0-1		
	11.9-17.52		
E		12.1-11.5-2	
			12.3-1.5-2
		15.8-5.5-3	15.8-1.5-2
	17.6-3.5-2		
		19.6-3.0-3	
		21.0-1.0-3	

* Left number, d spacing ((Å); center number, peak height; right number, peak shape with 1 being sharp, 2 being domal, and 3 being plateau

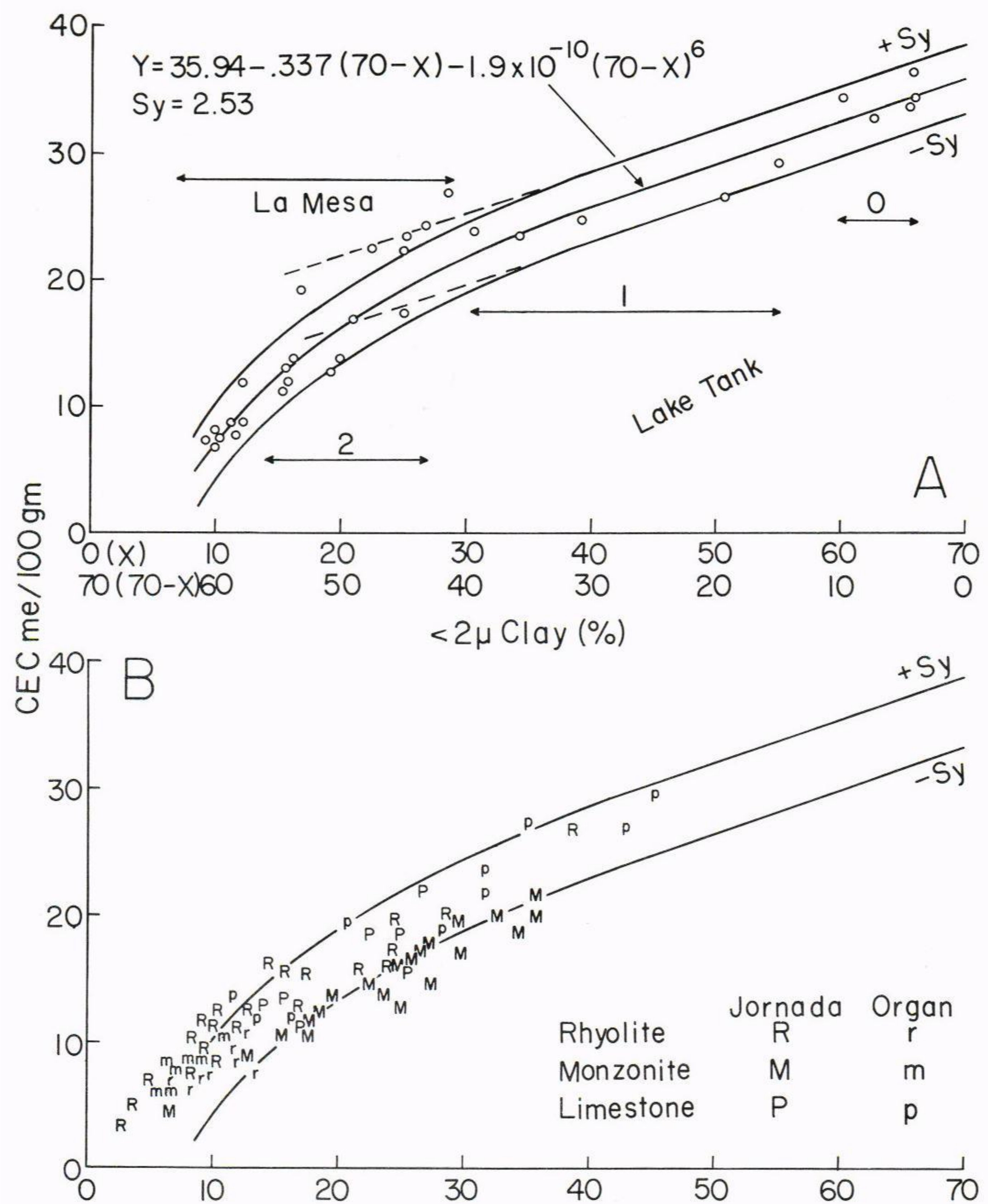


Figure 27

CATION-EXCHANGE CAPACITIES OF SEDIMENTS RELATED TO AMOUNT OF LESS THAN 2 MICRON CLAY

(A) In basin sediments whose clay-mineral suites arc alike; (B) in sediments of the Jornada and Organ fans and fitting the distribution of (A), indicating probable similar clay mineralogy.

gravel. Its C horizon overlies the mixed rounded gravels of late Kansan—Illinoian age at 15 feet deep.

A second traverse illustrating layering of surficial sediments begins at the new Cox Ranch headquarters in the NE¼NW¼ sec. 12, T. 23 S., R. 3 E., where a well penetrated 110 feet of rhyolite gravel and entered Soledad rhyolite bedrock. Downslope at a distance of 1.8 miles in the SW¼NE¼ sec. 3, T. 23 S., R. 3 E., 162 feet of rhyolite gravel was drilled without discernible break. The gravels thin to 1 foot in a cut along a pipeline in the NW¼ sec. 36, T. 22 S., R. 2 E., which is an additional 2.9 miles to the northwest. The section in the cut is very similar to the first case described except that the buried soil, beneath the surficial gravel with carbonate, has a distinct A2 horizon with subjacent B and C horizons (fig. 28A). On a carbonate-free analytical basis, this buried soil has a textural B horizon as clay content increases to 22.7 per cent from 10.5 per cent in the overlying A2 horizon and again decreases to 17 to 18 per cent in the underlying C horizon (table to). Carbonate is concentrated on faces of peds in the Bb horizon and can be traced upward into the carbonate of the surficial gravel, attesting to the secondary enrichment (fig. 28A). Carbonate nodules are in the C horizon of the paleosol but do not appear to be related morphologically to the secondarily enriched carbonate of the B horizon. Further, the matrix of the C horizon is calcareous, whereas the interiors of peds of the B horizons are leached. Two cycles of carbonate are involved and are demonstrated by radiocarbon dates. Carbonate of the B horizon is 20,300 ± 800 years, W-796, and the carbonate of the C horizon nodules is more than 30,00o years, W-797 (Rubin and Alexander). The radiocarbon ages fit the stratigraphic features of the paleosol, but validity of the time values per *se* may be questionable. In the gravel overlying the paleosol are cobbles of Paleozoic limestone that supplied some of the carbonate that secondarily enriched the subjacent paleosol. Consequently, the carbonate could be contaminated by old carbon.

A second paleosol crops out on lateral slopes below this paleosol level and also has a reddish-brown B horizon. At many other places in a broad belt for some distance east of the pipeline and extending westward to the terminal Jornada scarp, paleosols are common beneath the Jomada gravels. At some places, as many as three buried soils are in vertical sequence. Angular rhyolite gravel is within the loamy sediments that contain the paleosols and all overlie the mixed rounded gravels. Thus, the buried soils and containing sediments are related to the Jornada episode which stratigraphically is layered and historically is multicyclic.

In the monzonite sediment area, a number of arroyos descend linearly to the southwest and west from Organ village (fig. iB, G.5-1.5) and are incised as deeply as Io to 15 feet. As a result, as many as three soils are exposed in the arroyo walls, such as at a site in the SW¼ sec. 18, T. 22 S., R. 3 E. about 400 feet south of U.S. 7o (fig. 28B). For simplicity, the ground soil, upper buried soil, and lower buried soil are designated the upper, middle, and lower soils, respectively. All three have textural B horizons (table I1); the middle soil is most strongly developed texturally, having 38 per cent clay in its Bb horizon. Exclusive of the ground surface A horizon, all soils have greatest concentrations of organic carbon, clay, and free iron oxide in the B horizons. All soils also have carbonate horizons, of which the lower soil shows greatest development. The color of the B horizon of the upper soil is dark reddish brown and brown, different from the colors of the B horizons of the middle and lower soils, which have redder hue and stronger chroma and on this basis are distinct from the upper soil.

The soils are exposed in the walls of an arroyo that was the drainage ditch of the old road from Las Cruces to Organ village (fig. r B; F.1-2.1). The arroyo parallels U.S. 70 which bears S. 70° W. Upslope toward Organ village and downslope toward the Rio Grande, the brown soil thins so that its brown B horizon directly overlies the red Bb horizon of the middle soil. Farther upslope and downslope, the middle soil rises to the ground surface and extends across country. The brown soil is confined to a sedimentary lens that is inset on the Jornada surface. The sediments are oriented along a shallow drainageway and other drainage-ways that head near the Organ Mountains and extend N. 6o° W. toward the Jornada basin (fig. 1B; E to G, i.o to 2.5).

In the paleosols such as those in the pipeline cut, layering was indicative of earlier phase Jornada sedimentation. In the brown and red soil relations, layering marked by the brown soil indicates post-Jornada sedimentation. Farther eastward upslope toward the mountains, Organ sediments overlie members of the brown-red soil sequence. Consequently, the brown soil is older than Organ but younger than true Jornada and may represent modification of the Jornada surface during Picacho time. As Organ is a mountain-front analogue of the Fillmore valley-border episode, certainly there must have been mountain-front analogues of Picacho as well as Tortugas valley-border episodes. Detailed studies may be able to delineate such features.

Farther downslope toward the Rio Grande, the lower soil rises to or near the ground surface. When traced farther

TABLE 10. PIPELINE PALEOSOL*

Depth (in.)	Horizon	Color	Gravel > 2 mm (%)	Clay < 2 μ (%)	Organic carbon (%)	Free Fe_2O_3 (%)	$CaCo_3$ (%)
0-14	Cca	7.5YR 6/4	40.0	7.7	0.74	0.5	11.0
14-20	A2bca	5YR 6/4	——	10.5	0.26	0.5	4.0
20-25	A3bca	7.5YR 5/4	——	9.6	0.11	0.5	2.0
25-28	B21bca	5YR 5/4	——	15.9	0.11	0.6	1.0
28-53	B22bca	7.5YR 5/4	——	22.7	0.05	0.6	4.0
53-65	B3bca	7.5YR 5/4	——	17.4	0.05	0.6	7.0
65-89	C1cab	7.5YR 6/4	——	17.9	0.04	0.5	14.0
89 +	C2cab	7.5YR 6/4	——				

* Data from SSL-LN

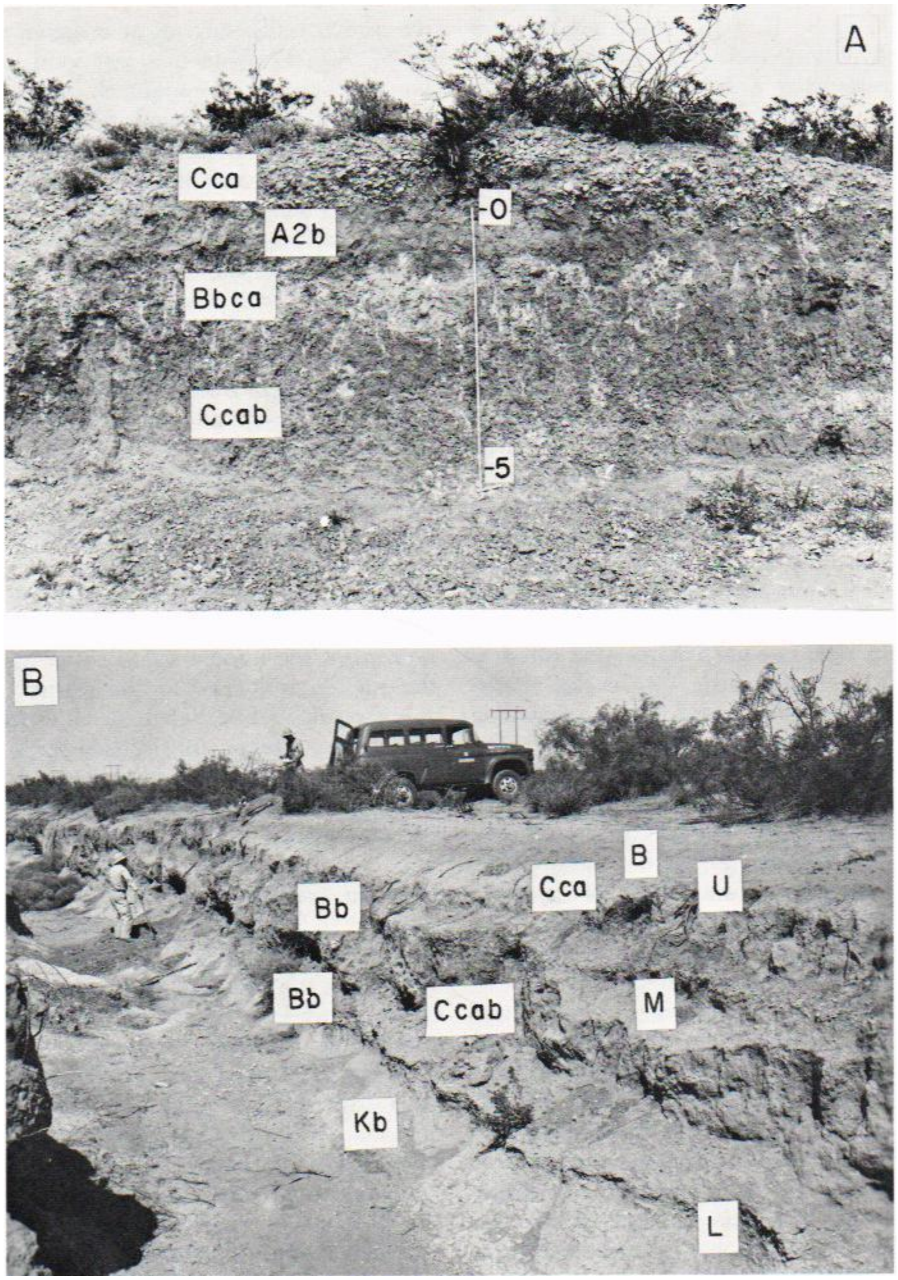


Figure 28

PALEOSOLS AND LAYERING OF SURFICIAL DEPOSITS

(A) Pipeline section showing gravel over buried soil. Soil horizons as indicated. (Scale in feet) Carbonate in Bbca horizon is 20,3000 800 years old and in Ccab horizon is more than 30,000 years old. (B) Arroyo along U.S. 70 showing 3 layers, upper, *U*, middle, *M*, and lower, L, and each with an associated soil. Soil horizons as indicated.

TABLE 11. SURFICIAL AND BURIED SOILS IN MONZONITE SEDIMENTS*

Depth (in.)	Horizon	Color	Clay < 2 μ (%)	C. E. C. (M. E. per 100 gms)	Organic carbon (%)	Fe_2O_3 (%)	$CaCO_3$	Remarks
0-5	A	5YR 3/3	17	16	0.6	1.1	<1.0	Surface soil
5-12	B2ca	5YR 3/4	28	18	0.6	1.2	8.0	(upper)
12-20	B3ca	5YR 4/4	26	16	0.5	1.2	15.0	
20-28	A&Bb	5YR 4/6	18	10	0.2	1.1	5.0	
28-36	B2b	2.5YR 3/6	38	21	0.3	1.3	5.0	Upper buried soil
36-46	B3cab	5YR 6/4	21	13	0.1	1.0	12.0	(middle)
46-66	Ccab	5YR 4/4	15	11	0.1	0.8	18.0	
66-79	B2b2	2.5YR 3/6	25	16	0.2	1.4	15.0	Lower buried soil
79-91	K1b2	5YR 6/4	21	14	0.1	1.0	32.0	(lower)
91-103	K2b2	7.5YR 6/4	19	13	0.1	1.0	34.0	

* Data from SSL-LN

westward to the remnant of La Mesa surface near Chandler Tank, sec. 21, T. 22 S., R. 2 E., the carbonate horizon of this soil is one of many that merges and becomes the thick carbonate horizon of the soil of the La Mesa surface. Thus, there is Jornada influence in the soils on the older surface.

When the lower soil is traced westward to the pipeline in sec. 23, T. 22 S., and R. 2 E. and then southward along the pipeline, it may be stratigraphically correlative of the dated paleosol in the pipeline section. These relationships, however, are not clear and require more detailed study.

WEATHERING

Most of the prominent weathering phenomena in the area are restricted to the surficial deposits. Bedrock in outcrop areas is generally fresh and little weathered. In the following discussion regarding alteration of surficial deposits, emphasis is placed on general principles that have wide application not only in the desert regions but elsewhere. Functional relationships are developed, and it is noted that certain weathering phenomena have specific relationship to geomorphic surfaces, whereas others do not. Following Simonson (1959), weathering is examined within a system of additions, removals, transfers, and transformations. Some of the important changes that take place are additions of organic matter, removal and additions of soluble salts and carbonates, transfers of organic carbon and sesquioxides, and transformations of primary into secondary minerals.

ORGANIC CARBON

Simonson (1959) pointed out that the nature and amount of organic carbon in any soil horizon is dependent upon the additions, transformations, and transfers in the past and present. These are controlled by climate, nature of the flora and fauna, and age of the soil. Additions and losses in soils of desert regions generally are small.

In the study area, the surface horizons of soils are increasingly darker colored up the rising western flank of the Organ—San Augustin—San Andres mountains. Such color change is related to greater organic carbon content with increase in elevation. Organic carbon content weighted for the upper 6 inches in soils increases on the Organ fan apron (less than 2000 to 5000 years old) and very similarly in soils on the Jornada piedmont and fans. Calculated lines of fit of data (fig. 2.9A) deviate only slightly between the two groups and for all samples. Apparently organic carbon content of the surface horizon is independent of age of geomorphic surface and probably is mainly post-Organ in age. The increase in organic carbon probably is related to an orographic climatic system; that is, higher rainfall and cooler temperatures at higher elevations. Rainfall in the Rio Grande Valley at New Mexico State University is 8 to 9 inches a year at 3890 feet elevation. At 6200 feet at Boyd Ranch in the Organ Mountains, annual rainfall is approximately 15 inches. However, lack of adequate climatic data prevents further quantification of the orographic system.

The transitory status of organic carbon in the soil surface horizon may be illustrated by comparison of data from A horizons in their natural state in sandy loam sediments associated with the Fillmore surface with data for soils in similar sediments on the same surface on the State University campus. Leveled, diked lawns on the campus were flood irrigated from about 1919-192o to 1952. Rio Grande water was brought along a lateral canal to a water storage pond and from there pumped to various lawns which were flooded. Commercial fertilizers have not been used on the lawns, although some manure may have been applied. Undoubtedly, the Rio Grande water contained an unknown amount of organic matter, but this could not have been more than a few parts per million. Since 1952, the campus lawns have been sprinkler irrigated with water supplied from several wells.

Organic carbon content in the surface horizon in the irrigated soils is 3.75 to 12.5 times as great as in the soils in their natural state without water applied by man (table 12). This has resulted in a distinct contrast in colors of the horizons. In the irrigated soils, the surface horizons are very dark gray and very dark grayish brown. In the natural soils, the colors are dark grayish brown and brown. Certainly, the increased amount of organic carbon in the irrigated soils cannot be attributed mainly to organic matter carried in flood irrigation water but must be the result of additions brought about by growth of a grass cover, presently bermuda, on the soil surface. The moisture factor of local climate has been increased manyfold, resulting in a continuous stand of vegetation whose growth and decay have effectively increased the organic carbon content of the subjacent soils. The change took place in 41 years from

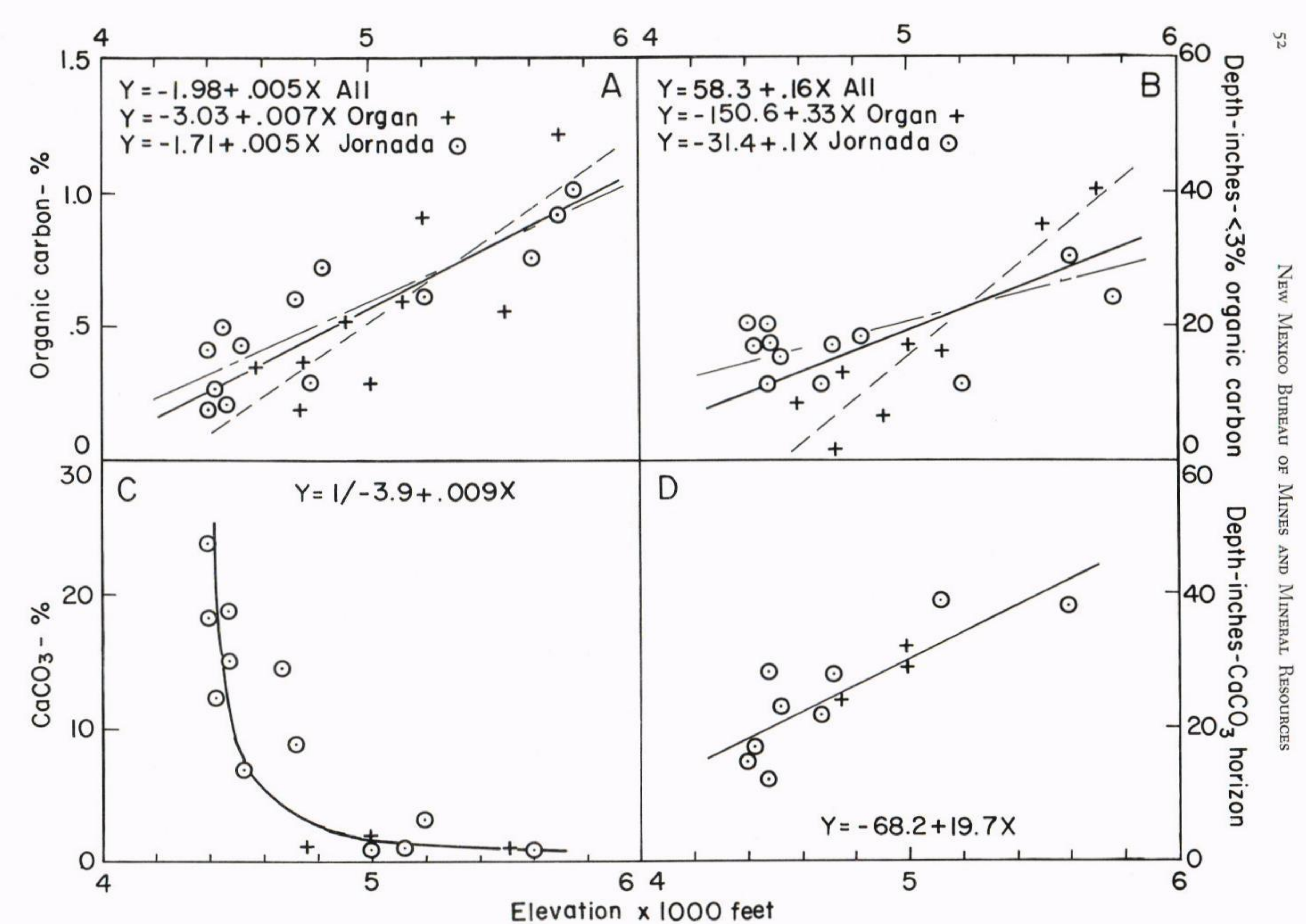


Figure 29

WEATHERING PROPERTIES IN SOILS ON ORGAN AND JORNADA SURFACES RELATED TO RISE IN ELEVATION TOWARD MOUNTAINS the initiation of irrigation to the time of sampling and analysis in 1960.

These additions of organic carbon are somewhat greater than those reported by Borst (1961), who measured 0.77, 0.28, and 0.16 per cent organic carbon at depths of o to 2, 2 to 12, and 12 to 6o inches respectively in sediments deposited following the failure of a dam in the Otay Valley, California, in 1916. There annual rainfall is about Io inches and the vegetation is dominantly chapparal and flattop buckwheat.

A second property of the soils, depth in inches to less than o.3 per cent organic carbon, also is related to elevation along traverses from the Rio Grande Valley to the mountains but may also be affected by the age of the geomorphic surface on which the soils occur. Calculated lines of fit of data (fig. 29B) deviate noticeably between soils on the Organ fan apron and Jornada piedmont and alluvial fans. The deviation is particularly evident below an elevation of 5200 feet where greater amounts of organic carbon have accumulated to greater depths in soils on the older geomorphic surface at similar elevations. Thus, the transfer of organic carbon to increasingly greater depths in the soil probably is not only related to the orographic-climate effects induced by topography but is also influenced by duration of weathering.

SOIL B HORIZONS

Two distinctive properties of the soils, color and clay in the B horizons, are related to age of geomorphic surfaces on which the soils occur. However, on a specific geomorphic surface there may be a considerable range within a property.

Color

Colors of soil horizons are determined by a comparison with the Munsell Soil Color Chart, which is arranged by three variables, hue, value, and chroma, that combine to describe all colors. Value indicates the lightness of a color and chroma indicates its strength or departure from a neutral of the same lightness. A specific color is coded as 10YR 5/4, where 10YR is the hue, 5 is the value, and 4 is the chroma. The YR indicates that the color is a combination of yellow and red. In the study area, colors of soil horizons range from 10R to 1 10YR hues, which encompass 10R, 2.5YR, 5YR, 7.5YR, and 10YR. Yellow increases in the same order, or conversely, red increases in the reverse order. There are 14o combinations of value and chroma within this range of hues, so many specifically quantified colors are possible. However, color distinctions can be made at the hue level in the area.

In the B horizons of soils in the alluvial fan, piedmont, and apron group, color comparisons must take into account the colors of rock particles that in part comprise the less than 2 mm size fraction. One variety of Soledad rhyolite is a weak red color with a hue of 10R. In addition, some of the soils do not have a B horizon, so to compare with a soil that does have one, an equivalent zone in the vertical profile must be used in place of a B horizon. In rhvolitic sediments, hues in soils on the Organ surface generally are

TABLE 12. COMPARISON OF ORGANIC CARBON IN SOILS IN NATURAL STATE ON FILLMORE SURFACE AND ON LAWNS OF STATE UNIVERSITY CAMPUS

Depth (in.)	Color*	Organic carbon (%)	Depth (in.)	Color	Organic carbon (%)
	A. Natural†			E. Irrigated	
0-5	10YR 4/2	0.14	0-4	10YR 3/2	1.5
5-17	10YR 4/2	0.11	5-8	10YR 3/2	0.8
17-25	10YR 5/2	0.11	8-13	10YR 4/2	0.3
25-45	10YR 5/2	0.05	13-20	10YR 4/2	0.3
	B. Natural			F. Irrigated	
0-5	7.5YR 4/2	0.16	0-4	10YR 3/1	1.4
5-10	7.5YR 4/2	0.14	4-7	10YR 3/2	0.6
10-19	7.5YR 4/2	0.11	7-12	10YR 4/2	0.3
19-30	7.5YR 4/2	0.09	12-20	10YR 4/2	0.3
30-46	7.5YR 4/3	0.15			
46-50	7.5YR 6/2	0.16		G. Irrigated	
50-55	7.5YR 5/4	0.05	0-5	10YR 3/2	0.6
			5-10	10YR 4/2	0.5
	C. Irrigated‡		10-16	10YR 4/2	0.4
0-6	10YR 3/1	2.0			
6-14	10YR 3/2	0.7			
14-23	10YR 3/2	0.8			
23-33	10YR 4/2	0.5			
	D. Irrigated				
0-5	10YR 3/2	1.8			
5-8	10YR 3/2	0.8			
8-13	10YR 4/2	0.4			
13-20	10YR 4/2	0.3			

* Munsell soil colors, moist
† Data from SSL-LN
‡ Data from Soil Conservation Service, University Park, New Mexico (SCS-UP)

5YR, whereas on the Jornada and Dona Ana surfaces, hues are 2.5YR or redder in color. Some soils on the Jornada surface are 5YR and do not differ from Organ surface soils. There is not a distinct difference between Jornada and Dona Ana colors. The time distinction is Recent for Organ, post-late Kansan–Illinoian for Jornada, and mid-Pleistocene for Dona Ana.

In monzonitic sediments, hues in soils on the Organ surface are IoYR and 7.5YR, whereas those on the Jornada surface are 5YR and 2.5YR. Soils on the possible Picacho age fill along drainageways (fig. 28B) are 5YR. The contrast from Organ to Jornada time is 1 to 3 hues redder and from Organ to Picacho (late Wisconsin) is I to z hues redder. In sediments derived from limestone, sandstone, and shale, hues are 10YR in soils on the Organ surface versus 7.5YR on the Jornada surface, or one step redder.

In B horizons or equivalent zones in soils in the basin sediments, hues are 5YR and 7.5YR on the Lake Tank o and I surfaces, respectively, which are of Recent age and 2.5YR on the Lake Tank 2 surface of late Pleistocene age. In the valley-border surface group, hues on the Fillmore surface are 10YR and 7.5YR, on the Picacho surface are 7.5YR and 5YR, and on the Tortugas surface are 7.5YR and 5 YR. The highest end member, Jornada, has B horizon hues of 5YR and 2.5YR. In this sequence, there is progressive stepwise increase in reddening as age increases from Recent to late Wisconsin to post-late Kansan–Illinoian.

All these associations of redder color in soil B horizons and increasing age of geomorphic surfaces suggest a relationship to time or duration of weathering. However, the significance of red color in soils may involve other factors; the problem is also in soils in many other regions and has been discussed by Thorp, Johnson, and Reed (1951), Frye and Leonard (1952.), Ruhe and Scholtes (1956), and Ruhe (1965).

Clay

Soils on the late Wisconsin and older geomorphic surfaces have textural B horizons, while those on Recent surfaces, Fillmore and Organ, generally lack such horizons.
A textural B horizon is identified as having more clay (less than 2 microns) than the overlying A and underlying C horizons. Even in rhyolite and other coarse, cobbly gravels, clay and sesquioxides coat pebbles and cobbles so that the rock fragments serve as "ped" nuclei in the B horizons of the soils.

A basic assumption in soil formation is that a B horizon forms from a C horizon, so if a soil has a textural B horizon, a horizon of clay accumulation, some of the clay in it must be inherited from the C horizon before it was altered to a B horizon. A second assumption is that clay may be eluviated from an overlying A horizon, translocated downward, and accumulated in the B horizon. This eluviation process may also include translocated clay particles that accumulate on the surface of the soil by some other additive process, for example, eolian activity.

The relationship of the amount of clay in B horizons or equivalent zone to C horizons may be shown by a comparison of the weighted per cent clay of the former two to the weighted per cent clay of the latter. *Equivalent zone* refers to a layer that is transitional between the A and C horizons in soils where textural B horizons are lacking. Analyses and calculations were made for five groupings in the alluvial fan, piedmont, and apron surfaces: (1) all soils, (2) all soils on the Organ surface, (3) all soils on the Jornada surface, (4) all soils formed in monzonitic sediments, and (5) all soils formed in rhyolitic gravel. Calculated regression lines for all groups are linear, as expressed by $Y = a + bX$, and those of groups (2) to (5) closely fit that of group (i). Thus, it is not only evident that part of the clay content of the B horizons is inherited from the C horizon, but the fit of data further suggests little addition from overlying horizons. If additives were translocated downward and accumulated in the B horizons or equivalent zones which range from little to quite strong textural development, fit of data should be more haphazard because such locations had to occur through widely varying kinds of sediments, from gravel to gritty loam, through time from the Recent to mid-late Pleistocene. The linear relationship exists regardless of the kind of sediment in which the soils formed or the age of the geomorphic surface on which they formed.

However, the ratios of clay in the B horizon or equivalent zone show distinct differences when the samples are stratified by geomorphic surface regardless of sediment in which the soils have formed. Ratios are o.63 to 1.17 for soils on the Organ surface and 1.18 to 2.03 for soils on the older Jornada surface. As soils on the Organ surface continue to develop, morphologies and properties should approach those of the soils on the Jornada surface.

Clay contents of B horizons of soils on the Jornada surface in the monzonitic-gravel area do not relate systematically to increase in elevation as does the organic carbon content of the A horizons. For example, along a traverse projected to a plane from the Organ Mountains toward the Jornada basin, ratios of weighted clay in the B horizon to weighted clay in the C horizon decrease from 1.89 to 1.22 and 1.18 in a distance of 3.8 miles with a decrease in elevation of 700 feet. The ratios then abruptly increase to 1.51 and continue to increase to 1.60 through a distance of 2.2. miles with a corresponding decrease in elevation of 300 feet. Throughout the whole traverse, the sediment is sorted as median particle-size diameters decrease with the logarithm of distance as $Y = 2.248 — 1.245 \log X$. The B/C ratios do not relate to this function, nor do they relate to gradient of slope.

At 3.8 miles along the traverse where B/C ratios suddenly increase, superposed sedimentary layers separated by paleosols of the Jornada piedmont are in close vertical assemblage (fig. 28B). The uppermost layer is the lens oriented along the old drainageway on the Jornada surface. The B/C ratio (1.18) of the soil formed on the layer corresponds systematically to the ratio (1.22) of the soil on the next subjacent layer where the latter soil emerges on the land surface mountainward. Basinward, B/C ratios of the emerged paleosol increase from 1.51 to 1.60. The distinct change in properties of the soils and the change in direction of trends of properties may be attributable to mergence of pedogenic zones. The lowest layer of sediment and its surmounted paleosol are increasingly closer to the land surface from a point 3.8 miles basinward.

Comparison of B horizons of soils on the valley-border surfaces in the latitude of Las Cruces is complicated by variations in parent material and degree of erosional modification of a geomorphic surface subsequent to its formation. Parent material of the Fillmore surface is sand of mixed mineralogic composition. The pediment part of this surface was cut into the sands that underlie the mixed rounded gravels of mid-Pleistocene age. The materials of the Picacho pediment are mixtures of angular rhyolite and mixed rounded gravel. The Tortugas pediment is cut in the mixed rounded gravels. Mountainward, the Jornada and Dona Ana surfaces are in rhyolite gravel.

Most of the soils selected for analysis were sampled from surface heights essentially flat along contours between bordering slope shoulders, so they may represent the most stable parts of a given surface. However, the Tortugas surface heights are convexly rounded between the bounding slope shoulders. Hence, stability of Tortugas surface would be difficult to conclusively demonstrate. Within these qualifications of variable materials and possible erosional modification of geomorphic surfaces, a comparison of soils may be made. In addition, the comparison will be carried across the soils on the Jornada and Dona Ana surfaces to the Organ Mountains to the east.

Certain properties of the soils do relate reasonably well to the sequence of geomorphic surfaces (table 13). Soils on the Fillmore surface of Recent age do not have textural B horizons. In the zone in the soil profile stratigraphically equivalent to B horizons of the other soils, the average amount of less than 2 micron clay weighted for the thickness of the zone is 5.1 per cent. The ratios of weighted clay in this zone to weighted clay in the subjacent C horizon are 0.96 and 1.06.

On the next older and higher Picacho surface of late Wisconsin age, the average amount of clay in the B horizon is 17.2 per cent; B/C ratios range from 1.46 to 2.31; and the average thickness of the B horizon is 13 inches. All those values progressively increase in soils on the successively older and higher Tortugas, Jornada, and Dona Ana surfaces. From Picacho to Dona Ana, the average clay content increases from 17.2 to 14.1 (exception) to 21.1 to 73.1 per cent, respectively. Thickness of the B horizon increases from 13 to 17 to 23 to 24 inches, and the amount of calcium carbonate increases from 17.9 to 21.8 to 37.4 to 63.8, respectively. The data show an increase in developmental properties of the soils with increase in age of geomorphic surface on which the soil formed; that is, the duration of weathering to which the soil has been exposed on the surfaces of the sequence.

Clay-mineral assemblages of the basin deposits are very similar (table 9), and some of the analyzed samples are from the soils on those surfaces. Cation-exchange capacities of the clays appear to stratify by age of sediments and surfaces (fig. 27A). The Lake Tank o surface is historical and La Mesa surface is mid-Pleistocene. La Mesa and Lake Tank 2 (late Pleistocene) C.E.C. values are considerably lower than Lake Tank I (Recent) and Lake Tank o values. This is not the result of weathering but is strictly a relationship of exchange capacity and amount of clay, as previously discussed. This conclusion is further substantiated by the relationships within the grouped data on the Organ (Recent) and Jornada (mid-late Pleistocene) surfaces (fig. 27B). Within the monzonite sediments, C.E.C. values are lower for the least weathered Organ set than for the greater weathered Jornada set. Within the rhyolite and limestone groups, there is haphazard arrangement of data of the two surfaces of different ages. Duration of weathering apparently has not been effective in altering clay minerals through a series of weathering stages, as proposed by Jackson et al. (1948). Otherwise, some systematic arrangement should be apparent in the clay-mineral suites, with kaolinite possibly being dominant in the soils of the Jornada and La Mesa surfaces and mica with montmorillonite increasing in soils of Lake Tank 2, Organ, and Lake Tank I and o surfaces. Instead, clay-mineral representatives of lesser stages of weathering dominate soils of historical to mid-Pleistocene age.

CALCIUM CARBONATE

A feature common in the soils in the area, whether on alluvial fans, piedmont, aprons, or on basin or valley-border surfaces, is a subsoil horizon of calcium carbonate concentration. In most soils, this horizon is so prominent that it is the first feature to catch an observer's eye. Gile discussed the manner in which carbonate occurs throughout and within the horizon and noted that specific properties are related to the amount of carbonate present. For example, as the amount of carbonate increases, bulk density (gm/cc) linearly increases, unconfined compressive strength (psi) logarithmically increases, and infiltration rate (in./hr) logarithmically decreases. In regard to the second property, some of the horizons have compressive strengths similar to concrete. These carbonate horizons are such prominent features in the soils of the arid region that their recognition as a master soil horizon, K horizon, has been proposed (Gile, Peterson, and Grossman). Geologists generally have preferred the term *caliche* for this layer, whether friable or indurated, but the indurated variety has been termed *calcrete* (Lamplugh, 1907). In the voluminous literature on caliche, explanation of its origin has involved lacustrine, fluvial, ascending ground water, or pedologic hypotheses, or caliche has been accounted for by chemical or biochemical deposition by surface waters, deposition by ground water, or as formation of Cca horizons of soils. *(See* Bretz and Horberg, 1949; Brown, 1956). For some reason, previous studies have resolved to one explanation of origin; few have suggested multiple origin.

In the study area, carbonate horizons occur in sediments of widely diverse composition that range from loo per cent rhyolite gravel to a limestone gravel with admixtures of sandstone and shale. All the sediments in the area (pl. 1) have some kind of horizon of carbonate accumulation from exceptionally weak to exceptionally strong development. These horizons are in sediments that texturally range from bouldery gravels to silt loarns. All rock types (pl. I) in their outcrop areas may have carbonate rinds. With the exception of Lake Tank o, all geomorphic surfaces have some kind of carbonate horizon.

TABLE 13. SUMMARY OF LESS THAN 2 MICRON CLAY AND CALCIUM CARBONATE DATA OF SOILS ACROSS VALLEY-BORDER SURFACES FROM RIO GRANDE AND EXTENDING EASTWARD TO ORGAN MOUNTAINS

Surface*	Elevation (feet)	Slope (%)	Clay† B horizon (%)	Clay average (%)	Clay† C horizon (%)	B/C	Thickness B horizon (inches)	Thickness average (inches)	$CaCO_3$‡ K horizon (%)	$CaCO_3$ average (%)	$CaCO_3$‡ ca horizon	K/ca	Thickness K horizon (inches)	Thickness average (inches)
F	4150	6	5.1	5.1	4.9	1.06	—	—	—	2.2	2.3	—	—	
F	4085	2	5.1		5.2	0.96	—		—		2.2	—	—	
P	4130	2	23.4		10.1	2.31	12		20.2		11.0	1.84	19	
P	4025	2	9.8		5.3	1.85	15		17.7		7.0	2.52	15	
P	4330	2	19.4	17.2	9.2	2.11	10	13	21.8	17.9	9.7	2.24	14	22
P	4250	2	14.1		6.4	2.03	5		12.7		2.4	5.31	22	
P	4410	2	19.5		13.3	1.46	23		17.1		8.0	2.13	39	
T	4235	2	14.3	14.3	5.6	2.56	17	17	21.8	21.8	3.3	6.70	30	30
J	4450	2	7.8		3.8	2.07	15		37.4	37.4	7.0	5.34	33	33
J	5600	8	29.3	21.1	17.7	1.65	30	23	—	—	1.0	—	—	
J	4725	4	26.1		14.3	1.82	26		—	—	8.5	—	—	
D	5760	9	73.1	73.1	37.3	1.95	24	24	63.8	63.8	—	—	—	

* Geomorphic surface: F, Fillmore; P, Picacho; T, Tortugas; J, Jornada; D, Dona Ana
† Clay weighted for thickness of B and C horizons; equivalent zone of B in F; clay on carbonate-free, less-than-2-mm basis; calculated from data of SSL-LN
‡ Calcium carbonate equivalent weighted for thickness of K or ca horizon; total soil basis; calculated from data of SSL-LN

Relationship to Materials and Surfaces

The occurrence of these horizons in sediments of varying composition introduces a problem concerning the source of calcium to form the abundant calcium carbonate in the carbonate horizons. Calcium oxide contents of Soledad rhyolite and monzonite and limestone of the Organ Mountains are o.16, 3.95 to 5.32, and 3o per cent, respectively (Dunham, 1935). These rocks, in order, contain o.003, 0.074 to 0.1, and 0.597 gram per cubic centimeter of calcium. If 1 cubic centimeter of each rock would thoroughly decompose and release all Ca to recombine with CO_2 and H_20, o.008, 0.19 to 0.25, and 1.49 grams of $CaCO_3$, respectively, would form. Converting to volume, 1 cubic centimeter of each rock could produce o.003, 0.069 to 0.092, and 0.55 cubic centimeter of secondary carbonate. Thus, in monzonitic and limestone sediments, chemical weathering resulting in transformation, transfer downward, and addition in the subsoil could account for thick horizons of abundant secondary carbonate. However, in rhyolite gravels and monzonite sediment, where volume transformation is negligible, quite thick layers would necessarily have to be thoroughly decomposed to form a subsoil carbonate horizon. In addition, there should be other products of transformation, such as abundant clay derived from feldspar. With this background, the distribution of carbonate horizons will be examined.

On the Jornada surface in the alluvial fan, piedmont, and apron area carbonate distribution is related to the orographic-climatic system that is controlled by the rise up the mountain front. As elevation increases, carbonate con-tent in the carbonate horizon decreases, as expressed by $Y = \frac{1}{-3.9 + 0.0089X}$ (fig. 29C). Depth to the carbonate nonzon increases with increase in elevation, as expressea by Y = — 68.2 + x9.7X (fig. 29D). In each case, X is elevation in feet and Y is $CaCO_3$ in per cent and depth to the carbonate horizon in inches. A few samples from the Organ surface fit in the distributions. With rise in elevation and corresponding increase in rainfall, soluble carbonate has been transferred to greater depths with a deeper penetrating wetting front. With greater moisture, some carbonate has been removed from the system so that the amount of carbonate decreases with elevation and the depth to the carbonate horizon increases. These relationships show the weathering and pedologic effects in the origin of caliche.

The relationship of carbonate horizons to age of geo morphic surfaces may be shown along a traverse from the Rio Grande Valley eastward across the valley-border group and then across the Jornada and Dona Ana surfaces to the Organ Mountains (table 13). The sediments are those detailed in the discussion on textural B horizons.

Below the Fillmore surface of less than 2620 years, weakly developed carbonate horizons have an average of only 2.2 per cent $CaCO_3$. Beneath the Picacho surface of late Wisconsin age, the average carbonate content is 17.9 per cent and the average thickness of the carbonate horizon is 22. inches. The average carbonate content increases to 21.8, 37.4, and 63.8 to the Tortugas, Jornada, and Dona Ana surfaces of progressively older ages, respectively. Average thickness of the carbonate horizon increases to 3o and 33 inches on the Tortugas and Jornada surfaces. The data show an increase in developmental properties of the carbonate horizon with increase in age of geomorphic surface. As these horizons are parts of the soil, that is, a ca or K horizon (Gile, 1961; Gile, Peterson, and Grossman), the pedological aspect of the origin of caliche or calcrete is evident.

Along this traverse, the carbonate horizons are formed in sands and gravels whose mineral and rock compositions should yield low amounts of calcium if the particles were thoroughly decomposed, which they are not. The sediments of the Picacho, Jornada, and Dona Ana surfaces are dominantly rhyolite gravel. Consequently, there must be an extraneous source of calcium to form the carbonate. An examination of a representative soil on the Picacho surface helps solve this problem.

Soil on Picacho Surface

This soil was briefly discussed on the dating of the Picacho surface. It was formed in rhyolitic gravel. Pebbles and cobbles constitute 41 to 88 per cent of the particles of the sediment (table 14). The soil has a thin A horizon overlying a textural B horizon which, in turn, rests abruptly on a K horizon, that is, a horizon cemented by carbonate (fig. 3oA; table 15). The K horizon, calcrete in the sense of Lamplugh, grades downward into a Cca horizon. The surface of the K horizon is rough and irregular and has the appearance of concrete that was poorly troweled. (fig. 3oD). Just beneath the calcrete surface is a banded layer comprised of many laminae (fig. 3oB) in which the carbonate content is 44 per cent. It lacks pebbles and cobbles and is an accretionary zone that effectively seals the lower calcrete. Infiltration rates on laminar surfaces such as this are less than o.i inch an hour (Gile). The nonlaminar calcrete is a conglomerate of pebbles, cobbles, and sand cemented by fine-grained carbonate. Some of the coarser particles are fragments of calcrete, indicating that more than one cycle of carbonate is involved (fig. 30C). These calcrete particles may be detrital as in the sense of a rhyolite particle, or they may be the result of a breakdown, rotation, and recementing in *situ*.

With carbonate in the system, the clay (less than 2 micron content) increases systematically downward from 12.7 to 17.5 and 20.3 per cent and abruptly abuts the surface of the K horizon at a depth of I I inches. Organic carbon content does likewise, being 0.28 to 0.42 and o.8o per cent. With carbonate removed, the clay, organic carbon, and free iron oxide contents continue at relatively high amounts downward into the horizons designated Kr and K2 and then decrease into the Cca horizon (table 5). These related subparallel distributions of clay, iron oxide, and organic carbon are characteristic of a B horizon of many soils. On a noncarbonate basis, this B horizon extends from depths of 2. to 25 inches and is a horizon of accumulation of these three constituents. These accumulations fulfill requirements of a B horizon of a solum (Simonson, 1957, p. 20).

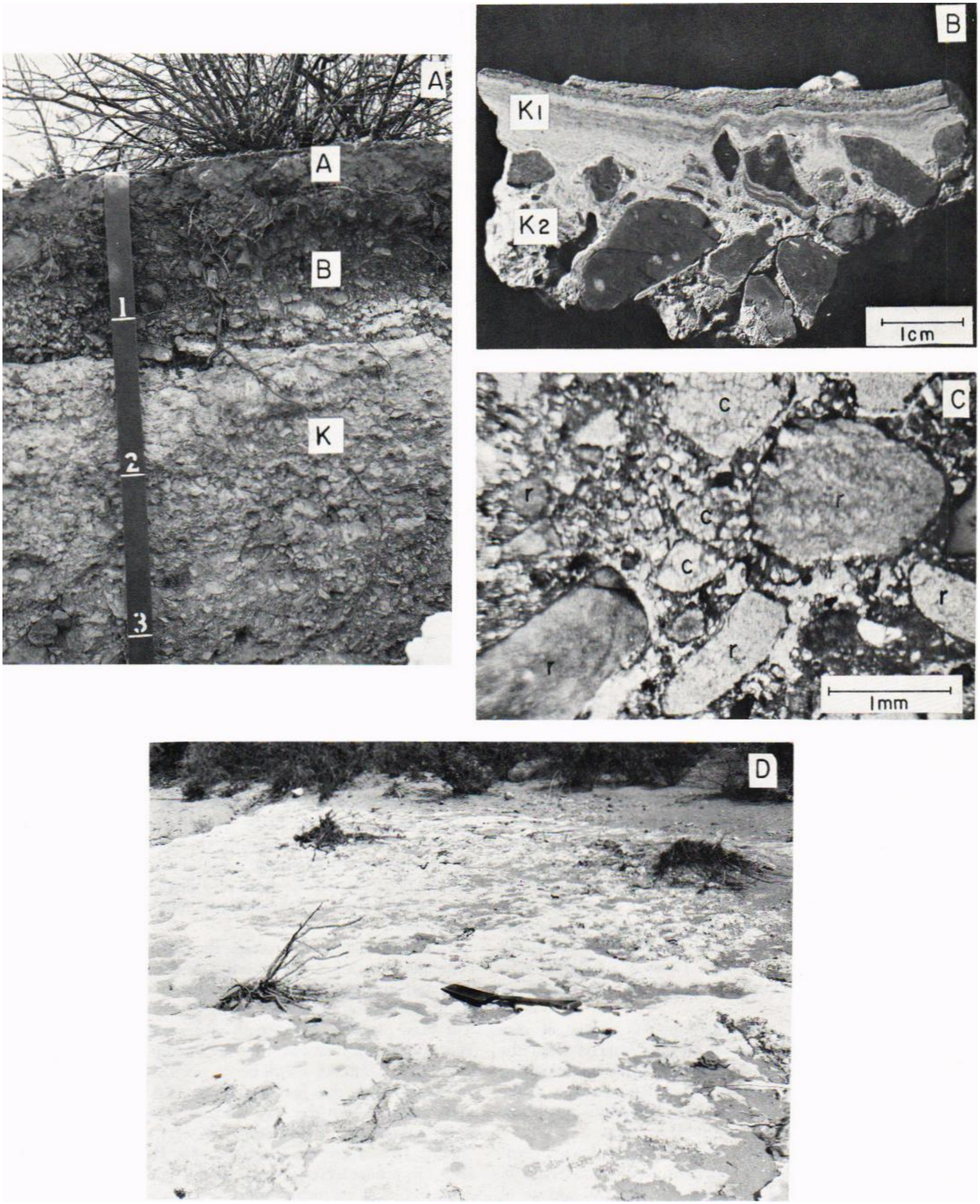


Figure 30

RADIOCARBON-DATED SOIL ON THE PICACHO SURFACE

(A) Profile with horizons as indicated and scale in feet. (B) Polished section of upper part of K horizon. *Organic* carbon sealed in Kr horizon is 9550 + 300 years old, but *inorganic* carbon of carbonate of same horizon is 13,850 + 600 years old. (C) Photomicrograph of Kr horizon. Particles of rhyolite, r, and cakrete, c, are cemented by fine-grained carbonate. (D) Surface of the K horizon or calcrete.

But abundant carbonate forms a laminar layer at the 11-to 12-inch depth and fills interparticle space to a depth of 25 inches. The exceedingly low infiltration rate at the surface of the laminar layer shows the presence of an almost impermeable barrier at II inches. Organic carbon could not have been transferred from the A horizon downward below

inches if the carbonate had been present. Clay and iron oxide could not have accumulated by downward transfer or formed if the impermeable barrier were present or if the horizon to a depth of 25 inches were plugged with carbonate. The part of the B horizon from I I to 25 inches had to form *before* sealing and plugging by carbonate. This is further indicated by the similar clay-mineral suites above and below 11 inches (table 14). This mineral distribution had to be present before cementation by carbonate. The accumulation of carbonate had to come later. This soil is polygenetic in the true sense.

When did these polycycles occur? *Organic* carbon sealed in the laminar layer is 955o ± 30o years old which represents the latest date at which accumulation of organic carbon could have begun; thus, this is a *minimum* age of a carbonate-engulfed B horizon. *(See* Perrin, Willis, and Hodge). Sealing and plugging by carbonate had to come after 955o years, and thus this is a *maximum* age of carbonate accumulation. This age neatly stratifies the poly-cycles near the generally accepted end of the last Wisconsin glacial (pluvial) episode. The clay-iron oxide-organic carbon cycle falls within the pluvial (wetter) episode, and the carbonate cycle falls within the postpluvial (drier) episode.

This neat stratification of soil polycycles raises four uncomfortable problems that are discussed in order: (I) the source of carbonate in the low calcium content rhyolitic gravel, (2) the interpretation of red soil color, (3) evidence for climatic change, and (4) the validity of radiocarbon dates of inorganic carbon in caliche or calcrete. Obviously, the carbonate in the soil on the Picacho surface has not been derived by decomposition of the gravel with release of calcium and recombination with carbon dioxide and water. As pointed out, thorough decay of one unit of volume of rhyolite may produce 0.09 unit of volume of carbonate. Approximately one foot of gravel, if decayed, could not produce the amount of carbonate in the soil. The gravel above the K horizon is not decayed (fig. 30A) and is fresh within the carbonate horizon (fig. 30B,C). The amount of clay expected from breakdown of feldspars is not present (table 14). The carbonate had to come from an extraneous source.

In eolian dust collected in traps in the area, the range of fallout of $CaCO_3$ for 1962-1964 is 0.035 to 0.067 gram a square foot (929 square centimeters) (calculated from data of SSL-LN). Converting these values to a weight-per-acre basis for the time available since formation of the textural B horizon of the Picacho surface soil, 16 to 31 tons of carbonate have fallen on each acre of this surface in the past 9500 years; since early Fillmore time (4900 years ago), 8 to 16 tons of carbonate have fallen; and since late Fillmore time (2600 years ago), 4 to 8 tons have fallen. In other dust traps in the study area, annual carbonate fallout is as much as o.3 gram/square foot, so the weight-per-acre values at times in the past could have been increased fifty- to one hundredfold. Thus, through time, appreciable amounts of carbonate could fall on the land surface even in areas of low calcium-content sediments, be taken into solution, transferred downward, and precipitated in a subsoil horizon. Brown proposed such a mechanism for origin of caliche on the High Plains in western Texas.

In the discussion of the red color of soil B horizons, relationships were shown of increasing redness to increasing age of geomorphic surface on which the soil occurred. The soil on the Picacho surface has a reddish B horizon and the color continues downward into the carbonate-engulfed zone. The red color, related to iron oxide, must be precarbonate

TABLE 14. CLAY MINERALOGY OF SOIL ON THE PICACHO SURFACE†

Depth (in.)	d Spacing Å									
	4.45	6.50	7.13	10.2	12.8	14.7	16.1	19.6	20.1	22.0
6-11	3.0 (2)*	2.5 (2)	7.5 (1)	21.0 (3)	16.0 (3)	11.0 (3)	8.0 (3)	3.5 (3)	3.0 (3)	2.0 (3)
11-12	4.0 (2)	——	6.5 (2)	9.5 (3)	7.5 (3)	7.5 (3)	10.0 (2)	3.0 (3)	2.0 (3)	1.0 (3)
12-25	4.5 (2)	——	4.5 (2)	8.0 (3)	10.0 (3)	11.0 (3)	9.0 (3)	4.0 (3)	2.0 (3)	1.0 (3)
25-50	——	1.0 (2)	5.0 (1)	15.0 (3)	20.0 (2)	15.0 (3)	7.0 (3)	2.0 (3)	1.0 (3)	——

† Carbonate free
* Peak height and shape where (1) is sharp, (2) domal, and (3) plateau

TABLE 15. PHYSICAL AND CHEMICAL PROPERTIES OF SOIL ON THE PICACHO SURFACE*

Depth (in.)	Horizon	Color (moist)	Gravel† (%)	Sand‡ (%)	Silt‡ (%)	Clay‡ $< 2\ \mu$ (%)	Fe_2O_3 (%)	$CaCO_3$ (%)	Organic carbon (%)
0-2	A	7.5YR 4/3	41.0	60.0	26.7	13.3	1.1	——	0.27
2-6	B1	7.5YR 4/4	57.0	68.8	19.6	16.6	1.2	1.0	0.37
6-11	B2ca	5YR 4/4	77.0	61.2	19.0	19.8	1.2	4.0	0.83
11-12	K1	5YR 6/3	——	58.0	18.5	23.5	1.3	44.0	0.73
12-25	K2	7.5YR 6/4	88.0	64.3	15.7	20.0	1.2	15.0	0.34
25-50	Cca	7.5YR 4/4	81.0	73.8	12.9	13.0	1.0	8.0	0.14

* Data from SSL-LN
† Whole soil basis, carbonate free
‡ Less-than-2-millimeter basis, carbonate free

in age, but this places the B horizon historically in the pluvial episode, suggesting the possibility of the effect of wetter climate. On the Fillmore surface of less than 2600 years, colors are brown. Brown color can now be related to younger age and drier climate and red color to older age and wetter climate. As usual, complications enter an analysis of soil color, and the usual conclusion is reached that "Color . . . is not a valid indicator of climate or time alone" (Ruhe, 1965, p. 762). As aptly stated by Simonson (1954), the product of a long interval of time and a low climatic intensity could be the same as the product of a short interval of time and a high climatic intensity.

There is no sound evidence in the study area from which strong inference may be made for a wetter pluvial episode predating 9500 years ago. The larger area of the basin fill associated with the Lake Tank **2.** surface in comparison with the fill of Lake Tank o surface suggests the former presence of a larger lake (pls. r and 2). Descendance of fine-grained alluvium along drainageways, some of which terminate at the margin of the older surface, also suggests possible wetter conditions (figs. 1B, 28B). The older basin fill and the alluvial fan postdate Jornada and predate the Recent Organ sediments. As pointed out, they may be late Wisconsin in age and correlative of Picacho. However, the radiocarbon-dated pollen studies at San Augustin Plains (Clisby and Sears, 1956) and the regional synthesis of pollen distribution (Martin and Mehringer, 1965) are more than suggestive of more moist climate in New Mexico during the late Wisconsin. The San Augustin Plains are only 130 miles northwest of the study area. Reconstruction of Wisconsin-age vegetations through pollen analysis places pinonjuniper woodland and yellow pine parkland in the near area. Leopold's (1951) hydrologic reconstruction of pluvial Lake Estancia in Torrance County, New Mexico, showed that a 5o per cent increase in rainfall was necessary to maintain the lake at its highest level. If temperatures were the same as those of the present, more than a 100 per cent increase in rainfall was necessary. In Harbour's (1958) restudy of the extinct lake, estimates of **22 to 31** inches of rainfall *were* required to maintain lake levels from the lowest to highest beaches. Present annual rainfall is 14 inches. The basin of pluvial Lake Estancia is 32o miles north of the study area. Within the framework of evidences from other but reasonably near areas, it may be inferred that a more moist environment also existed in southern New Mexico at a time prior to 9500 years ago.

A detailed examination of radiocarbon dates of *inorganic* carbon of the carbonate versus that of *organic* carbon sealed in carbonate raises questions concerning the validity of the absolute values of radiocarbon dates of caliche. The carbonate in the B horizon (fig. 3oA) is 5725 ± **200** years old (I-374). At a greater depth, soft, powdery carbonate on the surface of the laminar layer (K1 horizon) is 4575 ± 170 years old (1-375). *Inorganic* carbon of laminar layer is 13,850 600 years (1-392), but *organic* carbon *sealed in the layer* is 955o ± 300 years (1-616) or 4300 years younger. This is impossible. The age of the sealant has to be younger than that which is sealed.

Carbonate in the next lower laver, K. horizon, is 18,300 600 years (1-391) but at another lower depth, the carbonate age is 15,300 400 years (1-376) or 3000 years younger. The validity of the absolute values of these dates also is questionable. To further complicate matters, the age of a carbonate sample that includes all the horizons of the 4575 and 13,850 year dates and part of the horizon of the 18,300 year date is 11,900 ± 300 years old (Rubin and Alexander (W-786)). This last value almost approximates a simple average, 12,250 years, of the other three dates.

All the foregoing facts show absolute time discrepancy between inorganic and organic carbon values, stratigraphic inversion of absolute values, and discrepancy among values dependent upon method of sampling. Such discrepancies should be expected. Caliche has detrital grains of older carbonate (fig. 30C). Then too, the eolian dust falling on the soil surface is derived from older caliche and limestones as old as Paleozoic. These facts should lead one to suspect conclusions based on the radiocarbon age of caliche (Damon, Haynes, and Long, 1964) or the Cca horizon of a soil (Morrison and Frye, 1965).

Nonpedogenic Carbonate

Implications of the foregoing discussion are that weathering and pedogenic processes generate caliche. This is true, but in addition, carbonate is concentrated in layers and zones by processes other than those related to soil formation.

For example, in many arroyo walls, carbonate is concentrated along bedding planes in gravelly sediment. Commonly, these bedding planes are parallel to the ground surface and also parallel to pedogenic horizons of the soil solum. They occur within a depth range of 3 to 4 feet, suggesting a possible association with the soil (fig. 3,A). However, the bedding-plane concentrations at depths of **12 to** 20 feet are beyond the range of the wetting front of downward percolating soil solutions (fig. 3i B). In addition, these bedding plane accumulations are discordant to the planar attitude of the ground surface and its associated soil horizons (fig. 3,C). The beds may rise to and merge with the carbonate horizon that is associated with the soil. Slopes truncate the bedding pattern, showing that the carbonate was deposited along bedding planes prior to slope formation. In one example (fig. 31C), the carbonate beds parallel the Picacho surface but are beveled by a slope descending to the Fillmore surface. Hence, the bedded caliche is older than Fillmore and related to Picacho.

At many places in the walls of arroyos descending from the Dona Ana and Robledo mountains, very thick calcretes are exposed at the base of gravels and overlying bedrock (fig. 31D, E). Thick veins of carbonate along structural planes penetrate the underlying rock as much as 10 **to 15** feet. Commonly, the surface exposures of these calcretes are case-hardened, but when this surface layer is broken away, the caliche is not indurated but is relatively soft and friable. These thick basal calcretes and caliche may be equivalent to Kottlowski's (1960a) "medial tongue of boulder conglomerate" of his lower Santa Fe group.

All these bedded carbonate accumulations and basal caliche zones certainly arc the result of ground-water cementation. Their concentration along bedding planes, their resting on more impermeable materials, and their lack of association with other recognizable soil features attest to

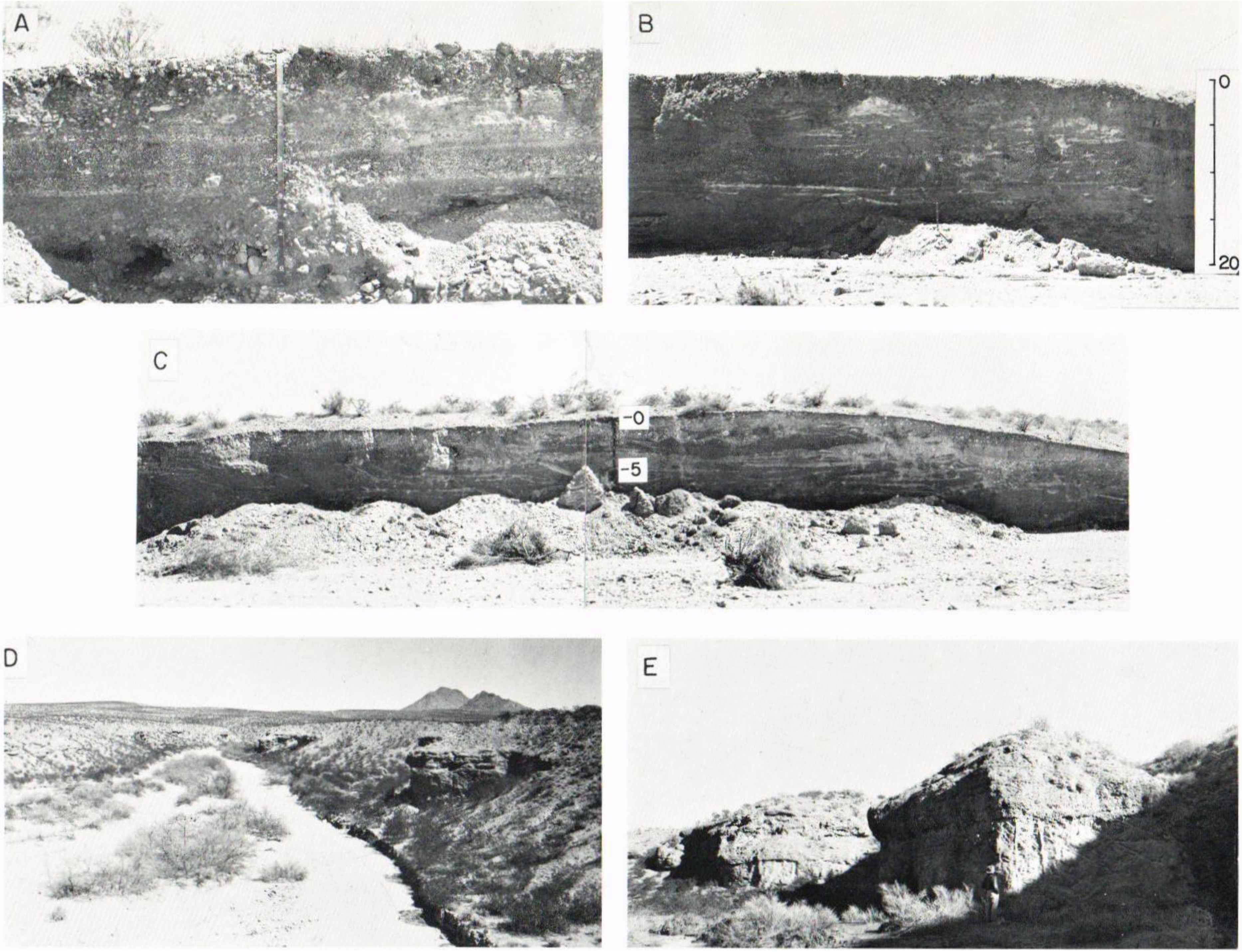


Figure 31

BEDDING-PLANE CONCENTRATIONS OF CARBONATE IN SURFICIAL DEPOSITS

Shallow depth (A) to greater depth (B) below Jornada surface; (C) beneath Picacho surface; (D) in basal gravel above bedrock; (E) with carbonate veins extending downward into bedrock. (Scales where shown in feet) their origin in the subsurface and not at or near the ground surface.

Consequently, caliche, cakrete, or carbonate horizons in the area are probably a combination of all these processes of origin. They may be related to pedogenic processes with simple solution of carbonate rock and subsequent precipitation of secondary carbonate. They may have an additive source of carbonate by eolian deposition. They may have the effect of ground-water deposition. There may also be deposition from surface waters. It would be extremely difficult to separate and delineate any part of a carbonate horizon that could be ascribed solely to one process.

Summary

Bedrock crops out on mountain summits and slopes, on rock pediment, and in the walls of canyons and arroyos. Rock types are Paleozoic limestones, dolomites, sandstones, and shales, Tertiary rhyolites, andesites, and other volcanic rocks, and monzonites, quartz monzonites, and syenomonzonites. Small, isolated areas of basalt are related to Pleistocene volcanic vents. The rock areas serve as sources for sediments that form the surficial deposits.

The area is block-faulted mainly along the Rio Grande trench and in the mountains. Major faults are along the mountain fronts but may strike across country disrupting older geomorphic surfaces. Many transverse faults are oblique and normal to the strike of major faults. Canyons in the mountains commonly are oriented along transverse faults.

The Doña Ana Mountains are an ellipsoidal structural dome whose geographic parameters can be described by the ellipse, $\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1$. The major axis of this structure parallels the trend of the structurally controlled Rio Grande trench and the strike of the Robledo fault. Morphometric features such as direction of drainage lines, bedrock distribution, distribution of exhumed basin sediments, and profiles of older geometric surfaces conform to structural components of the dome.

Major displacements along faults and axes of the dome took place in post-Tortugas pre-Picacho or late Pleistocene time. Minor tectonic adjustments continued into the Recent.

Geomorphic surfaces are grouped physiographically as alluvial fans, piedmonts, and aprons that adjoin the mountain fronts, basins and scarplet surfaces, and valley-border surfaces that are adjacent to the Rio Grande. Profiles of alluvial fans are described in terms of elevation and distance by $Y = 1/a + bX$ and the piedmont and aprons by $\log Y = a + bX$. Basins and adjoining areas are described as $Y = a + bX$. In addition, radii of curvature of contours and centers of radii of these land forms have specific geometry. Sediment distribution from source areas is related to the spatial geometry.

Rock pediment is minor in the area and is composed of several levels and surfaces so that its origin is multicyclic. These rock pediments are essentially exhumed surfaces resulting from erosion subsequent to structural deformation related to doming.

The geomorphic surfaces range in age from historic time to post late Kansan—Illinoian. The oldest surface is dated relative to a subsurface vertebrate fauna and younger surfaces by radiocarbon. A valley-border surface and its mountain front analogue are multicyclic in origin and are 1100 to 4900 years old. A late Wisconsin surface is more than 9550 years old. Most of the surfaces have counterparts that are correlative along the Rio Grande from El Paso, Texas, to north of Albuquerque, New Mexico.

Surficial deposits, generally designated as *Qal* on geologic maps, are delineated, defined, and mapped on the basis of texture and composition and spatial relations of one body versus another. Sediments of fans, piedmonts, and aprons generally are gravels, although textures are widely diverse. Lithologic composition controls the size of gravel on many of the fans. Rhyolite forms coarse gravel and monzonite forms finer sediment. Downslope on alluvial fans and piedmont, median diameters of monzonitic sediment are related to distance from source area as $Y = a + bX$ or $Y = a + b \log X$. Basin sediments differ texturally and range from sandy loams to clays.

Distribution of rock constituents of the surficial deposits relates to the geometry of land forms and in places is independent of the present drainage net. The net descends to the Rio Grande, which trenched the area after formation of older geomorphic surfaces. Composition of surficial deposits on the valley-border surfaces is a mixture of locally derived lower basin sediments and angular gravels transported along through arroyo systems.

Clay-mineral assemblages are very similar, regardless of kind of sediment or age of associated geomorphic surface. Consequently, cation-exchange capacities of fine-earth fractions are related to amount of clay in the sediment.

Surficial deposits commonly are layered and separated by paleosols which can be traced with reasonable continuity across country. The paleosols are usable stratigraphically in delineating and relating bodies of sediment.

Some of the weathering features in surficial deposits are related to the age of the associated geomorphic surface but others are not. On the fans and piedmont, organic carbon and carbonate content and depth to carbonate horizon are related to the orographic-climatic regimen controlled by the rise up the mountain front. In the valley-border surface sequence, increase in redness of the soil B horizon, amount of clay in and thickness of the B horizon, and amount of carbonate in and thickness of the carbonate horizon are related to age of the geomorphic surface. However, complications are introduced by possible climatic changes of the pluvials. Clay minerals are apparently little altered through time.

The origin of carbonate horizons (ca and K horizons pedologically; caliche and calcrete geologically) is in part pedologic, in part the result of ground-water deposition, and in part the result of surface-water deposition. In low calcium content sediments, the source of carbonate is eolian dust that falls on the ground surface, is dissolved and transferred downward, and precipitated in a subsurface zone.

Detailed analysis points out the discrepancies that occur and that are to be expected in the radiocarbon dates of the inorganic carbon of the carbonate in caliche.

References

Bachman, G. O., and Myers, D. A. (1963) *Geology of the Bear Peak NE quadrangle, Dona Ana County, New Mexico,* U.S. Geol. Surv., Misc. Geol. Inv. Map I-374.

Bretz, J H., and Horberg, L. (1949) *Caliche in southeastern New Mexico,* Jour. Geol., v. 57, p. 491-511.

Borst, George (1961) *Note,* Soil Science, v. 91, p. 289.

Brown, C. N. (1956) *The origin of caliche on the northeastern Llano Estacado, Texas,* Jour. Geol., v. 64, p. 1-15.

Bryan, Kirk (1938) *Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico* (*in* Rio Grande joint investigation in the upper Rio Grande Basin in Colorado, New Mexico, and Texas), Natl. Res. Committee, Washington, Regional Planning, pt. 6, p. 197-225.

Coleman, N. T., and Mehlich, A. (1957) *The chemistry of soil pH* (*in* Soil), U.S. Dept. Agr., Yearbook, p. 72-79.

Clisby, K. H., and Sears, P. B. (1956) *San Augustin Plains–Pleistocene climatic changes,* Science, v. 124, p. 537-539.

Damon, P. E., Haynes, C. V., and Long, A. (1964) *Arizona radiocarbon dates V, Radiocarbon,* v. 6, p. 91-107.

Denny, C. S. (1941) *Quaternary geology of the San Acacia area, New Mexico,* Jour. Geol., v. 49, p. 225-260.

———— (1965) *Alluvial fans in the Death Valley region, California and Nevada,* U.S. Geol. Surv., Prof. Paper 466.

Dunham, K. C. (1935) *The geology of the Organ Mountains with an account of the geology and mineral resources of Dona Ana County, New Mexico,* N. Mex. Inst. Min. and Tech., State Bur. Mines and Mineral Res., Bull. 11.

Frye, J. C. (1954) *Graded slopes in western Kansas,* Kansas Geol. Surv., Bull. 109, p. 81-96.

————, and Leonard, A. B. (1952) *Pleistocene geology of Kansas,* Kansas Geol. Surv., Bull. 99.

Gardner, J. L. (1951) *Vegetation of the creosote bush area of the Rio Grande Valley in New Mexico,* Ecological Mono., v. 21, p. 379-403.

Gile, L. H. (1961) *A classification of ca horizons in soils of a desert region, Dona Ana County, New Mexico,* Soil Sci. Soc. Am., Proc., v. 25, 52-61.

————, Peterson, F. F., and Grossman, R. B. (1965) *The K horizon: a master soil horizon of carbonate accumulation,* Soil Science, v. 99, p. 74-82.

Grossman, R. B., and Millet, J. L. (1961) *Carbonate removal from soils by a modification of the acetate buffer method,* Soil Sci. Soc. Am., Proc., v. 25, p. 325-326.

Hadley, R. F., and Rolfe, B. N. (1955) *Development and significance of seepage steps in slope erosion,* Am. Geophys. Union Trans., v. 36, p. 792-804.

Harbour, Jerry (1958) *Microstratigraphic and sedimentological studies of early man site near Lucy, New Mexico,* unpub. M.S. thesis, Univ. N. Mex.

Hardy, E. L. (1941) *Climate of New Mexico* (*in* Climate and man), U.S. Dept. Agr., Yearbook, p. 1011-1024.

Hawley, J. W. (1965) *Geomorphic surfaces along the Rio Grande Valley from El Paso, Texas, to Caballo reservoir, New Mexico,* N. Mex. Geol. Soc., Guidebook, Sixteenth field conference, Southwestern New Mexico II, p. 188-198.

Humphrey, R. R. (1958) *The desert grassland,* Ariz. Agr., Exper. Sta., Bull. 299.

Jackson, M. L. (1956) *Soil chemical analysis–advanced course,* Pub. by author, Dept. Soils, Univ. Wisc.

Jackson, M. L., Tyler, S. A., Willis, A. L., Bourdeau, G. A., and Pennington, R. P. (1948) *Weathering sequence of clay-size minerals in soils and sediments: I,* Jour. Phys. Colloid Chem., v. 52, p. 1237-1260.

Jensen, C. E. (1964) *Algebraic description of forms in space,* U.S. Forest Serv., Central States Forest Exper. Sta., Columbus, Ohio.

Kelley, V. C., and Silver, Caswell (1952) *Geology of the Caballo Mountains,* Univ. N. Mex., Publ. in geology, n. 4.

Kottlowski, F. E. (1953) *Tertiary–Quaternary sediments of the Rio Grande Valley in southern New Mexico,* N. Mex. Geol. Soc., Guidebook, Fourth field conference, Southwestern New Mexico, p. 144-148.

———— (1958) *Geologic history of the Rio Grande near El Paso,* West Texas Geol. Soc., Guidebook, p. 48-51.

———— (1960a) *Reconnaissance geologic map of Las Cruces thirty-minute quadrangle,* N. Mex. Inst. Min. and Tech., State Bur. Mines and Mineral Res., Geol. Map 14.

———— (1960b) *Depositional features of the Pennsylvanian of south-central New Mexico,* Roswell Geol. Soc., Guidebook, Northern Franklin Mountains and southern San Andres Mountains, p. 34, 74, 96-130.

————, Cooley, M. E., and Ruhe, R. V. (1965) *Quaternary geology of the Southwest* (*in* The Quaternary of the United States), Princeton, N. J.: Princeton Univ. Press, p. 287-298.

————, Flower, R. H., Thompson, M. L., and Foster, R. W. (1956) *Stratigraphic studies of the San Andres Mountains, New Mexico,* N. Mex. Inst. Min. and Tech., State Bur. Mines and Mineral Res., Mem. 1.

Lamplugh, G. H. (1907) *Geology of the Zambezi Basin around Batoka Gorge,* Quart. Geol. Soc. London, v. 63, p. 162-216.

Lauritzen, C. W. (1955) *Ways to control losses from seepage* (*in* Water), U.S. Dept. Agr., Yearbook, p. 311-320.

Lee, W. T. (1907) *Water resources of the Rio Grande Valley in New Mexico,* U.S. Geol. Surv., Water-Supply Paper 188.

Leopold, L. B. (1951) *Pleistocene climate in New Mexico,* Am. Jour. Sci., v. 249, p. 152-167.

Mammerickx, Jacqueline (1964) *Quantitative observations on pediments in the Mojave and Sonoran deserts (southwestern United States),* Am. Jour. Sci., v. 262, p. 417-435.

Martin, P. S., and Mehringer, P. J. (1965) *Pleistocene pollen analysis and biogeography of the Southwest* (*in* The Quaternary of the United States), Princeton, N. J.: Princeton Univ. Press, p. 433-451.

Melton, M. A. (1965) *The geomorphic and paleoclimatic significance of alluvial deposits in southern Arizona,* Jour. Geol., v. 73, p. 1-38.

Miller, J. P. (1958) *High Mountain streams: effects of geology on channel characteristics and bed material,* N. Mex. Inst. Min. and Tech., State Bur. Mines and Mineral Res., Mem. 4.

————, and Wendorf, F. (1958) *Alluvial chronology of the Tesuque Valley, New Mexico,* Jour. Geol., v. 66, p. 182-187.

Morrison, R. B., and Frye, J. C. (1965) *Correlation of the middle and late Quaternary successions of the Lake Lahontan, Lake Bonneville, Rocky Mountain (Wasatch Range), southern Great Plains, and eastern Midwest areas,* Nevada Bur. Mines, Rpt. 9.

Perrin, R. M. S., Willis, E. H., and Hodge, C. A. H. (1964) *Dating of humus podzols by residual radiocarbon activity,* Nature, v. 202, p. 165-166.

Reiche, Parry (1938) *Recent fault scarps, Organ Mountain district, New Mexico,* Am. Jour. Sci., v. 36, 5th ser., p. 440-444.

Robinson, G. W. (1949) *Soils, their origin, constitution, and classification,* New York: John Wiley & Sons, Inc.

Rubin, M., and Alexander, C. (1960) *U.S. Geological Survey radiocarbon dates V,* Am. Jour. Sci., Radiocarbon supp., v. 2, p. 129-185.

Ruhe, R. V. (1962) *Age of the Rio Grande Valley in southern New Mexico,* Jour. Geol., v. 70, p. 151-167.

———— (1964) *Landscape morphology and alluvial deposits in southern New Mexico,* Assoc. Am. Geog. Annals, v. 54, p. 147-159.

———— (1965) *Quaternary paleopedology* (*in* The Quaternary of the United States), Princeton, N.J.: Princeton Univ. Press, p. 755-764.

———— (1966) *Pedology* (*in* Encyclopedia of earth sciences), New York: Reinhold Publishing Corporation (in press).

————, and Daniels, R. B. (1965) *Landscape erosion–geologic and historic,* Jour. Soil and Water Conserv., v. 20, p. 52-57.

————, and Scholtes, W. H. (1956) *Ages and development of soil landscapes in relation to climatic and vegetational changes in Iowa,* Soil Sci. Soc. Am., Proc., v. 20, p. 264- 273.

Shreve, F. (1942) *The desert vegetation of North America,* Botannical Rev., v. 8, p. 195-246.

Simonson, R. W. (1954) *Identification and interpretation of buried soils,* Am. Jour. Sci., v. 252, p. 705-732.

———— (1957) *What soils are* (*in* Soils) U.S. Dept. Agr., Yearbook, p. 17-30.

———— (1959) *Outline of a generalized theory of soil genesis,* Soil Sci. Soc. Am., Proc., v. 23, p. 152-156.

Tator, B. A. (1953) *Pediment characteristics and terminology,* Assoc. Am. Geog. Annals, v. 43, p. 47-53.

Thompson, L. M. (1952) *Soils and soil fertility,* New York: Mc-Graw–Hill Book Company, Inc.

Thorp, J., Johnson, W. M., and Reed, E. C. (1951) *Some post-Pliocene buried soils of central United States,* Jour. Soil Sci., v. 2, p. 1-19.

Troeh, F. R. (1965) *Land form equations fitted to contour maps,* Am. Jour. Sci., v. 263, p. 616-627.

Tuan, Yi-Fu (1962) *Structure, climate, and basin land forms in Arizona and New Mexico,* Assoc. Am. Geog. Annals, v. 52, p. 51-68.

Wright, H. E. (1946) *Tertiary and Quaternary geology of the lower Rio Puerco area, New Mexico,* Geol. Soc. Am. Bull., v. 57, p. 383-456.

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