Monte Desert of San Juan, Argentina, as Photographed by ASTP

Delia M. Warner[a] *and Farouk El-Baz*[a†]

ABSTRACT

Apollo-Soyuz photographs of the Monte Desert in southeastern San Juan, Argentina, were used for a reconnaissance survey of large-scale desert landforms. The Apollo-Soyuz color photographs were helpful in distinguishing lineaments and probable faults, drainage patterns, rock types, and soil-tonal variations. These photographs were especially useful in studying the distribution of sand deposits and large-scale dune morphology.

The photographs reveal that the physiographic setting of the study area is characterized by mountain-and-bolsón topography controlled mainly by faulting. Most of the lineaments detected on the photographs appear to correspond to faults, and some of them may provide evidence of recent fault movement in the area. Typical topographic features include barren, deeply dissected block mountains bordered by slopes of alluvial materials that descend to a flat-floored desert basin.

The most prominent features on the desert floor are two dune fields. The larger field lies south of the town of Vallecito and is approximately 1300 km^2; the smaller dune field is near the town of Marayes and is approximately 160 km^2.

In the southern part of the Vallecito dune field, draa-size complex ridges display steep western flanks and gently sloping eastern flanks. These ridges are diagonally crossed by smaller linear dunes. In the central part, draa-size crescentic dunes with elongated horns abound; these horns may be affected by a seasonal cross wind called the zonda. The complex array of transverse, longitudinal, and oblique elements displayed by the Vallecito dunes cannot easily be explained. These patterns may be controlled by changes in climate, underlying and surrounding topography, wind regime, amount of sediment available, and grain-size characteristics. It is recommended that fieldwork be conducted to establish the roles of these factors in the formation of the complex Vallecito dunes.

INTRODUCTION

Photographs taken from Earth orbit provide a very practical means of studying the vast desert environment. Because of their large areal coverage, these orbital photographs are especially helpful in mapping regional patterns of sand distribution, in studying large-scale dune morphology, and in determining the direction of sand movement (refs. 1 to 4). In addition, deserts are particularly suitable for orbital photography because the general lack of cloud cover over arid regions improves image quality and because the size, remoteness, and inaccessibility of many deserts make reconnaissance ground surveys difficult and costly. Such preliminary surveys, which would include the general descriptions of desert landforms and the selection of areas for detailed fieldwork, can easily be made with orbital photographs.

[a]National Air and Space Museum, Smithsonian Institution.

[†]Principal Investigator.

For these reasons, desert studies were an important part of the Earth Observations and Photography Experiment on the Apollo-Soyuz Test Project (ASTP), and excellent data were obtained of desert regions in many parts of the world (ref. 1). Of particular interest here are the ASTP data pertaining to part of the Monte Desert of Argentina. In this study, photographs and visual observations by the ASTP crewmembers are used to survey large-scale desert landforms of the Monte Desert. As part of the study, thematic maps of sand distribution are presented, and the morphology of large-scale dune forms is examined.

ASTP DATA

The ASTP photographs of Argentina include 11 photographs taken with a 70-mm Hasselblad reflex camera and 1 photograph taken with a 35-mm Nikon camera. The photographs were obtained shortly after sunrise on spacecraft revolution 73 (July 20, 1975) and on revolution 88 (July 21, 1975); the Sun-elevation angles were 20° and 15°, respectively. Both near-vertical and low-oblique Hasselblad photographs were taken, and the area covered by individual frames ranged between 2500 km^2 and 6400 km^2. In contrast, the Nikon photograph covered more than 30 000 km^2 (fig. 1).

For Argentina, the verbal data include the astronauts' comments on (1) the shape of a dune field in the Monte Desert, (2) the dune patterns within the same field, and (3) the relationship of these dunes to adjacent mountains. A transcript of the ASTP crewmembers' visual observations is in reference 2.

STUDY AREA

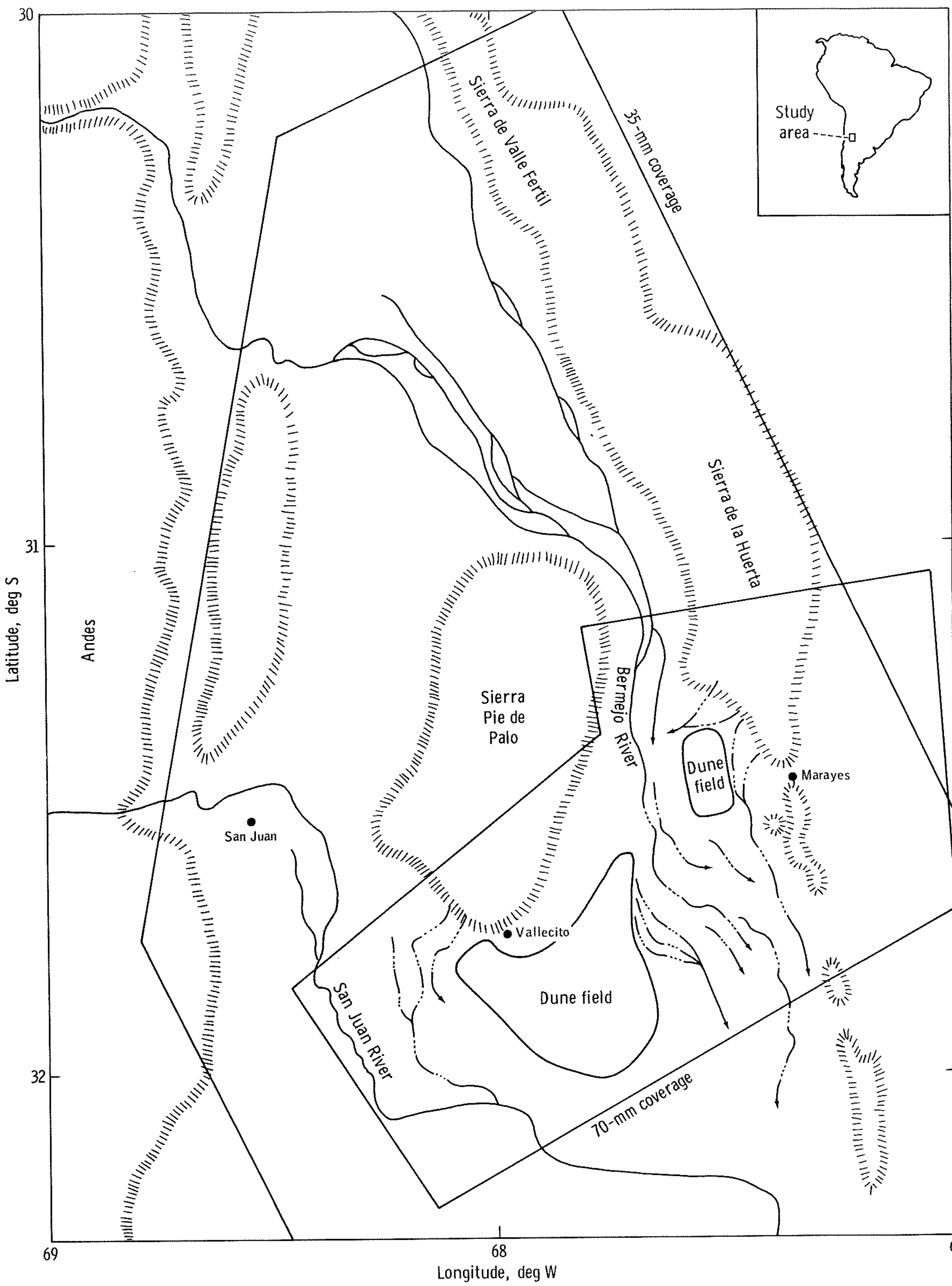
The ASTP photographs of Argentina provide an excellent regional view of desert landforms in part of the Monte Desert, a rainshadow desert lying along the eastern base of the Andes between latitudes 28° and 35° south (refs. 5 and 6). In this region, the high Andean Cordillera acts as an orographic barrier to moisture-laden easterly moving Pacific air; this brings heavy precipitation to the windward Chilean slopes, but the winds that descend the eastern leeward slopes are dry. The Monte Desert environment is characterized by flat-bottomed depressions that are often occupied by salt pans and that are usually bounded by high mountains (ref. 6).

The ASTP Hasselblad photographs only cover a small part of the Monte Desert in the southeastern corner of San Juan Province. The center of the study area is located at latitude 31°45′ south and longitude 67°45′ west (fig. 1).

Southeastern San Juan Province is one of the most arid parts of Argentina. According to meteorological records for its capital, San Juan City (31°36′ S, 68°33′ W), the mean annual precipitation averaged over a period of 20 years is only 84 mm (3.3 in.).[1] Temperatures vary annually between a mean maximum of 298.7 K (25.6° C) and a mean minimum of 283.2 K (10° C). Figure 2 shows the monthly values for mean maximum temperature, mean minimum temperature, and mean precipitation. According to these data, most of the rainfall in San Juan City occurs in the hot summer months (December through February) when evaporation is most intense. As a result, the amount of water available for runoff is small (ref. 7, p. 205). In fact, the only permanent streams in the study area (the San Juan and Bermejo Rivers) originate high in the Andes. Further evidence for the aridity of southeastern San Juan is provided by Burgos and Vidal (ref. 8) who calculate a mean annual potential evapotranspiration of approximately 900 mm and a mean annual water deficiency between 700 and 800 mm.

[1]Meteorological data for the city of San Juan were obtained from the National Climatic Center in Asheville, North Carolina.

FIGURE 1.—Sketch map of southeastern San Juan, Argentina, showing the boundaries of the ASTP photographic coverage with the 35-mm Nikon camera and the 70-mm Hasselblad camera. →


30
31
32
69
68
67
Latitude, deg S
Longitude, deg W
Andes
Sierra de Valle Fertil
35-mm coverage
Study area
Sierra de la Huerta
Sierra Pie de Palo
Bermejo River
Dune field
Marayes
San Juan
Vallecito
Dune field
San Juan River
70-mm coverage

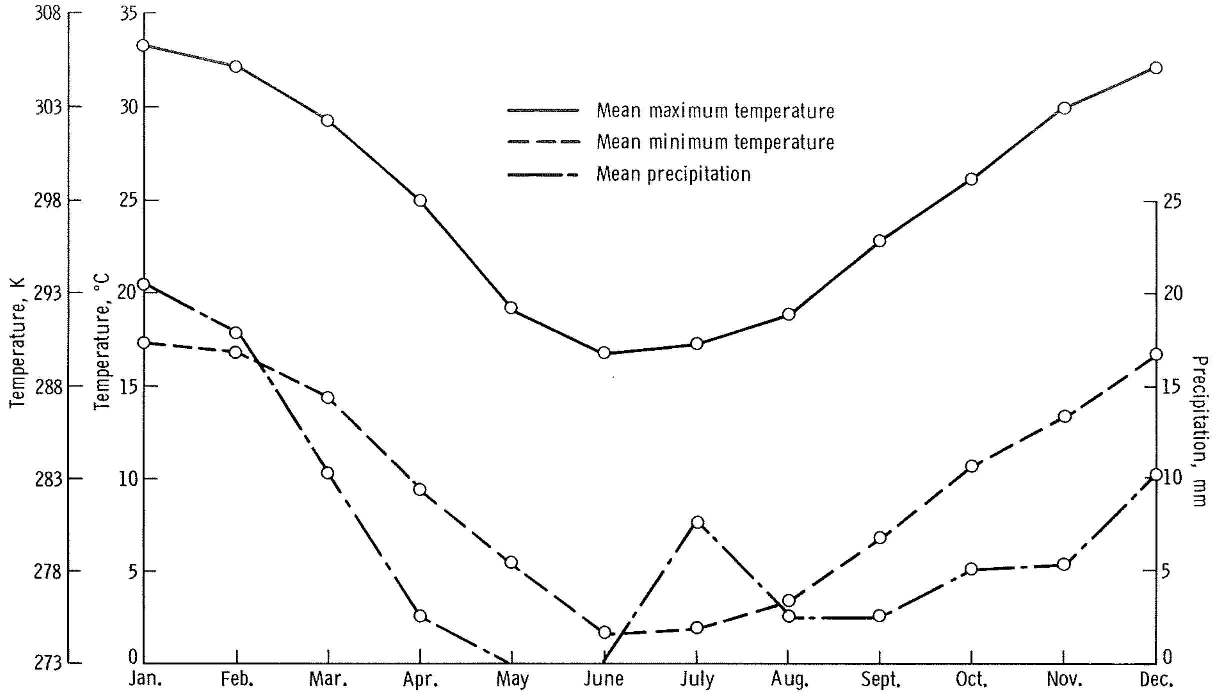


FIGURE 2.—Graph showing the monthly values for mean maximum temperature, mean minimum temperature, and mean precipitation for San Juan City. Meteorological data were obtained from the National Climatic Center in Asheville, North Carolina.

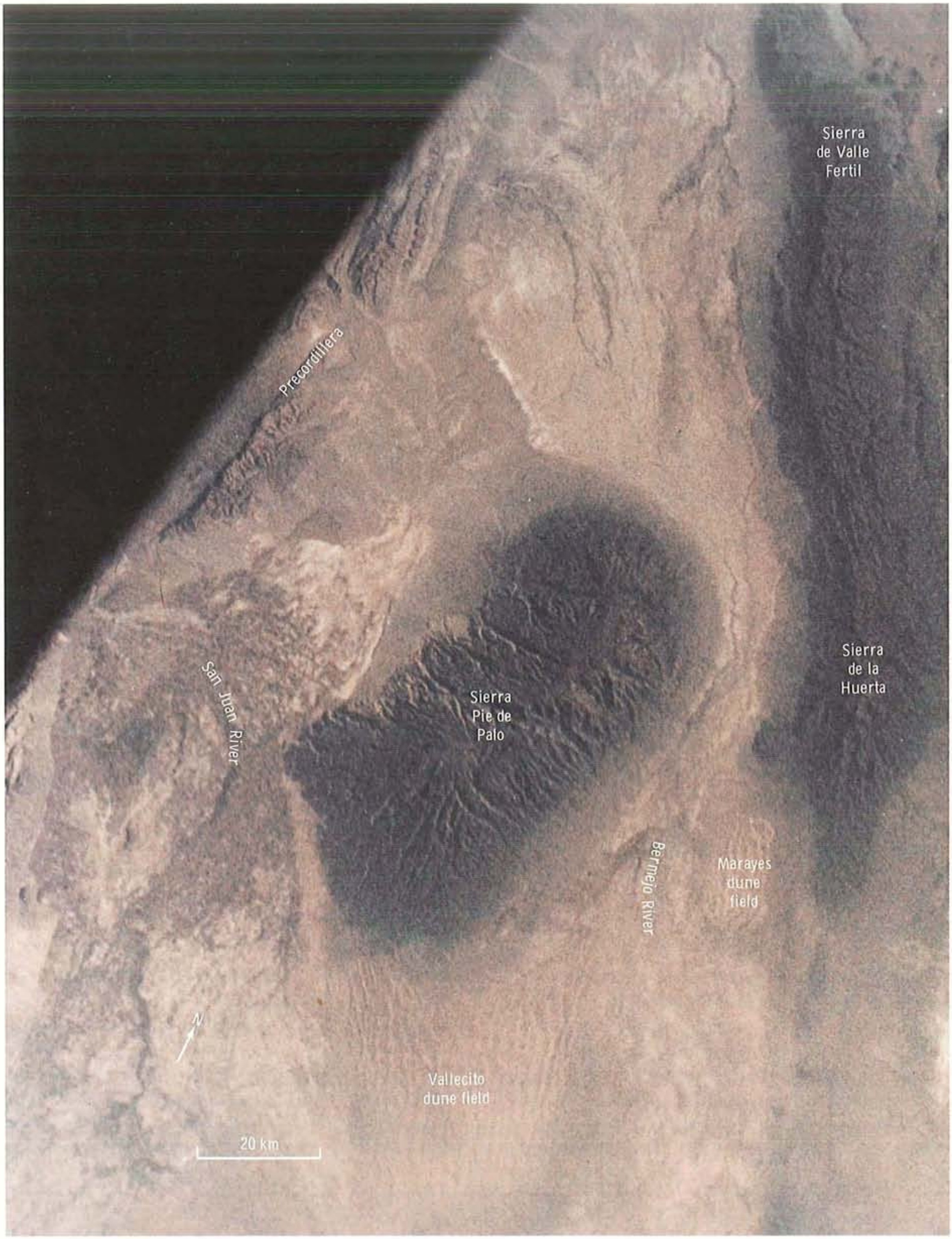
Meteorological data for San Juan City indicate that local surface winds are predominantly from the south. However, another noteworthy surface wind is the zonda, a warm, dry katabatic wind that descends the lee side of the Andes (ref. 9, p. 1156). Data on surface-wind velocity and direction reveal that in San Juan the zonda is a strong seasonal wind from the northwestern quarter occurring mainly from June through August. For these 3 months, the maximum winds observed over 6 years were from the west (20 m/sec in June), the northwest (20 m/sec in July), and the northwest (25 m/sec in August).

PHYSIOGRAPHIC SETTING

The physiographic setting of the study area is characterized by fingerlike, generally north-south-trending mountain ranges and deep alluvium-filled fault basins (ref. 7, p. 201). Within these basins, drainage is essentially endorheic, and playas often occupy the lowermost parts of the basin floors. This is known as mountain-and-bolsón topography and is similar to the basin-and-range physiographic province in the western United States. In southeastern San Juan, elevations range from 500 m on the desert floor to more than 2500 m in the mountains.

The ASTP photographs reveal the typical topographic features that distinguish the Argentinean mountain-and-bolsón landscape. Figure 3 is an ASTP Nikon photograph covering most of eastern San Juan. Although the quality of this photograph is poor, the major landforms are easily recognized. These landforms include barren, deeply dissected mountains bordered by slopes of alluvial materials that descend to a flat desert basin known as Travesía Bolsón. It is in-

FIGURE 3.—ASTP Nikon photograph showing some of the typical topographic features of southeastern San Juan, Argentina. These features include barren, deeply dissected block mountains encircled by slopes of alluvial materials. Slopes descend to a flat-floored desert basin on which the most conspicuous features are two dune fields (AST-11-679). →


Sierra de Valle Fertil
Precordillera
San Juan River
Sierra Pie de Palo
Sierra de la Huerta
Bermejo River
Marayes dune field
N
Vallecito dune field
20 km

teresting to note that the only agricultural patterns distinguishable in this photograph are situated where the San Juan River comes down from the Andes and debouches onto the flat surface of Travesía Bolsón.

On the Nikon photograph (fig. 3), two different rock units can be distinguished on the basis of texture, color, and form. To the far west, rocks of the Precordillera comprise the first group and are characterized by their lighter tone and by their appearance as elongate asymmetric ridges of folded rocks. Rocks of the second group are darker in tone and have a massive appearance. These include the north-northeast trending Sierra Pie de Palo and the north-northwest trending Sierra de la Huerta, which rise more than 2500 m above the surrounding desert plain.

Sierra Pie de Palo and Sierra de la Huerta are structurally related to the Pampean Ranges, which are basically block mountains bounded by north-south-trending faults (refs. 7 and 10). They are composed of late Precambrian to early Paleozoic metamorphics and migmatites frequently intruded by plutonic rocks (ref. 10). The Pampean Ranges owe their present-day morphotectonic structure to block faulting and tilting in the Tertiary and Quaternary (refs. 10 and 11). The fact that tectonic activity in the study area persists to this day is attested by the occurrence of strong earthquakes; the city of San Juan was virtually destroyed by an earthquake on January 15, 1944. In addition, the tectonic nature of the landscape can be seen in the regional outlines of Sierra Pie de Palo and Sierra de la Huerta (fig. 3); these mountains have the appearance of tilted blocks bounded on their longer sides by roughly parallel faults.

Parts of Sierra Pie de Palo and Sierra de la Huerta were also photographed with the Hasselblad reflex camera. Although these photographs do not cover as large a geographic area as the Nikon photograph (fig. 1), they are superior in quality and resolution. For example, in figure 4 the topographic manifestations of faults and fractures are well displayed, and photolineaments can easily be mapped. This can, in part, be attributed to the relatively higher resolution of the Hasselblad photograph and to the low Sun-angle illumination, which accentuates relief.

When the photolineaments observed on the ASTP photographs were compared with faults on a published geologic map of the area (ref. 12), it was evident that a number of new features could be recognized (fig. 5). For example, in figure 4 three parallel lineaments that are visible along part of the eastern flank of Sierra Pie de Palo may be indicative of recent fault movement in the area. The most prominent lineament is marked by a sharp, linear contact between the mountain front and the alluvial slopes and by triangular facets that truncate mountain spurs ("A" in figs. 4 and 5). The other two lineaments, which occur toward the base of the alluvial slopes, run parallel to the mountain front. The topographically higher of these two lineaments ("B" in figs. 4 and 5) is on the lower alluvial slope and is distinguished by the sharp color difference between the gray alluvial sediments above the lineament and the lighter toned material below it. At the base of the slope, the lowermost lineament ("C" in figs. 4 and 5) appears to be a low scarp when viewed stereoscopically. This could be explained by a fault parallel to the mountain front, which was responsible for the exposure of previously buried sediments.

On and around Sierra de la Huerta, a number of lineaments that are probably the surface expressions of faults and fractures were also mapped from ASTP photographs. In figure 4, the most prominent feature is an almost north-south-trending lineament ("D" in figs. 4 and 5) cutting across the alluvial slopes bordering the western flank of Sierra de la Huerta. On the geologic map of San Juan (ref. 12), this feature is drawn as a fault (fig. 5). Between this fault and the mountain to the east, the ASTP photographs revealed deeply incised drainage channels ("E" in fig. 4); this entrenchment could be caused by tectonic uplift of the massif.

Another interesting feature depicted on the ASTP photographs is the dome-shaped rock body projecting from the main mass of Sierra de la Huerta ("F" in fig. 4). In plan view, this rock body is elliptical, and on the photograph, it is similar in color to Sierra de la Huerta. Its eastern and western sides are parallel to major lineament trends in the area. Although its dome shape is suggestive of an intrusive origin, it may just be an inselberg whose outline is structurally controlled.

The mountains in the study area are entirely surrounded by slopes of alluvial materials. When infrequent rainstorms occur over the uplands, sediment-laden streams flow down the normally dry steep-sided mountain gorges and deposit most of their load when they encounter the sharp break in slope at the mountain front. The surfaces of the alluvial slopes are characterized by intricately branching systems of stream channels. The paths of these channels are largely controlled by slope, although in one area a rectangular drainage pattern indicates structural control ("G" in fig. 4). In addition, as discussed later, sand deposits have affected drainage patterns.

SAND DEPOSITS

Viewed from Earth orbit, eolian sand deposits have a characteristic appearance and distribution, which can be controlled by a number of factors such as the wind regime, rainfall, vegetation, sand supply, and topography (refs. 3, 4, and 13). On the ASTP photographs of San Juan Province, regional patterns of sand distribution and dune morphology were easily studied. For mapping sand deposits, the most important recognition elements were texture and color. Interpretations of dune morphology, on the other hand, relied on form and pattern and were facilitated by the low Sun-angle illumination (15° to 20°).

In southeastern San Juan, the alluvial slopes surrounding the mountains descend to the flat-floored Travesía Bolsón. This plain is slightly tilted to the east, and its surface is covered by sand dunes and fluviolacustrine deposits (ref. 14, p. 2689). On the floor of the bolsón, the most conspicuous features are two dune fields (fig. 6). The larger field lies south of the town of Vallecito (31°45′ S, 67°59′ W) and will be referred to as the "Vallecito" dune field. The smaller field will be designated the "Marayes" dune field after Marayes (31°29′ S, 67°22′ W), a town 12 km east of the dunes.

Vallecito Dune Field

In figure 6, the most prominent feature on the floor of Travesía Bolsón is the heart-shaped Vallecito dune field, which covers approximately 1300 km^2. On its northern margin, the dune field extends close to the base of Sierra Pie de Palo, which rises more than 2000 m above the surrounding plain. This northern margin is sharp and well-defined, and the boundary between the sand and the alluvial slopes bordering the mountain is easily distinguished. Stream channels descending the slopes are, for the most part, deflected around the dune field. However, some channels enter the field and, during occasional storms, probably wash into the north-central part of the field and flood interdune areas. It is likely that occasional runoff from the uplands has a part in controlling the northern margin of the Vallecito field.

To the west and east, the Vallecito dune field is surrounded by a flat desert plain with intermittent streams and sand deposits. On this plain, interesting patterns of sand distribution are revealed in the relationships between sand deposits, stream channels, cultivated lands, and topography. The nature and distribution of materials on the surface of Travesía Bolsón were interpreted from the ASTP Hasselblad photographs.

On the surface of Travesía Bolsón, immediately west of the Vallecito dunes, three kinds of surface deposits are recognized. One of these deposits is a highly reflective white material that may be a saline deposit. On the basis of color and texture, the other two kinds of deposits are interpreted as sand (figs. 7(a) and 7(b)). The first type of sand deposit is characterized by dark tan-colored sands and by dune forms. These windblown deposits are of wide extent and appear to pose a threat to cultivated lands. Because cultivation is limited by climate in this part of San Juan, irrigation is impor-

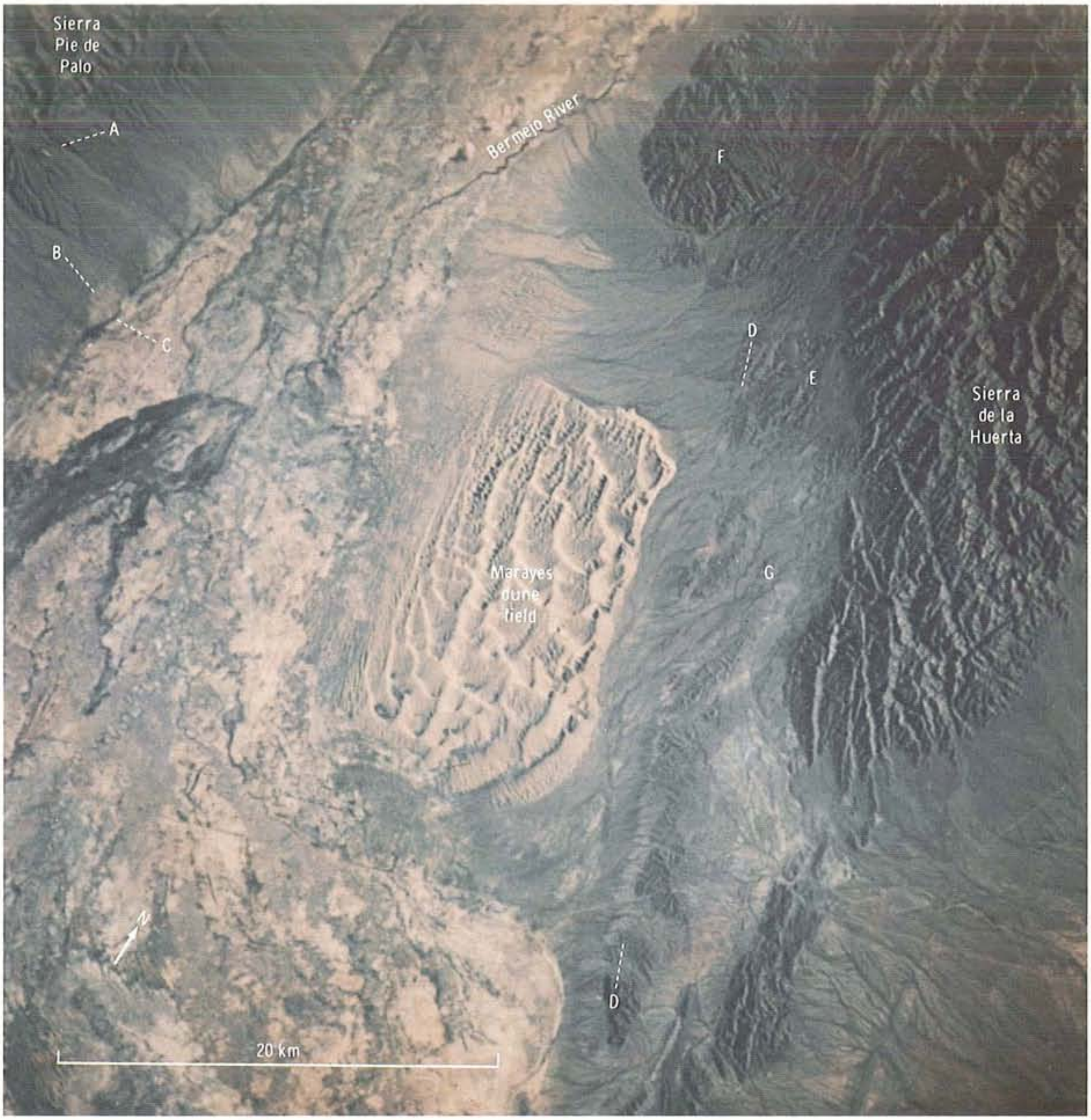


FIGURE 4.—ASTP Hasselblad photograph showing parts of Sierra Pie de Palo and Sierra de la Huerta. In this photograph, the topographic manifestations of faults and fractures are well displayed as photolineaments. Points "A" to "G" designate specific locations referred to in the text (AST-23-1913).

tant, and farmlands exist only along the western side of the basin where streams come down from the Andes. It is easy to imagine how the agricultural economy of this region could be adversely affected by strong southerly winds acting on the sandy soils and dunes (ref. 7).

The second type of sand deposit west of Vallecito dune field is of limited extent (fig. 7(b)). In plan view, these deposits are fan-shaped with an apex lying close to Sierra Pie de Palo and branches extending to the south and south-southeast. No dune forms are observable in these

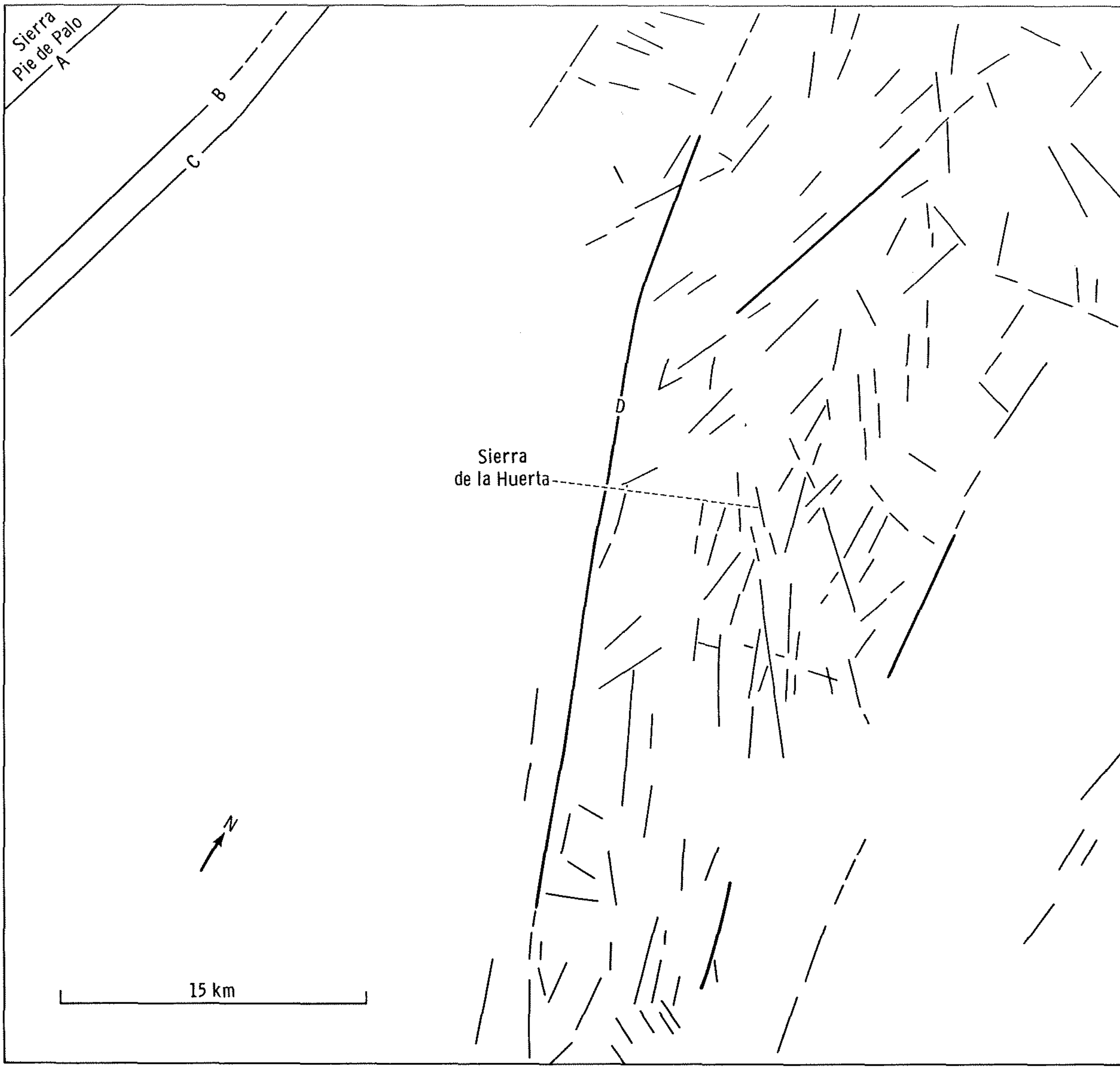


FIGURE 5.—Sketch showing photolineaments mapped from a 4× enlargement of AST-23-1913. Bold lines indicate lineaments drawn as faults on a published geologic map of San Juan (ref. 12). Points "A" to "D" designate lineaments referred to in the text.

deposits, and the sand is lighter in color than sands of the first type. These light-toned sand deposits appear to originate close to the southwestern flank of Sierra Pie de Palo.

Along the base of the mountain, a narrow band of the first type of sand occurs, and in places, it is breached by stream channels. It seems likely that, after an occasional heavy rainfall in the upland, runoff would rapidly move downslope along stream channels and wash away the windblown sand at the foot of the slope. The short-lived streams, after spreading out laterally across the plain, would soon deposit their load as they disappear. Therefore, the light-colored sand deposits may be the result of fluvial rather than eolian deposition.

East of the Vallecito dune field, the ASTP photographs reveal small linear dunes migrating

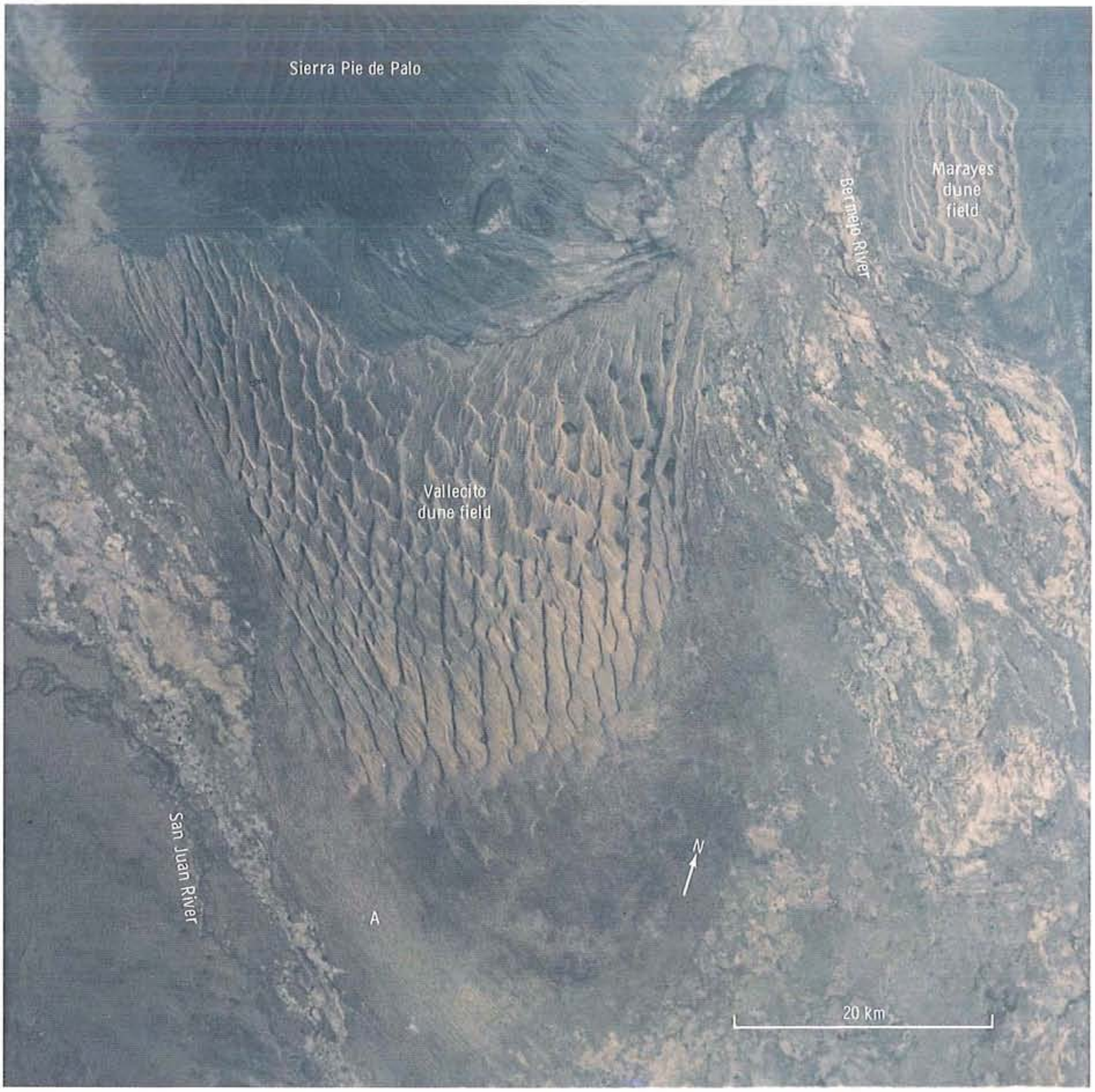


FIGURE 6.—ASTP Hasselblad photograph showing the complex sand dune patterns characterizing the Vallecito and Marayes dune fields (AST-27-2340). The letter "A" designates the location of narrow linear dunes referred to in the text.

toward and merging with the larger Vallecito field (figs. 6 and 8). The trends of these dunes veer in a clockwise manner from NW-SE to NNE-SSW. This change in trend is probably the result of a change in the prevailing wind pattern, which would be deflected by the protruding Sierra Pie de Palo. These linear dunes are generally less than 5 km long; their dune/interdune ratio is approximately 1:1; and some Y-junctions that open to the southeast are present. These dunes are probably longitudinal forms parallel to the prevailing wind direction. Outside the southwestern corner of the Vallecito field, similar linear dune forms occur ("A" in fig. 6), but the northwestward migra-

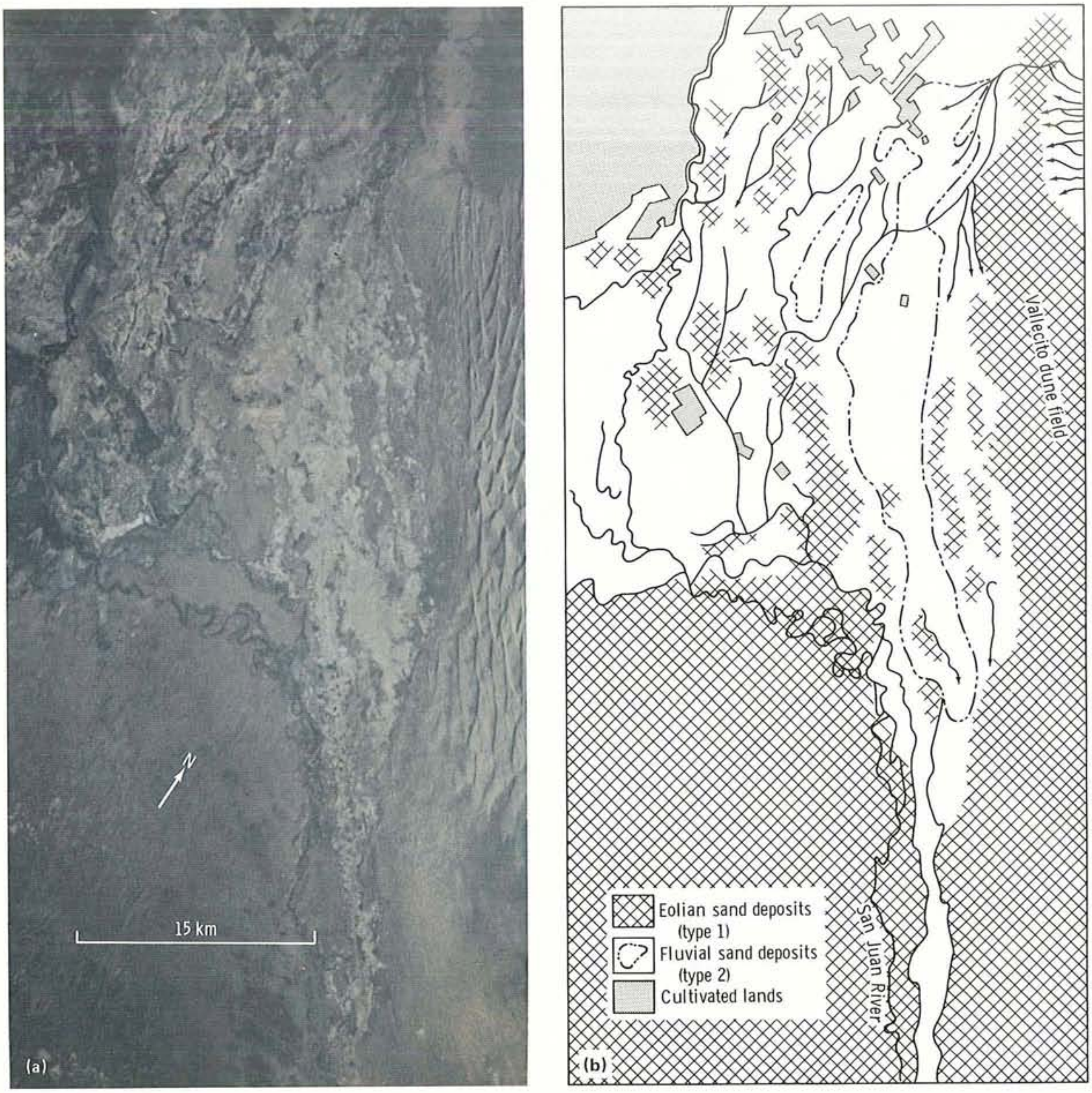


FIGURE 7.—Sand distribution west of the Vallecito dune field. (a) Part of Hasselblad photograph AST-23-1910 showing area covered by figure 7(b). (b) Sketch illustrating the relationship of sand deposits with stream channels and cultivated land. Two types of deposits are shown. The first type is probably eolian, but the second type of deposit may be fluvial.

tion of these dunes appears to be limited by a stream channel and a steep, narrow north-south-trending sand ridge.

In addition to the linear dune forms east of the Vallecito field, somewhat amorphous dark-colored sand deposits could also be discerned on the ASTP photographs. Figure 8 shows that the distribution of these deposits is intimately related to the subparallel drainage pattern. This type of drainage pattern can be attributed to either a pronounced regional slope or to parallel topographic features, which in this case would be the sand deposits (ref. 15). It is difficult to determine whether the sand distribution is governed by the


Marayes
dune
field
N
Vallecito dune field
10 km

FIGURE 8.—Sketch showing sand distribution east of the Vallecito dune field. Two types of eolian sand deposits are indicated: (1) narrow, linear dunes (dotted lines) and (2) amorphous dark-colored sands (circle and dot pattern). (Drawn from an enlargement of AST-27-2340, fig. 6.)
⟵

drainage pattern or whether the opposite case is true and the drainage pattern is controlled by the distribution of sand deposits.

The ASTP photographs reveal that the Vallecito dune field displays a fishscale pattern of numerous, irregular crescentic dunes and linear sand ridges. During postmission debriefings, the ASTP crewmembers described this unusual dune field as follows (ref. 2, p. 196):

> Okay, it's right over the edge of the Andes Mountains. Where the mountains end, there is a little area in between and those (dunes) start. And you could really see how they were crescents; it looked like maybe the head of a crescent would wash out, and it would tend to be a linear one with lineations on a side . . . .

Study of the ASTP photographs show two different size eolian bedforms within the Vallecito field (fig. 6). The major forms have wavelengths greater than 0.5 km and will be referred to as draa (ref. 16). The minor forms, which are migrating over the draa, are dunes. The existence of these draa-size bedforms implies a plentiful supply of sand, most of which is probably derived from the fluvio-lacustrine deposits of Travesía Bolsón.

In the southern part of the field, draa-size complex ridges display steep western flanks and gently sloping eastern flanks. The crests of these draa ridges are not absolutely straight, and they exhibit curved crescentic elements. These ridges appear to be complex combinations of linear and crescentic elements. The distance from crest to crest varies between 1 and 2.3 km, and small linear dunes are alined diagonally across the eastern slopes of the draa.

The central part of the Vallecito dune field is characterized by imbricated draa-size crescentic forms with elongated horns. In the western half of the field, the right-hand horn is the one that is usually elongated. This could be attributed to the action of an important crosswind, perhaps the seasonal zonda. Superposed on these draa forms is a finer pattern of parallel linear dunes whose trends are consistent with the trends of the elongated horns.

In the northwestern part of the field, sharp-crested narrow linear ridges 5 to 11 km long are characteristic. In the northeastern part, sand cover is incomplete, and the substrate is exposed in sand-free hollows. A decline in dune size is observed toward the northeastern and northwestern edges of the field. This is most likely a function of sand supply.

On orbital photographs, the Vallecito dune field presents a complex array of transverse, longitudinal, and oblique trends. These complex patterns can be attributed to a number of factors such as changes in climate, the underlying and surrounding topography, the wind regime, the amount of sediment available, and grain-size characteristics (ref. 13). The roles of each of these factors can only be determined through extensive and detailed fieldwork, although some inferences can be made about the wind regime from a study of ASTP photographs. This is done by analyzing dune trends and slipface orientations.

Probably the most important factor in determining dune form is the direction and strength of the wind in relation to the sand supply (ref. 17, p. 13; ref. 18). To provide further data on the wind regime in the study area, N-Summaries of surface-wind velocity and direction were obtained from the National Climatic Center in Asheville, North Carolina. These N-Summaries contain data on the percentage occurrence by velocity categories (e.g., 0.51 to 1.54 m/sec, 2.06 to 3.09 m/sec (1 to 3 knots, 4 to 6 knots) etc.) and by direction of surface winds at San Juan City. These data are plotted on circular histograms (called sand roses) according to the method described by McKee et al. (ref. 4) (fig. 9). To obtain a better idea of the distribution of winds capable of moving sand, only winds greater than 5.1 m/sec (10 knots) are used in the calculations. The sand roses in figure 9 show, by month, the potential movement of sand from 16 compass directions; the arrows point downdrift and indicate the hypothetical resultant direction of potential sand movement.

According to the wind data, the prevailing sand-moving winds at San Juan City are from the south, although strong seasonal winds (zonda) from the northwestern quarter occur from June through August. For San Juan City, the annual resultant direction of potential sand movement is toward approximately N5°E. At the Vallecito dune field, 60 km southeast of San Juan City, the dune patterns seem to indicate that the prevailing winds are from the south and southeast. In addition, the dominance of the right-oblique element in the western part of the field suggests the presence of an important crosswind, probably the seasonal zonda. This interpretation of wind regime is based on an analysis of (1) the trends of linear dune forms east of the Vallecito field and (2) the orientations of slipfaces on the crescentic draa forms within the dune field (fig. 10). It was assumed that the crescentic slipfaces were transverse to the prevailing winds and that the linear dunes were longitudinal and parallel to the wind direction.

The occurrence of a topographic obstruction (Sierra Pie de Palo) in the path of the prevailing sand-moving southerly and southeasterly winds has the effect of channeling the wind and diverting sand movement around the flanks of the mountain. However, most of the sand leaving the dune field and blowing around the mountain is probably carried back down to the south by intermittent streams, which soon dry up as they wander across the plain. For example, sand blown around the northeastern side of Sierra Pie de Palo may be channeled to the north along the valley

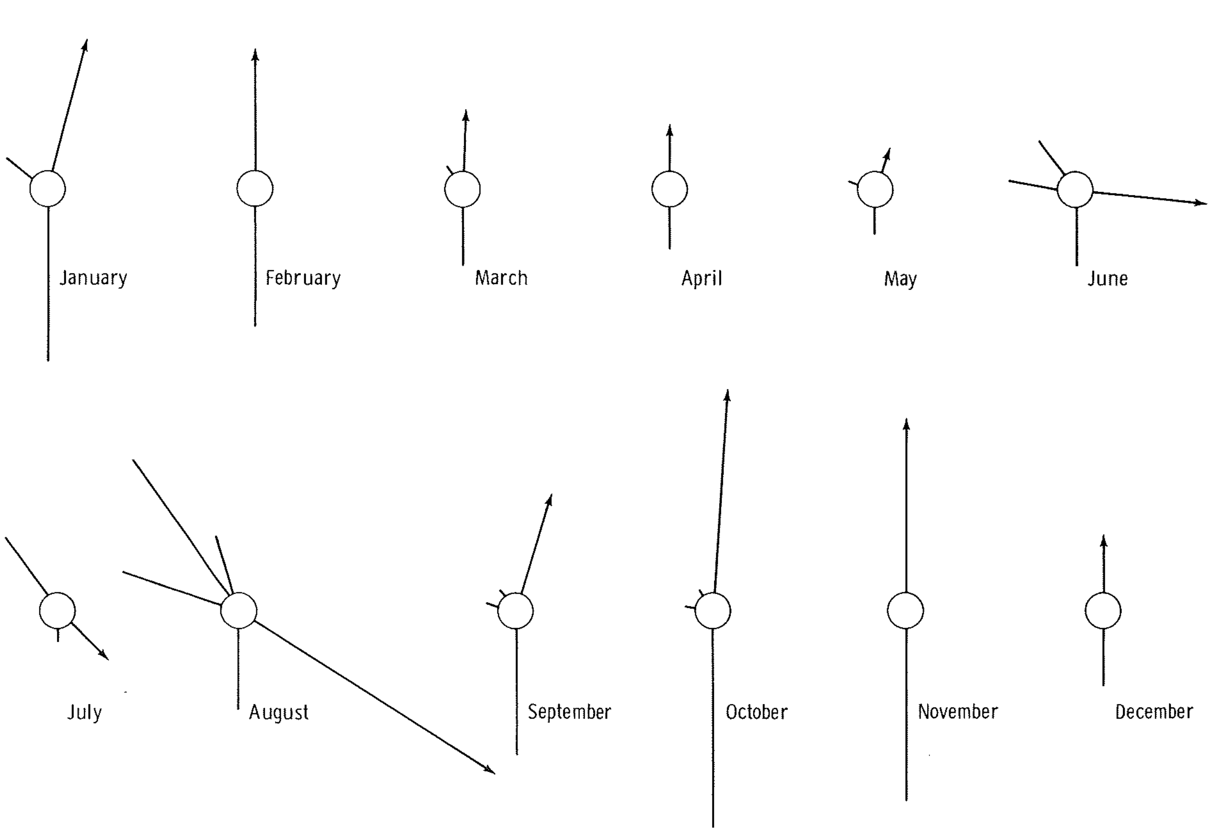


FIGURE 9.—Sand roses for San Juan City showing by month the potential movement of sand from 16 compass directions. Arrows point downdrift and indicate the resultant direction of potential sand movement. These diagrams show that the prevailing sand-moving winds at San Juan are from the south, although strong seasonal winds from the northwestern quarter occur from June through August.

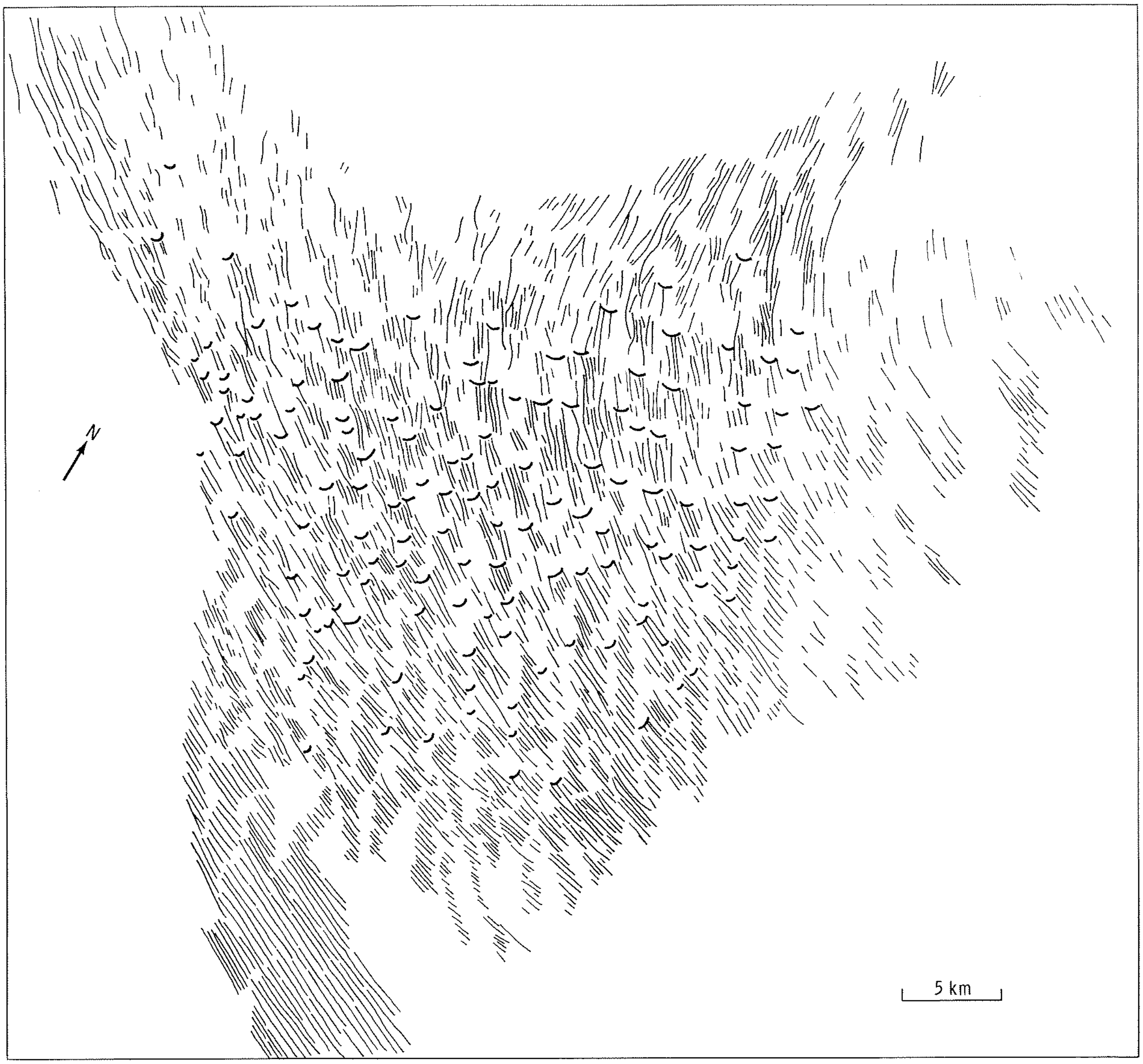


FIGURE 10.—Sketch showing draa-size crescentic elements (bold lines) and dune-size linear elements in and around the Vallecito dune field.

between Sierra Pie de Palo and Sierra de la Huerta. Some of this sand may blow into the Marayes dune field, approximately 25 km northeast of the Vallecito dunes. However, the migration of most of the sand is probably controlled by the Bermejo River, which flows down the valley. Sand may be carried to the south by any of the numerous channels into which the river subdivides. These channels spread out across the plain to the east and southeast of the Vallecito field and soon dry up and deposit their load. The sand may then, once again, be picked up by the wind and blown to the north.

Marayes Dune Field

The Marayes dune field (fig. 11(a)) lies at the foot of Sierra de la Huerta and occupies an area of approximately 160 km^2. The eastern margin of the

FIGURE 11.—The Marayes dune field. (a) Enlargement of part of AST-23-1913. (b) Sketch showing draa-size crescentic elements (bold lines) and dune-size linear elements. Circles indicate the locations of draa-size forms resembling star dunes.

field roughly parallels the 1000-m contour, and the field's rectangular shape is strongly influenced by bordering topographic highs. On the northern and eastern borders of the field, there is a sharp boundary between the sand and the alluvial slopes, and the dunes seem to have altered the courses of streams coming down from the mountain (fig. 11(b)). The western margin of the field is less well defined.

On ASTP photographs, the Marayes dunes are depicted as a complex network of crescentic and linear elements (fig. 11(b)). The most prominent features are the draa-size crescentic forms over which dune-size forms are superposed. The orientations of these crescentic forms, which are transverse to the effective winds, seem to indicate a predominantly bimodal regime of winds from the southeast and south. In the eastern part of the field, dune forms that resemble star dunes may indicate a more complex wind regime. These forms are found at the nodes in the draa patterns where three different trends meet (fig. 11(b)).

CONCLUSIONS

Color orbital photographs are useful in studies of arid environments. This is particularly true in distinguishing lineaments and probable faults, drainage patterns, rock types, and soil-tonal variations. These photographs are especially useful in studying the distribution of sand deposits and

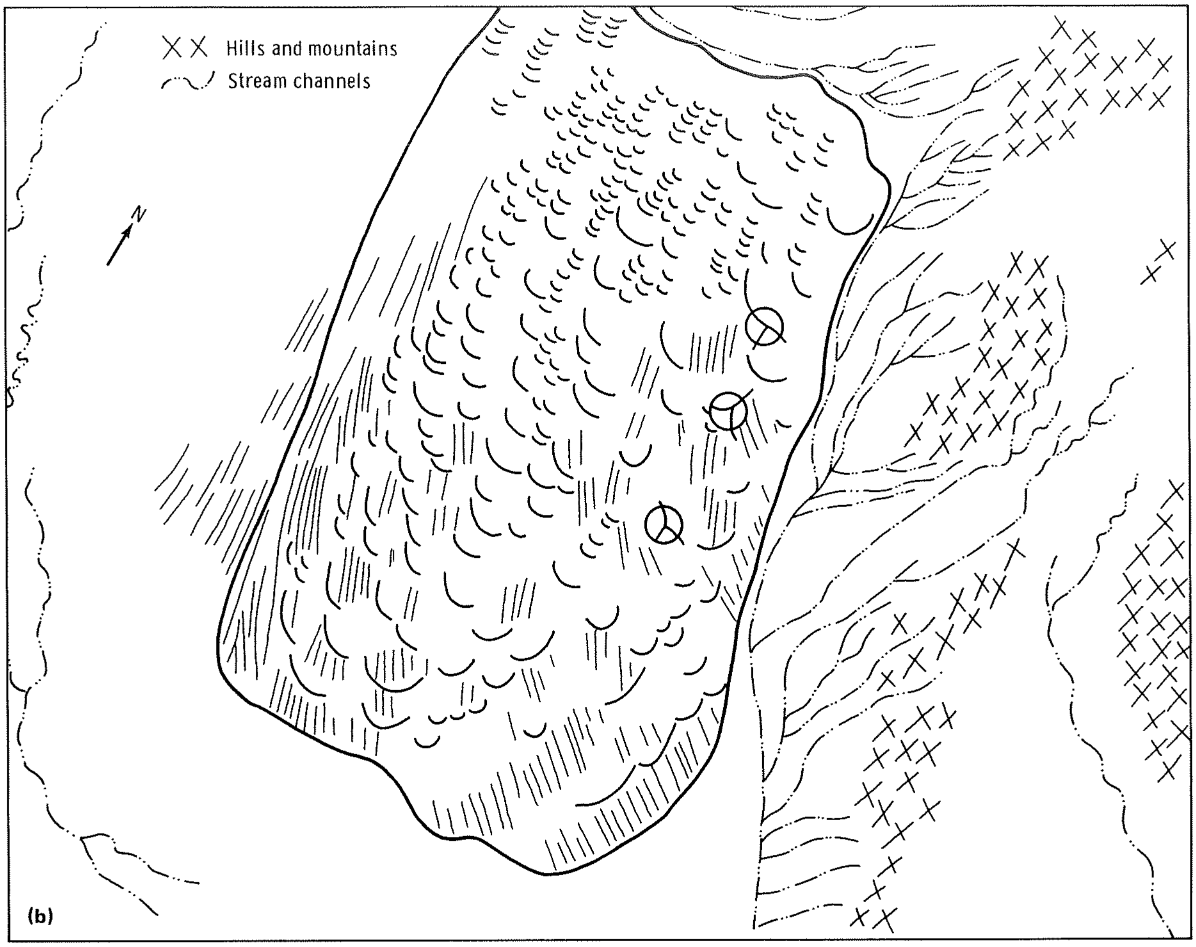


FIGURE 11.—Concluded.

large-scale dune morphology. Low Sun-elevation angles enhance the utility of the ASTP photographs, and it is recommended that additional color, low Sun-elevation photographs be taken of desert regions from Earth orbit.

The study of the two unusual dune fields in southeastern San Juan, Argentina, resulted in the recognition of complex dune patterns that are controlled by numerous factors. The ASTP photographs and preliminary results have been supplied by the authors to the Geological Survey Department of Argentina. It is recommended that field investigations be conducted to establish the relationships between the sand dune patterns and the underlying desert surface, the surrounding mountain highs, the amount of available sand, the grain size, and the local wind regime. Deciphering complex dune patterns such as those displayed by the Vallecito dunes will help in the study of other complex desert dunes. Field investigations would perhaps be best made in cooperation with Argentinean researchers whose understanding of the local geography and geology would be essential.

REFERENCES

1. El-Baz, Farouk; and Mitchell, D. A.: Earth Observations and Photography Experiment MA-136. Sec. 10 of Apollo-Soyuz Test Project Preliminary Science Report. NASA TM X-58173, 1976.

2. El-Baz, Farouk: Astronaut Observations From the Apollo-Soyuz Mission. Vol. I of Smithsonian Studies in Air and Space, Smithsonian Institution Press (Washington, D. C.), 1977.

3. McKee, Edwin D.; and Breed, Carol S.: An Investigation of Major Sand Seas in Desert Areas Throughout the World. Paper G6 in Third Earth Resources Technology Satellite-1 Symposium, Stanley C. Freden, Enrico P. Mercanti, and Margaret A. Becker, eds., vol. I, sec. A, NASA SP-351, 1974, pp. 665-679.

4. McKee, Edwin D.; Breed, Carol S.; and Fryberger, Steven G.: Desert Sand Seas. Sec. 2 of Skylab Explores the Earth, NASA SP-380, 1977, pp. 5-47.

5. Cornejo, Arturo: Resources of Arid South America. Arid Lands in Transition, Harold E. Dregne, ed., Publication No. 90, American Association for the Advancement of Science (Washington, D. C.), 1970, pp. 345-380.

6. McGinnies, William G.; Goldman, Bram J.; and Paylore, Patricia, eds.: Deserts of the World. University of Arizona Press, 1968.

7. Shanahan, Edward William: The Pampean Hinterland and the Pre-Cordilleras. South America. Methuen (London), 1959, Chapter XVI, pp. 201-216.

8. Burgos, J. J.; and Vidal, A. L.: The Climates of the Argentine Republic According to the New Thornthwaite Classification. Ann. Assoc. American Geog., Henry Madison Kendall, ed., vol. 41, 1951, pp. 237-263.

9. Fairbridge, Rhodes W.: The Encyclopedia of Atmospheric Sciences and Astrogeology. Encyclopedia of Earth Sciences Series, vol. II, Reinhold Publishing Corp., 1967.

10. Bonorino, F. González: Argentina. The Encyclopedia of World Regional Geology, Part 1, Rhodes W. Fairbridge, ed., Encyclopedia of Earth Sciences Series, vol. VIII, Dowden, Hutchinson & Ross, Inc. (Stroudsburg, Pa.), 1975, pp. 15-21.

11. Bailey, H. P.; Simpson, B. B.; and Vervoorst, F.: The Physical Environment: The Independent Variable. Chapter 2 in Convergent Evolution in Warm Deserts, Gordon H. Orians and Otto T. Solbrig, eds., Dowden, Hutchinson & Ross, Inc. (Stroudsburg, Pa.), 1977.

12. Argentina, Direccion General De Investigacion Y Desarrollo: Estudio de cuencas aluvionales en las provincias de San Juan y Mendoza. 1973, 4 volumes.

13. Cooke, Ronald U.; and Warren, Andrew: Geomorphology in Deserts. University of California Press, 1973.

14. Dessanti, Raúl: Geologic Outline of Natural Regions of Mendoza, Argentina. Bull. American Assoc. Petr. Geol., vol. 42, no. 11, 1958, pp. 2670-2691.

15. Feldman, Sandra; Harris, Stuart; and Fairbridge, Rhodes W.: Drainage Patterns. The Encyclopedia of Geomorphology, Rhodes W. Fairbridge, ed., Encyclopedia of Earth Sciences Series, vol. III, Reinhold Publishing Corp., 1968, p. 288.

16. Wilson, Ian G.: Aeolian Bedforms—Their Development and Origins. Sedimentology, vol. 19, no. 3/4, Dec. 1972, pp. 173-210.

17. Bigarella, João José: Eolian Environments: Their Characteristics, Recognition, and Importance. Recognition of Ancient Sedimentary Environments, J. Keith Rigby and Wm. Kenneth Hamblin, eds., Paleontologists and Mineralogists, Special Publication No. 16, 1972.

18. Holm, Donald August: Desert Geomorphology in the Arabian Peninsula. Science, vol. 132, no. 3437, Nov. 1960, pp. 1369-1379.