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GEOLOGY AND SEDIMENTATION ALONG THE LOWER RIO SALADO IN NEW MEXICO

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The geomorphology and Tertiary geology of the lower part of the Rio Salado drainage are closely related to the history of the local sand dunes. Dunes form along the north bank of the Rio Salado for seven miles upstream from the mouth and on the south bank along the east side of Loma Blanca.

Denny (1940, 1941) reported that the dune sand came from the Rio Salado. Since the Rio Salado drainage includes extensive outcrops of Cretaceous rocks, the dunes were expected to contain a Cretaceous type of heavy mineral suite (Allen and Balk, 1954). However, the dunes contain a heavy mineral suite typical of crystalline rocks.

The geomorphology is dominated by Quaternary pediments modified by gullying; the pediments apparently reflect changing base levels of the Rio Grande and Rio Salado.

The Rio Salado is a typical large desert arroyo with intermittent stream flow from west to east in central New Mexico. Within the mapped area, it empties into the Rio Grande which is the north-south trunk drainage stream in this part of New Mexico. The mouth of the Rio Salado is about 15 miles north of Socorro and about 2½ miles north of the small farming community of San Acacia.

Vegetation along much of the Rio Salado is sparse with bare patches of ground between the plants. Very active dunes have no vegetation but do include partly buried trees. A few hardy plants may survive on dunes, which are moderately active, only to be left behind by deflation when the dunes move. Salt cedar trees grow in the Rio Salado and a few juniper trees are scattered over the rest of the area. Creosote bush, cactus, tumbleweed, and grasses grow throughout the area, except in very active erosion zones.

STRATIGRAPHY

Mapped units in the area include the Popotosa Formation and Santa Fe Group of Tertiary age and alluvial and aeolian deposits of Quaternary age.

POPOTOSA FORMATION

The type locality of the Tertiary Popotosa Formation is along Silver Creek three and one half miles west of the San Acacia quadrangle. Denny estimates the thickness of the Popotosa to be between 3000 and 5000 feet. It consists of red-brown silts and sands grading upward into thin, brown-weathering, calcite-cemented sandstones, and gray to brown volcanic conglomerates. The conglomerates become more massive to the west and upward in the section. Gypsum beds up to one inch thick are interbedded with the red-brown silts and sands; gypsum veins are common.

On the southern end of Valle Frutosa, gypsum beds grade out west of the faults crossing Arroyo Rendija. Bentonite beds present here are overlain by thin-bedded, calcite-cemented, brown-weathering sandstone containing clay balls. The bentonite beds are about ten feet thick. Bentonite also crops out in the canyon of Arroyo Rendija near the faults, but the outcrops are too small to be shown on the map (fig. 1).

Canada Popotosa is floored by alluvium resting on the Popotosa Formation. Most of the sands and silts here contain less gypsum than in Valle Frutosa; bentonite is thicker than in Valle Frutosa. The bentonite has been mined for use in drilling mud and for sealing earth under stock tanks. The bentonite bed is included within red-brown silts and sands. A fault scarp along the east side of the valley is formed by brown-weathering conglomerate on the north end which grades into sandstone to the south. The conglomerate-sandstone lies conformably over the silts and sands.

A composite sample of the Popotosa sands and silts has a medium of $+2.8\phi$, a mean of $+2.78\phi$, and a Phi standard deviation of 0.70. Eighty-seven per cent of the grains have a diameter between $+2\phi$ and 4ϕ; thus, it is classified as a fine to very fine sand.

A frequency count of the nonopaque heavy minerals from one sample shows 59 per cent hornblende and 23 per cent barite. The barite is authigenic. Four per cent of the hornblende is basaltic and about 1 to 2 per cent is blue-green. Other minerals in the sample are apatite, augite, biotite, epidote, garnet, kyanite, monazite, sphene, tourmaline, and zircon.

The Tertiary Popotosa playa deposits and conglomerates were tilted and probably faulted before the Tertiary Santa Fe Group was deposited. General

*Summarized by Roy Foster from a M.S. thesis submitted to the New Mexico Institute of Mining and Technology.

uplift or a change in local base levels produced a series of pediments and terraces which are presently being dissected in a semiarid climate similar to that which prevailed in Popotosa time.

Denny (1940) classifies the lower sands and silts of the Popotosa Formation as playa sediments deposited in a semiarid climate because of the gypsum beds and the regular thin bedding of the red-brown sediments. Mechanical analysis supports the classification suggesting a combination of aeolian and fluvial deposition. Denny (1940) supposes a volcanic provenance for the playa deposits similar to that for the overlying conglomerates. The nonopaque heavy mineral suite confirms this. Authigenic barite and concertina augite suggest that there was some diagenesis of the sediments even though they are not lithified. This agrees with Denny's contention that the gypsum veins are of secondary origin. The bentonite bed was probably an ash fall before diagenetic processes altered it to clay.

The Popotosa conglomerates' intertonguing and pinching out to the east suggests a highland source area not far west of the present Popotosa outcrops.

SANTA FE GROUP

The Tertiary Santa Fe Group in the mapped area includes two facies. The older of the two is called the Loma Blanca Facies and the younger, which rests on the Loma Blanca facies, is referred to as the upper facies of the Santa Fe Group. As mapped, the Santa Fe Group only appears east of the Loma Pelada Fault zone. It is possible, however, that some of the upper facies have been misclassified as pediment gravel.

The Loma Blanca facies is gray-white sand except for occasional small yellow-weathering sandstone lenses. The sands are usually unconsolidated, yet they form steep slopes. The lenses are commonly cemented with calcite. Pebble conglomerates, olive-colored clay lenses, and clay balls are common. Cross-bedding, flow structures, and slump structures are also common but usually not well exposed.

In the vicinity of Arroyo Tio Lino, the Loma Blanca sands are partially capped by gravels that often form steep slopes. When the gravels are missing or are not cemented, the slopes are gentle. Weathering processes do not permit the internal structure of the sand to be seen in this area.

Four samples of Loma Blanca facies show a median ranging from 1.2ϕ to 2.8ϕ, a mean ranging from 1.43ϕ to 2.88ϕ, and Phi standard deviation ranging from 0.67 to 0.95.

Frequency count of the nonopaque heavy minerals in four Loma Blanca facies samples show hornblende ranging from 14 to 72 per cent with only one sample showing blue-green hornblende. Augite ranges from 2 to 50 per cent. Other minerals present are acmite, apatite, barite, epidote, fluorite, garnet, kyanite, sphene, tourmaline, zircon, and zoisite. The augite has developed concertina structure.

Clastic dikes form small ridges locally. The dikes are coarser than the surrounding sand and are generally cemented with calcite. At one locality, the dike is cemented with a manganese oxide mineral. An emission spectrograph powder analysis of a sample from this area showed strong concentrations of calcium, aluminum, iron, silicon, magnesium, and manganese; medium concentrations of sodium and titanium; and weak concentrations of lead, molybdenum, vanadium, and potassium.

The upper facies of the Santa Fe Group refers to tan-weathering, interbedded, lenticular sands and gravels. One flow of andesitic lava is also included in this facies. Pediment gravels are difficult to distinguish from the upper facies and in places appear to grade into it. Lithologically, the gravels of the pediments and upper facies each contain boulders up to six inches in diameter of sandstone, limestone, and igneous rock. Some of the limestone boulders contain fossils which appear after the boulder is etched with weak hydrochloric acid. Calcite and caliche are common cementing agents, but their distribution is irregular and lenticular.

The upper facies seldom is clearly exposed along the north bank of the Rio Salado, but small outcrops may be seen along the south bank, and it forms cliffs along the Rio Grande.

One sample was taken of the upper facies which had a median of 0.8ϕ, a mean of 0.89ϕ, and a Phi standard deviation of 1.11.

Clay and pebble layers, cross-bedding, and slump structures indicate a fluvial mode of deposition for the Loma Blanca sands. The mechanical analysis supports this theory and suggest that some of the sand is aeolian. The olive color of the clay indicates that the environment was more reducing than during Popotosa time. Diagenesis is indicated by the calcite veins, authigenic barite, and concertina augite. Denny's (1940) conclusion from the gravel types that the sediments are of crystalline and volcanic origin is confirmed by the nonopaque heavy mineral suite.

The gravels and sands of the Santa Fe upper facies suggest a fluvial deposition of these sediments. Mechanical analysis supports this view and suggests that some of the sand may be aeolian.

PEDIMENT GRAVELS

Pediment gravels are mapped as separate units only west of Arroyo Tio Lino and Loma Blanca, but they may extend east of these areas on any of the pediments. The gravels may be as much as 35 feet thick, according to Denny (1941). They are lithologically similar to the upper facies of the Santa Fe Group and appear to grade into the upper facies.

The tan-weathering pediment gravels contain boulders of limestone, sandstone, jasper, chert, and igneous rocks as much as one foot in diameter. Some of the limestone boulders contain fossils. Lenticular sands and silts are interbedded with the gravels. Caliche and calcite are irregularly distributed cementing agents.

Along the north bank of the Rio Salado between Cañada Popotosa and Arroyo Tio Lino, a pediment gravel approximately 30 feet thick contains gravel layers which are cemented for several hundred yards. The pediment gravel overlies both the Lomo Blanca facies and the Popotosa Formation. Elsewhere in the mapped area, extensive cemented gravel layers within pediment gravels are not seen.

QUATERNARY ALLUVIUM

The Quaternary alluvium consists of deposits similar to the Santa Fe Group, but it contains less conglomerate and is nowhere consolidated. In places, it is being eroded by the arroyos which deposited it.

Along Cañada Popotosa and in Valle Frutosa, the alluvium is almost all silt and sand similar to the Popotosa playa deposits, but it is a little browner. The Rio Salado channel alluvium contains intermixed gravels generally covered with sands. The upper and lower terrace alluviums are more tan-colored than the alluvium of the Valle Frutosa and the valley of the Cañada Popotosa. All alluvial deposits are poorly sorted and do not exceed pebble-size grains.

STRUCTURE

The mapped area is situated on the western edge of the Rio Grande structural depression which is formed by generally north-south trending normal faults that produce a horst and graben structure. Some geologists prefer to place the edge of the Rio Grande depression as far west as the faults along the Bear Mountains on the Colorado Plateau. The Ladron Mountains and the Lemitar Mountains just west of the area mark the edge of the Colorado Plateau.

The major structural feature in the mapped area is the Loma Pelada Fault zone. It has a possible displacement of at least 1000 feet. It is a north-south trending, steeply dipping fault zone which brings the Loma Blanca facies down against the silts and sands of the Popotosa Formation. Other small faults in the area probably related to the Loma Pelada zone have displacements ranging from a few tens of feet to less than two hundred feet. At the entrance to the narrow gorge of the Arroyo Rendija, a small thrust fault may be seen in the outcrop.

The Popotosa Formation is broken and tilted by faults but only slightly folded. Sediments on the west side of Valle Frutosa are tilted to the west, whereas those on the east side are tilted eastward. Cross section AA′ on the geologic map shows the structural and stratigraphic interpretation. Dips in the Popotosa are generally about 30 degrees, but dips have been recorded up to 71 degrees. Dips along the east side of the Cañada Popotosa are generally southward. Dips within the Loma Pelada zone are very irregular.

Loma Blanca facies show only minor deformation along the west side of Loma Blanca. The absence of general evidence of deformation in the Loma Blanca facies may be due to their lack of consolidation or distinct bedding except in the area just mentioned.

The pediment gravels are undisturbed by the faulting except for a slight displacement near Arroyo Rendija. Usually they rest unconformably on the Popotosa Formation.

GEOMORPHOLOGY

The topography is typical of a semiarid climate. Socorro averages less than 10 inches of rain a year, but more rain falls in the mountains. It is these mountain rains and snows which provide the intermittent flow for the usually dry Rio Salado. West of the mapped area, the Rio Salado often has a small flow of water which disappears into the subsurface before reaching Cañada Popotosa.

Across the San Acacia and La Joya quadrangles, the Rio Salado has a fairly uniform gradient of about 33 feet a mile. The gradient of the Rio Grande is about 4 feet a mile in this area. Elevations range from a little less than 4700 feet above sea level at the mouth of the Rio Salado to more than 5500 feet west of Valle Frutosa. The total relief in the area is about 820 feet. The depth of the channel in which the Rio Salado flows is variable. Its depth increases upstream toward the Sierra Ladron. It also narrows westward, passing through a winding canyon several hundred feet deep north of Cerro Colorado in the Riley quadrangle. The channel is a mile wide where it enters the Rio Grande and narrows to three quarters of a mile just before entering the Riley quadrangle.

Arroyos tributary to the river generally occupy narrow valleys; their width depends upon the size of their drainage basin and the resistance of the sediments through which they flow. Cañada de la Tortola and Cañada Popotosa have built flood plains within their valleys, but at present they are deepening their channels.

PEDIMENTS AND TERRACES

Quaternary pediments have been recognized in this area. They are defined by their "approximate elevation of grade above the flood plain of the Rio Grande" (Denny, 1941). The Cañada Mariana pediment is defined as 50 feet above grade. The Valle de Parida pediment is 150 feet above grade. The Tio Bartolo pediment is 250 feet above grade. The Ortiz pediment is 400 feet above grade. Other surfaces recognized are "residuals above Ortiz? or Tio Bartolo surfaces," and "dissected surfaces, undifferentiated" (Denny, 1941). The three pediments and the "dissected surfaces, undifferentiated" were mapped during this study. The Ortiz pediment is not an obvious surface within the San Acacia quadrangle.

In the map area, most of the "pediments" might better be called surfaces because bedrock seldom obviously floors the plains. The problem here not only is with concealed pediments but also with pediments on older alluvial deposits. Therefore the "pediments" outlined on the geologic map are of plains and remnants of plains which form the surface topography today. The names and the term *pediment* are retained from Denny (1941).

In this area the youngest pediment, Cañada Mariana, may not be a pediment but instead may be a terrace deposit associated with the ancestral flood plains of the Rio Salado and Rio Grande. The surfaces north and south of the Rio Salado seem to be related, but along the east side the northern surface drops 200 feet to the flood plain of the Rio Grande. This makes it difficult to define the northern Cañada Mariana using Denny's definition. Denny (1941) also considers the identification of this northern Cañada Mariana pediment questionable.

The "dissected surfaces undifferentiated" are younger than the Valle de Parida pediment and formed on horizontal Santa Fe Group sediments. The surfaces are covered by loose sand and gravel, but in outcrops along the Rio Grande channel an irregular bed of caliche appears just beneath the surface.

Valle de Parida is clearly an aggraded surface, but the relationships between the present topography and the buried topography are not shown clearly on the map. In places underneath the Valle de Parida pediment, upturned beds of the Popotosa Formation are covered by calcite-cemented gravels. The distinction between upper facies gravels and pediment gravels is not sharp because the gross lithologies are similar and the overlying gravels may be thick. This problem is well illustrated in the bluffs along the north bank of the Rio Salado.

Tio Bartolo is the highest pediment and was formed on horizontal Santa Fe upper facies. This pediment has the smallest areal extent. It may have covered the entire area at one time, and the other pediments have been cut from it. If this is true, it follows that the Santa Fe Group completely covered the Popotosa Formation when the Tio Bartolo pediment was formed. If the surface on the Popotosa Formation under the 30-foot-thick gravels is a pediment, and these gravels are Santa Fe upper facies remnants, then this surface predates the Tio Bartolo.

The terraces formed on Quaternary alluvium have been delineated on the map. The Upper Terrace segment southeast of the bridge over the Rio Salado probably correlates with the Upper Terrace segments near Arroyo Chanthe. But the first terrace may have been formed by the Rio Salado while the Arroyo Chanthe terrace was formed by the Rio Grande.

The Lower Terrace is related to the Rio Grande and is a remnant of a surface that formed just prior to the development of the present flood plain.

STRUCTURAL EFFECTS

The effect of structure on the physiography along the Loma Pelada Fault zone is indicated by the line of steep slopes formed by resistant beds on the downthrown side of the fault. The number of faults near where Arroyo Rendija enters Valle Frutosa suggests structural control for this narrow canyon. Faulting may control the straight front that forms the west side of Valle Frutosa, but other field evidence was not found to substantiate this hypothesis.

A series of base level changes for the Rio Grande, and hence the Rio Salado, may be due to general uplift in this area or to structural changes along the Rio Grande depression. The Rio Grande channel formerly was farther east (Denny, 1940), and it may be that structural movements have relocated the river to its present channel. Whatever the local reason for these base level changes, the pediments have been profoundly modified by them. As each pediment has been raised relative to the local base level, the Rio Salado has lowered its channel and triggered the dissection of the existing pediments. The succession of seven surfaces identified in the area and the channeling of the arroyos through their alluvium suggests

that the structural adjustments may still be occurring.

Denny (1941) proposed that the lower Rio Salado did not have its present drainage area when the Tio Bartolo pediment was being formed. The lower Rio Salado is supposed to have inherited its present drainage system by piracy of an earlier drainage pattern which entered the Rio Grande south of Socorro. The meanders of the Rio Salado in the deep, winding canyon west of the mapped area suggest that the Rio Salado cut the canyon after the meanders were formed on the Tio Bartolo surface.

AEOLIAN SAND DEPOSITION

Two basic types of dunes form in the mapped area, barchan and seif or longitudinal dunes. Most of the dunes along the north bank of the Rio Salado are barchans. The direction of movement of the barchans varies with the nearby topography. The most westerly dunes in the Rio Salado move down the valley in an easterly direction. The most easterly dunes shift their direction of movement gradually to the north. During the summer of 1962, the dunes near U.S. 85 shifted until they were moving north-northwest. Casual observers of the dunes have the impression that over the last few years, the dunes near U.S. 85 generally moved toward the northeast. Several years ago dunes were observed crossing U.S. 85 from the northwest; that is, moving toward the southeast. Aerial photographs taken in 1952 show the dunes essentially as they are now, but Denny's dune crest lines indicate an effective wind from the west-northwest in 1939.

Dunes along the eastern side of the Loma Blanca are longitudinal dunes or sandfalls. A few incipient dunes form on the south and west side of the Loma Blanca about halfway up the slope from Arroyo Chanthe. Small dunes form on either side of the clastic dike on Loma Blanca, depending upon the direction of the wind. These dunes depend upon the ample supply of loose sand in the Loma Blanca and are almost stationary, although they are not covered by vegetation.

WIND PATTERNS

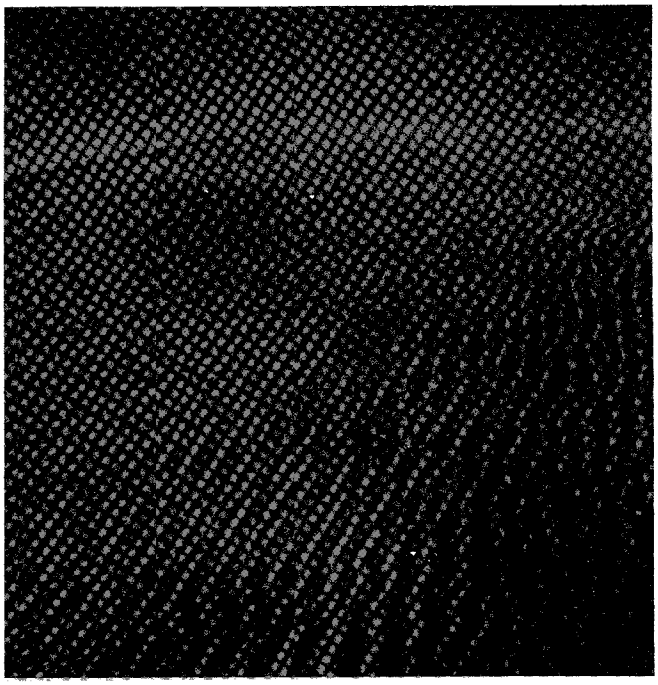
Wind patterns for Socorro, New Mexico are probably not exactly the same as those in San Acacia; however, the dune shapes in the Rio Salado during the summer of 1962 generally are consistent with the wind data collected at Socorro.

The attitudes of the Rio Salado dunes were first observed by the author on March 1, 1962. At that time, they showed an effective dune-shaping wind direction from the west-southwest. Later, in April 1962, a more accurate estimate of the effective wind direction which shaped the barchans was made. The effective wind appeared to be from the west-southwest. In June 1962, the effective wind direction had shifted to the south-southeast. All the above observations were made on dunes near U.S. 85. Studies show clearly that the potentially most effective winds came from the northwest during January, and the wind still did not fit the barchan structures in February. One can conclude only that the northerly winds were not effective in shaping the dunes. The dunes were damp enough on March 1 that holes dug into them maintained vertical walls. These dunes lie in the lee (to northerly winds) of a bluff which is part of the trough of the Rio Salado. This drop in elevation may be sufficient to destroy the effectiveness of the northerly winds. As can be seen by the map, the main Rio Salado dunes do not generally climb out of the trough and onto the Cañada Mariana surface. This may be due to these northerly winds sweeping the sand back into the trough.

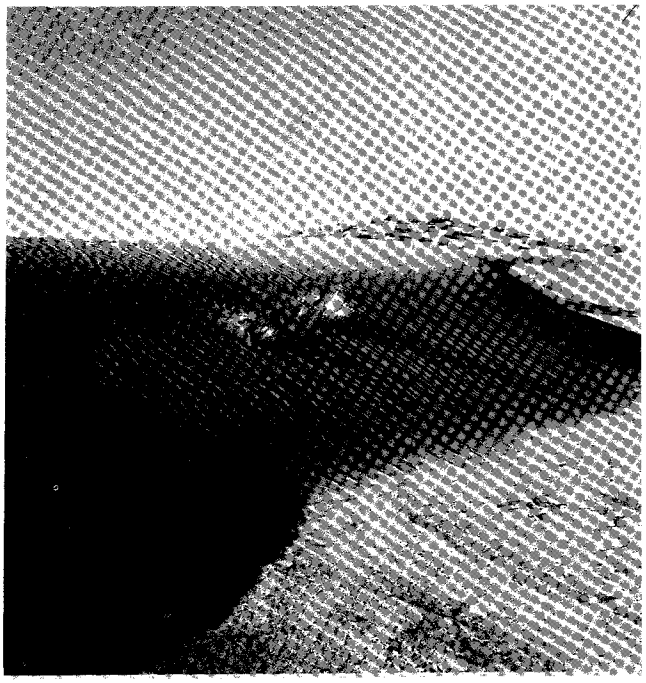
Sands forming the dunes on the north side of the Rio Salado appear to come mostly from the Rio Salado. But much of this sand has a local source in the Loma Blanca facies which is brought to the Rio Salado both by wind and water. Minor quantities of sand probably are blown directly to the dunes from the Loma Blanca facies.

CONCLUSIONS

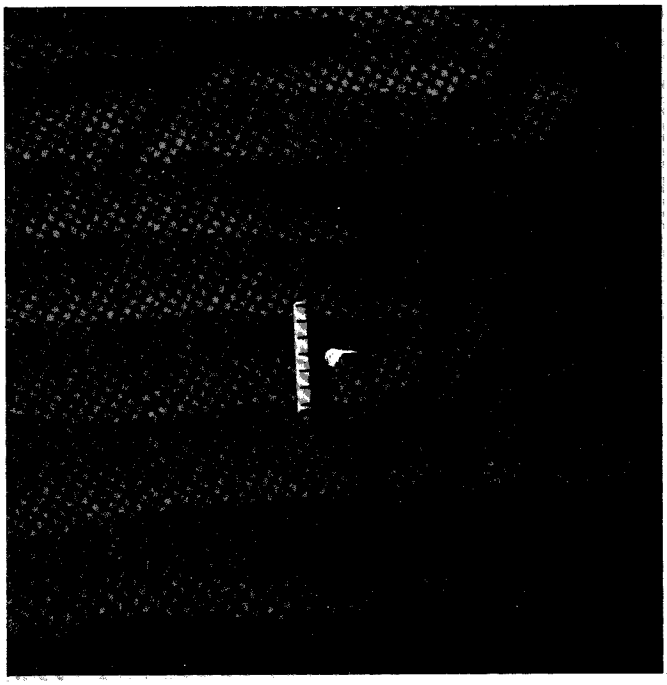
A hypothetical history of the sands in the dunes along the Rio Salado may begin in the Cenozoic igneous rock of the Datil volcanic field where the earliest rocks were basic volcanic flows. The later rocks were acidic flows, pyroclastics, or intrusives. The highly metamorphosed rocks were associated with the Ladron Mountain block. This ultimate provenance was exposed in a semiarid climate such that mechanical weathering was faster than chemical weathering. Wind and water transported the newly freed sediments to the playas of the Popotosa Formation. As the relief in the western source area increased, the fine sediments were incorporated with the coarse sediments to form conglomerates. The area of the Popotosa Formation was tilted, eroded, and became a provenance for the Santa Fe Group. The Loma Blanca facies continued to receive sediments from a provenance similar to that of the Popotosa, but transportation was almost all by river. Later, as the topographic relief became greater, the fine river sands were covered by coarser sands and gravels. Uplift continued so the Loma Blanca and the Popotosa were again exposed to erosion by wind and water which moved sediments to the Rio Salado. These



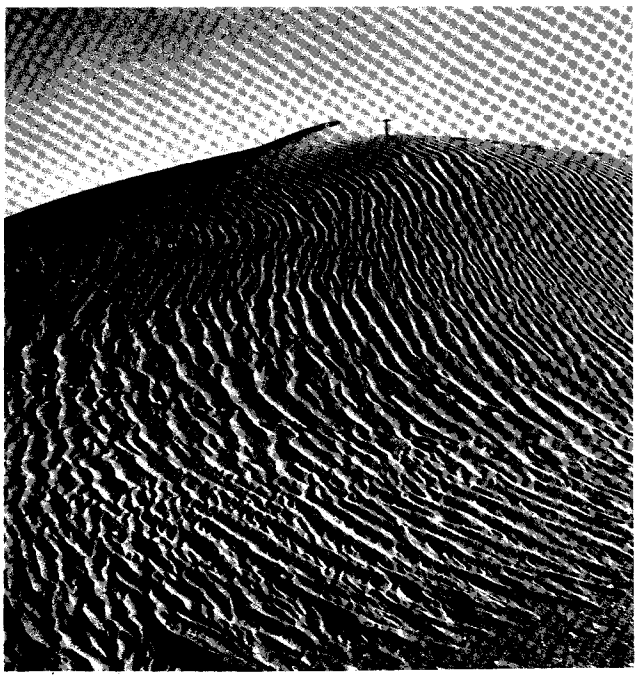
A.



B.



C.



D.

FIGURE 3

A. The distance between major ripple marks is about 5½ inches.

B. Note pattern of ripple marks on dune showing how wind shifts direction as it crosses dune.

C. Ripples and cross ripples on active sand dune. Scale division 1 inch.

D. Sand dune with lip at top of avalanche slope probably caused by a change in wind direction. Geologic pick near lip for scale.

second-cycle sediments mingled with sediments being brought from the Datil volcanic field where a provenance similar to that of the Popotosa and Loma Blanca is exposed. Wind transported the sediments from the Rio Salado to the dunes. Thus, most of the sands in the dunes are multicycle, although their angularity suggests that they are single-cycle sediments.

A few dunes migrate out of the Rio Salado. These dunes may be somewhat protected by the embankments to the north. It is not meant to imply that the sands do not cross the Cañada Mariana surface. They obviously do as indicated by the sand sheet covering this surface. Also, sandfalls occur along the west bank of the Rio Grande trough, and sand shadows are very common on the slope west of U.S. 85 where it enters the Rio Grande at the northern edge of the area. The sands from the Rio Salado dunes cross the Cañada Mariana surface but generally not in the form of dunes.

In 1962, sand dunes along the north side of the Rio Salado were shaped more by southern winds during the hot summer months than by the northern winds during the cooler winter months. The most westward dunes were not greatly affected by the 1962 wind shifts from northwest to southwest in March and from southwest to south-southeast in May and June. This suggests that local topography is the factor controlling the wind effectiveness. During recent years, winds from the southwest quadrant have had more influence on the dunes than winds from other quadrants.

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