Photointerpretive mapping from space photographs of Quaternary geomorphic features and soil association in northern Chihuahua and adjoining New Mexico and Texas

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1969, pp. 116-129. https://doi.org/10.56577/FFC-20.116

in:

The Border Region, Chihuahua and the United States, Cordoba, D. A.; Wengerd, S. A.; Shomaker, J. W.; [eds.], New Mexico Geological Society 20th Annual Fall Field Conference Guidebook, 228 p. https://doi.org/10.56577/FFC-20

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PHOTOINTERPRETIVE MAPPING FROM SPACE PHOTOGRAPHS OF QUATERNARY GEOMORPHIC FEATURES AND SOIL ASSOCIATIONS IN NORTHERN CHIHUAHUA AND ADJOINING NEW MEXICO AND TEXAS[1]

by

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ABSTRACT

Space photographs of the earth cover large regions under instantaneous, uniform lighting conditions. The better ones have many advantages over air-photo mosaics in providing synoptic views of both strongly and subtly imaged geologic, soil, and geomorphic features, without distracting detail. To be most useful for photointerpretive mapping of such features, space photographs should have: (1) ground resolution of at least 200 ft, and preferably 100 ft or better; (2) color or multi-spectral imagery, with high discrimination in the yellow-red region of the spectrum and also (3) vertical, stereoscopic, and continuous cloud-free coverage over the region to be mapped.

The accompanying maps of Quaternary geomorphic features and soil associations are the first systematic space-photo-interpretive maps of a large terrestrial area to be published. Geomorphic features are mapped both according to type, which requires relatively little interpretation, and as to age, which requires considerably more interpretation.

The soil-association map is a pedologic, not an engineering soils map. Its small scale generally precludes the differentiation of individual soil series or even single "great groups" of soils; commonly it is necessary to map composites of several great groups, called soil assocations, that occur together in a given kind of terrain unit. In selecting the map units, primary emphasis is placed on features that can be determined directly from the space photos, namely (1) color of the ground surface, or where possible, the soil surface, and (2) topographic-geomorphic relations. The photointerpreter who understands the interrelations of soils and various kinds and ages of landforms under different climatic, geologic, and vegetation conditions, can interpret the soils that typify a given terrain unit. Some ground data are necessary to control the interpretation of soil features such as the character of the B and, if present, Cca horizons; these data were obtained from unpublished soil-survey reports of a few areas and from field traverses by the author.

RESUMEN

Las fotografias espaciales de la tierra cubren grandes regiones en condiciones de iluminatión instantánea y uniforme. Las mejores tienen varias ventajas sobre los aereofotomosaicos ya que sumunistran aspectos sinópticos de los rasgos geológicos geomórficos y del suelo que han sido fotografiados, sean marcados o débiles, eliminado detalles poco importantes.

Para que sean Utiles en la elaboración de mapas fotointerpretativos de los rasgos geológicos, geomórficos y del suelo, las fotografias espaciales deben tener: (1) resolución terrestre de por lo menos 200 pies y preferiblemente de 100 pies y aUn mejor; (2) un conjunto de imágenes en color o multiespectral, con alta discriminación en la region rojo-amarilla del espectro; e igualmente capacidad de cubrir la region de la cual se va a claborar el mapa, en forma (3) vertical, estereoscópica y continua.

Los mapas que se publican aqui sobre los rasgos geomórficos cuaternarios y sobre las asociaciones del suelo, son los primeros mapas en incluir interpretación fotoespacial de una area terrestre amplia. Los rasgos geomórficos estan dibujados en los mapas de acuerdo tanto con el tipo, lo cual requiere relativamente poca interpretación, como con la edad, lo cual requiere más interpretación. El mapa de la asociación del suelo es agronómico-pedológico y no un mapa de suelos para ingenieria. En general, la escala pequena impide la diferenciación de series individuates de suelos y aun "grupos grandes" aislados de suelos; comunmente es necesario elaborar mapas compuestos de varios grupos grandes, llamados asociaciones de suelos, las que se presentan juntas en un tipo dado de terreno unitario. Al seleccionar las unidades de mapas, se ha dado énfasis a rasgos que pueden determinarse directamente de las fotografias espaciales, es decir (1) color de la superficie de fondo (cuando es posible, de la superficie del suelo) y (2) relaciones topografico-geomórficas. El fotointerpretador que entiende las interrelaciones de suelos de diferentes tipos y edades, puede hacer le interpretación de los suelos que caracterizan una cierta unidad de terreno. Algunos datos del terreno han sido necesarios para controlar la interpretación de los rasgos del suelo, tales como el catheter de los horizontes B y (si están presentes) Cca; estos datos se obtuvieron de informes no publicados sobre exploración de suelos de unas pocas areas y de mis propios viajes al campo.

1. Publication authorized by the Director, U.S. Geological Survey.

INTRODUCTION

The maps accompanying this paper represent a pragmatic experiment in applying photointerpretive techniques to space photography for small-scale mapping of Quaternary geomorphic features and soil associations. They are the first published maps of a large terrestrial area prepared largely from systematic study of available space photographs with a minimum of ground control. Most of the region mapped has never had its Quaternary geology, geomorphology, and soils mapped adequately, even on a scale as small as 1:1 million.

Essential ground control was obtained from the few published and available unpublished geologic, soil, and land classification maps, and by my own rather coarse network of field traverses through the area. I am especially indebted to Dr. John W. Hawley and Mr. Leland H. Gile, of the U.S. Soil Conservation Service, and Mr. Harrison J. Maker, Soil Scientist, Department of Agronomy, New Mexico State University, for making available unpublished soil survey reports and maps of several areas in southern New Mexico, and for enlightening discussions on geomorphology, soil classification, and soil genesis in this region. Special thanks are due Ing. Guadencio Flores Mata, Director of the Dirreción de Agrologia, Secretaria de Recursos Hydraulics of Mexico, for making possible a cooperative field excursion during May 26-30, 1969, in northern Chihuahua to obtain field-control data for the mapping. I also am greatly indebted to the following persons for valuable discussions and many courtesies while they accompanied me on this field excursion; Ing. Luis Alberto Martinez (in charge), Ing. Eduardo Benitez, Ing. Norberto Juarez, and Sr. Oscar Munoz, of the Cd. Chihuahua office of the Secretaria de Recursos Hydraulics, and to Ing. Jesus Estrada and Ing. Ruben Rodriquez of the Mexico, D. F., office, of this bureau.

Photointerpretive mapping of Quaternary geomorphic features and soil associations is simpler than that of pre-Quaternary geology, because it requires less interpretation and inference than does mapping of most bedrock and stratigraphy and structure. The geomorphic features and soils are at the surface of the earth and immediately below it; consequently, much information about them can be obtained directly from study of the space photographs, without requiring secondary or tertiary levels of interpretation. Nevertheless, the soil-association map requires considerably more interpretation than does the map of geomorphic features, as we will see later in the discussions of these maps.

GENERAL INFORMATION ABOUT SPACE PHOTOGRAPHS OF NORTHERN CHIHUAHUA AND THE ADJOINING U.S.

The space photographs of the region with which we are concerned were taken during six different Gemini and Apollo missions of the National Aeronautics and Space Administration (NASA) from 1965 to 1969. They were exposed at altitudes between 101 and 130 statute miles above the earth using either Hasselblad or Maurer cameras equipped with 80 mm or 76 mm (3-inch) focal-length lenses, using 70 mm film and providing 58 mm square photographic images (frames). All the space photographs, except the Apollo 6 (502) and Apollo 9 multispectral series, were taken in color with the camera hand-held by an astronaut. The Apollo 6 (502) photos were taken in color automatically from an unmanned space capsule with a Maurer camera. Most of the Apollo 9 photographs were shot in color with a hand-held Hasselblad, but for the Apollo 9 multispectral series four Hasselblad cameras, operating simultaneously and filtered to image different parts of the photographic spectrum, were used.

Table 1 gives details on the available space photographs that cover northwestern Chihuahua and adjoining parts of New Mexico and Texas. Figures 1 and 2 reproduce two of the best of these photos. It is obvious from table 1 that at present the coverage in Chihuahua is limited to the northern half of the state and that the highest quality coverage extends only a few miles south of the US-Mexico border.

DESIRABLE QUALITIES OF SPACE PHOTOGRAPHS FOR MAPPING GEOLOGIC AND GEOMORPHIC FEATURES AND SOILS

A fundamental advantage of space photography for mapping geologic and geomorphic features and soil associations is their large-area synoptic coverage registered instantaneously under uniform lighting conditions. Aerial photographs cannot equal this advantage. Air-photo mosaics always have tonal contrasts from differences in sun angle and exposure between adjacent flight lines, and sometimes even between adjacent frames. These contrasts are spurious details that may obscure various subtle changes in images, particularly those associated with large patterns that extend beyond a single air photo—for example, gradual changes in bedrock lithology, soil properties, vegetation, and in patterns of minor erosional and structural features. Such gradational features commonly are not evident from study of aerial photographs and air-photo mosaics. Space photographs, with their synoptic, uniformly illuminated coverage, provide exceptional opportunities to integrate both the strongly and the subtly imaged features without the "noise" of distracting detail, and consequently to determine relationships that might be missed by photointerpretation of aerial photographs alone.

Space photographs that are taken in continuous sequence during the same orbital revolution, so that they adjoin, or preferably overlap, are even more advantageous than single space photographs, in that they provide a virtually instantaneous comprehensive image of a very large region. The time intervals between individual photographs in such a series are so brief that illumination and sun angle remain essentially uniform over tremendous distances. For example, the 37 frames of the Apollo 6 (502) series, that cover the 1200-mile belt from northeastern Baja California to eastern Texas were taken in less than 5 minutes, an average of 8 seconds apart.

A combination of as many as possible of the following qualities is desirable for space photographs that are to be used for mapping geologic and geomorphic features and soils.

TABLE 1. DATA ON GEMINI AND APOLLO SPACE PHOTOGRAPHS THAT PROVIDE COVERAGE IN NORTHWESTERN CHIHUAHUA AND ADJOINING PARTS OF NEW MEXICO AND TEXAS

MISSION AND FRAME NOS.	DATE AND GMT TIME[1]	ALTITUDE ABOVE SEA LEVEL (NAUTICAL MILES)[2]	CAMERA[3] AND FILTER	FILM	VERTICALITY (TILT)[5]	STEREOSCOPIC COVERAGE
Gemini IV IV-8-16 to IV-8-26	June 5, 1965 1743 to 1744	88-90[4]	Hasselblad 500-C. Haze filter.	Ektachrome MS (SO-217)	36°-50°[4] to south and southwest	No (frames overlap but varying amounts and directions of tilt make stereo images out of register).
Gemini IV IV-5669; IV-5670	Aug. 26, 1965 1614	112[4]	Hasselblad 500-C. Haze filter.	Anscochrome D-50	IV-4-69: 15°[4] IV-4-70: medium tilt	No
Apollo 6 (502) VI-1444 to VI-1448	April 4, 1968 0755-0756 (solar time)	102±	Maurer 220G. Haze filter.	Ektachrome special order 121	Ca. vertical	Yes; ca. 60% overlap
Apollo 7 VII-1797	Oct. 15, 1968 1713	94	Hasselblad 500-C. Filter 2A.	Ektachrome special order 121	Ca. vertical	No
Apollo 7 VII-1798	Oct. 15, 1968 1713	94	Hasselblad 500-C. Filter 2A.	Ektachrome special order 121	Ca. vertical	No
Apollo 7 VII-2028	Oct. 12, 1968 1808	125	Hasselblad 500-C. No filter.	Ektachrome special order 121	Ca. vertical	No
Apollo 9 AS 9-21-3307; AS 9-21-3308	Mar. 9, 1969 1938	103	Hasselblad 500-C. Haze filter.	Ektachrome SO 368	Vertical	80% overlap with each other
Apollo 9 AS 9-22-3458; AS 9-22-3459; AS 9-22-3460	Mar. 9, 1969 1937	103	Hasselblad 500-C. Haze filter.	Ektachrome SO 368	Vertical	Yes
Apollo 9 (SO-65 Multispectral) AS 9-26-3754 to 3757	Mar. 9, 1969 1937	103	4 Hasselblad 500-C cameras. See footnote 6 for filters.	Camera A, Ektachrome Infrared; cameras B, C, & D, Panatomic-X 3400	Vertical (± 5°)	70% overlap

[1] Time of photography from National Aeronautics and Space Administration. To convert Greenwich Mean Time (GMT) to local time, subtract 6 hours for Central, and 7 hours for Mountain Standard Time.

[2] One nautical or air mile equals 6080 feet. To convert nautical miles to statute miles, multiply by 1.152.

[3] The Hasselblad cameras all had 80mm focal-length Zeiss planar f 2.8 lenses; the Maurer camera had a 76mm (3-inch) focal length Ektar f 2.8 lens; both types of camera use 70 mm film and make 58 mm square frames.

[4] Determined from computer operations for vertical rectification of the photographs.

[5] Tilt measures the departure from vertical.

[6] Camera A, Photar 15 filter (film/filter transmission response = 0.510-0.890 micrometers (color-infrared) O; Camera B, Photar 58B filter film (film/filter transmission response = 0.470-0.610 micrometers ("green")); Camera C, Photar 89B filter (film/filter transmission response = 0.680-0.890 micrometers (infrared)); Camera D, Photar 25A filter (film/filter transmission response = 0.590-0.715 micrometers ("red")).

(1) Image detail. The sharpest possible image is desirable. The degree of detail that is imaged by a space photograph is dependent upon (a) the resolving power of the camera lens/film system and (b) the scale number of the photograph. The theoretical resolving power of a lens/film combination is conventionally expressed in lines per millimeter, which is the reciprocal of the smallest observable separation of adjacent lines in a test pattern consisting of parallel alternating black and white lines of the same width. The actual capacity of a lens/film system to resolve detail varies with the size and shape of an object, its degree of contrast with the background, and conditions of illumination, exposure, and photographic development. The scale number is the distance from the camera to the ground, divided by the focal length of the camera lens. A unit distance on the photograph multiplied by the scale number is equivalent to the same unit distance on the ground. If a space photo is taken at 100 miles (528,000 feet) altitude with a camera with a 3-inch (1/4-foot) focal length lens, its scale number will be 2,112,000, conventionally expressed as the ratio 1:2,112,000.

A commonly used term for image detail is ground resolution, which is the width, measured on the ground, of one line of resolving power; thus it combines the two factors of scale and resolving power. It commonly is expressed in terms of feet. It is strongly influenced by the shape of the object. Linear features such as roads, streams, and some geologic boundaries can be resolved at a resolution about one-tenth less than that needed to detect equidimensional objects (Wobber, 1968).

For mapping geologic and related features on scales as small as 1:500,000 and 1:1 million, a medium degree of ground resolution, neither too high nor too low, is preferable. About 100 feet seems to be optimum. The sharpest Apollo space photos attain this optimum. The medium resolutions are too low to enable identification of most man-

TABLE 1 (continued)

MISSION AND FRAME NOS.	GROUND RESOLUTION (ESTIMATED IN FT)	AREAL COVERAGE	CLOUD COVER	GENERAL COMMENTS
Gemini IV IV-8-16 to IV-8-26	300 to > 1,000, depending on tilt	Continuous across southern New Mexico and northern Chihuahua as far south as about lat. 29° 45′ N.	None	Tilt increases from west to east. Frames IV-8-23 to 26 are excessively oblique. Over-all bluish cast and deficient in reddish hues, increasing in direction of tilt, so that the imagery becomes increasingly poor in quality toward the south.
Gemini IV IV-5669; IV-5670	IV-4-69: 200 ±; IV-4-70: 200 ± to > 1,000, depending on tilt	IV-4-69 is ca. 100 mi. square, centering near White Sands, New Mexico; IV-4-70 is tilted south, with N boundary near Las Cruces, N. Mex., and S boundary somewhat south of Villa Ahumada, Chih.	None	First trial of high-resolution, red-enhancing color film for space photography; superior to the other Gemini photos of this area in resolution and red discrimination.
Apollo 6 (502) VI-1444 to VI-1448	100-200	Continuous across southern New Mexico and as much as 30 miles S of US-Mexico border, in a strip ca. 100 miles wide.	None	Superior in all respects; have low (ca. 25°) sun angle.
Apollo 7 VII-1797	400±	Ca. 100 miles square, centering 25 miles E of Nuevo Casas Grandes; barely adjoins VII-1798.	Scattered clouds, ca. 10%.	Good color balance but relatively poor resolution.
Apollo 7 VII-1798	400±	Ca. 100 miles square; Villa Ahumada is just north of center of north edge; barely adjoins VII-1797.	Widely scattered small clouds, < 5%.	Good color balance but relatively poor resolution.
Apollo 7 VII-2028	300-400	Ca. 140 miles square; El Paso is at extreme NE corner.	Widely scattered small clouds, > 5%.	Good color balance but only fair resolution. SW 2/5 of frame masked by hatch window.
Apollo 9 AS 9-21-3307; AS 9-21-3308	100±	Each ca. 100 miles square; center of 3307 is ca. 33 miles W of El Paso; center of 3308 is Cd. Juarez.	Clouds obscure 30% of S ¼ of 3307 and 40% of S ⅓ of 3308.	Outstanding except parts are obscured by clouds.
Apollo 9 AS 9-22-3458; AS 9-22-3459; AS 9-22-3460	100±	Ca. 100 miles square; 3458 centers over Columbus, N. Mex.; 3459 over Palomas volcanic field near Columbus; 3460 over El Paso.	3458 has a few clouds along S margin; 3459 a trace of clouds at S margin; 3460 has 25% clouds in S ½.	Outstanding in resolution and color discrimination; one or two corners are masked by hatch window; 3460 is moderately impaired by cloud cover in S ½.
Apollo 9 (SO-65 Multispectral) AS 9-26-3754 to 3757	100-200	Continuous 82 ± mile-wide band along US-Mexico border as far east as 25 miles west of El Paso.	10% in AS 9-26-3754, decreasing to 2% in AS 9-26-3757.	The superior resolution and the stereoscopic, vertical, and especially the multispectral coverage (providing simultaneous images from 4 different parts of the photographic spectrum) make the Apollo 9 multispectral series of unique importance in space photography. Northern parts of the frames are slightly to moderately obscured by clouds.

made objects by inherent detail, such as is required for all but the coarsest surveys of cultural features and for military intelligence analysis. For instance, arms control inspection requires a minimum ground resolution of 20 feet (Davies, 1966) . Nevertheless, the potential scientific yield from space photographs with 100- to 200-foot resolution is very high. Resolutions of this magnitude actually are more useful than finer ones because they filter out much of the extraneous detail, so that the major elements are made more clearly evident—the forest can be seen instead of individual trees. Especially important is the way in which small differences in color can be seen that might be otherwise obscured because of the distracting clutter of detail at higher resolutions. At resolutions of 100 to 200 feet, enough of the minor topographic details can be identified so that features such as Quaternary lava fields, cinder cones, dune areas, pluvial-lake shore features, and the various degrees and types of dissection of piedmont and other alluvial surfaces can be clearly identified. As Lowman (1968, p. 24) observed: "If units are large in area, low resolution can be tolerated since the contact can be consistently delineated, although located with relatively low precision." Higher resolution obviously permits the differentiation of smaller sized units, as well as more accurate placement of boundaries between the larger units.

During the spring of 1968 I tried using 8" x 8" color transparency enlargements of Gemini 4 and 5 photos for 1:250,000-scale mapping of soil associations over large parts of southern Arizona, southeastern California, and adjoining parts of Mexico. These early space photos had ground reso-

FIGURE 1.
Gemini IV mission, frame 5670. A southward-oblique photograph, taken about 127 statute miles above sea level, showing the whole eastern part of the mapped area—the Rio Grande Valley, El Paso-Juarez area, to south of the southern edge of the mapped area.

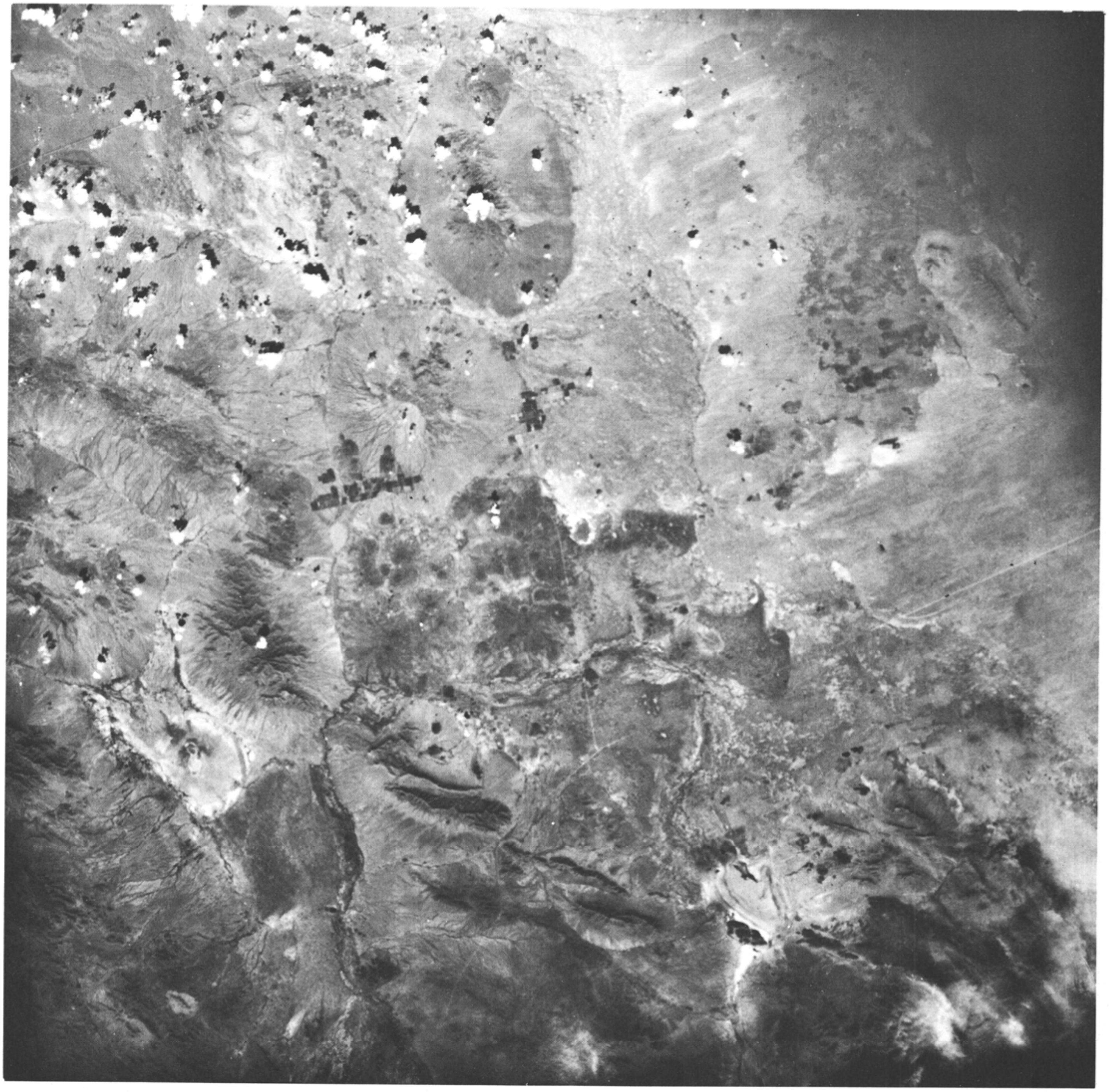

FIGURE 2.

Apollo 9 mission, multispectral SO-65 series, frame 3757, band BB ("green"). One of the latest "multispectral," vertical, stereoscopic space photographs. Centers approximately over Columbus, New Mexico; Deming, N.M. at north edge and Ascensión, Chih. at south edge. Includes Lagunas Moscos and Guzman, Palomas volcanic field, and lowermost course of Rio Casas Grandes.

lotions ranging from about 300 to more than 400 feet, and much lower in the distant parts of the more oblique photos; also, their color discrimination was poorer than in the space photos taken since 1967. I concluded that the Gemini 4 and 5 photos were generally inadequate for attaining the accuracy of photointerpretation that is suitable for 1:250,000-scale mapping. Nevertheless, I was able to use these photos, supplemented in places by Apollo 6 photos, to prepare a 1:1 million-scale soil-association map of the southwestern US-northern Mexico region. I am optimistic that the superior ground resolution and color discrimination of the best of the newer space photos, such as the Apollo 6 and the Apollo 9 multispectral series, will be adequate for 1:250,000-scale photointerpretive mapping of soil associations and geomorphic features.

The improved resolution of the Apollo compared with the Gemini photographs is mainly because of development of higher resolution film; the quality of the camera lens systems, and their focal length, has remained essentially the same for all space photos taken to date.

Two factors affect image quality that are independent of the scale of the photograph and the resolution of the lens/film system, Atmospheric haze due to water vapor, dust, smoke, or smog has impaired some space photos, particularly those taken over humid lowlands. Properly filtered color-infrared photography penetrates such haze very well because it eliminates the shorter-wavelength blue and green light, which is excessively scattered by haze. To date, color infrared has been used successfully only in the Apollo 9 multispectral photography. Some space photos also have been impaired because of "deposits" that formed on the hatch window of the spacecraft due to outgassing of window sealants, (and other causes), through which the photos were taken.

(2) Color *discrimination.* Although color film has somewhat lower resolution than black and white film, it has greater total data storage/yield and generally it is preferred for geologic photointerpretation. Color film was used for all the Gemini and Apollo space photos, except for 3 bands of the recent Apollo 9 multispectral series which were taken with Panatomic-X film.

Absolute color fidelity is not desirable in the photographs used for photointerpretive mapping of soils and geologic features. Atmospheric scattering, mainly because of moisture, causes considerable loss of color in the blue and green spectral region as well as loss of contrast and resolution. Loss by scattering is much less in the longer wavelengths of the photographic spectrum. This is fortunate, for in this region the yellows, browns, and reds are by far the most useful ones for interpretation of soils and geology. Consequently, for such interpretation it is desirable to use a film emulsion that has an enhanced response to the red region. The desirability of red-enhancing film can be seen by comparing the Gemini with the Apollo photographs. Nearly all the Gemini photographs were taken with film that has high sensitivity to the blue-green region; therefore these photos tend to be too blue and deficient in reddish hues. Special red-enhancing high-resolution film was used, however, for a few Gemini and for all the hand-held Apollo photographs.

The Apollo 6 (502) series of photos is an excellent example of the superior qualities of such film. Accentuation of the reddish hues produces greater contrast between slight differences in redness of the ground surface, which is a great advantage in photointerpretive mapping of soil associations. The loss of contrast and resolution by atmospheric haze also is somewhat reduced.

During the Apollo 9 mission several series of multispectral photographs were taken of the southern United States, particularly the southwestern part. These photographs represent a unique, significant advance in space photography of the earth. They were taken by 4 Hasselblad cameras mounted together on the hatch window of the spacecraft, with all 4 cameras operating simultaneously for each "shot." Each camera was filtered to image different parts of the photographic spectrum (see footnote 6, Table 1). The shots shots were spaced to provide stereo overlap of about 60%, and the spacecraft was stabilized so that the photographs were shot within 5° of vertical. These multispectral photographs are superior in their ground resolution and furnish far more comprehensive and detailed information from the important parts of the photographic spectrum than is available from any previous space photographs; thus they undoubtedly will be of great scientific importance.

(3) *Verticality.* Space photographs taken perpendicular to the earth's surface are preferable to oblique photographs for most photointerpretive and mapping purposes. Vertical photographs greatly facilitate transfer of mapped data from the photos to standard base maps, because there is little or no distortion from true planimetry. Moreover, such photographs remain in register throughout the image when viewed under a stereoscope. Also, their color balance and ground resolution remain the same everywhere on the photograph. Oblique photographs, however, increasingly lose resolution and discrimination of reddish hues in the direction of their tilt, as greater segments of the atmosphere are penetrated. More distant parts become so degraded that they are useless for reliable photointerpretation and mapping.

Relatively few of the space photos taken with hand-held cameras are vertical or nearly so. However, two groups of continuous-series vertical photographs have been taken with cameras mounted in the hatch window of the spacecraft: the Apollo 6 (502) series from an unmanned space capsule and the Apollo 9 multispectral series.

(4) Stereoscopic coverage. Comprehensive viewing of space photographs under a stereoscope, preferably under a magnifying stereoscope, permits much more accurate determination of topographic detail than is possible from non-stereoscopic viewing. The small base-to-height ratio of stereoscopic images from space photos permits height estimates of minor topographic details to be made, with the sharpest photos, within plus or minus 30 to 100 feet, depending upon the ground resolution. Comprehensive stereo viewing, with all parts of the image in register, generally is not possible unless the space photos are essentially vertical — oblique photos commonly vary in the amount and direction of tilt, so that they cannot be gotten into satisfactory register.

(5) Continuous coverage. Continuous coverage is, of course, essential if geologic and allied features are to be mapped comprehensively over a large region. In most parts of the earth that have been photographed from space the coverage is still very limited and that by vertical photos particularly so. The most continuous coverage and the most photographed region in the world is the United States-Mexico border region. The Apollo 6 and Apollo 9 multispectral series are outstanding in providing continuous vertical stereoscopic coverage in this region. Unfortunately the Apollo 9 multispectral photography was seriously impaired by extensive cloud cover, so that only about 45% of the total coverage by this series in the southwest is partly usable for geologic and allied mapping purposes.

PHOTOINTERPRETIVE MAPPING FROM SPACE PHOTOGRAPHS AND SELECTION OF MAP UNITS

The techniques of photointerpretive mapping of Quaternary geomorphic features and soil associations from space photographs resemble those used in photointerpretive mapping of such features from aerial photographs, with an obvious difference: the scale of mapping (currently 1:1 million) is much smaller than is customary for photogeologic maps and the detail that can be seen and utilized from the photographs in terms of ground resolution is far less. This means that relatively gross characteristics must form the basis for interpretation, compared with the relatively minute ones commonly used.

In selecting and defining the map units, first consideration has been given to differentiating criteria that can be determined directly from the space photographs, such as topographic features and color of the ground surface, without supplementary ground or other information. However, an effort has been made to interpret these criteria in terms of conventional map units. The small map scale necessitates certain compromises in the selection of map units. In some cases a single type of feature is large enough to be shown by a simple map unit, for example the flood plain of a river, an active sand dune area, or a playa. More commonly, however, it is necessary to resort to map units that represent composites of several types of features that occur in close combination and cannot be shown separately on a map of this scale. Frequently the boundaries of these composite units are gradational and must be shown arbitrarily. Some types of composite units tend to change gradually in the "mix" of their components.

QUATERNARY GEOMORPHIC FEATURES

The map of Quaternary geomorphic features shows these features both as to type and as to age. (Fig. 3) Classification as to geomorphic type requires the least interpretation because merely the gross morphology needs be identified and this can be determined directly and unambiguously from elements of topographic form that are discernible from local tonal variations, textures, and patterns seen on the space photographs. Topographic-geomorphic features such as sand-dune areas, the bajada (piedmont) surfaces of the intermontane basins and their various degrees of dissection and erosion, playas, flood plains, and hills, mountains, lava fields, and escarpments of pre-Quaternary rocks, are readily distinguished on the space photos.

Classification as to age requires closer observation of details on the photographs and considerably more interpretation. The leading clues as to age of a geomorphic feature are: (1) relative height above stream level, for stream terraces and dissected alluvial fans and piedmonts, (2) depth and maturity of dissection and erosion, and (3) maturity, and sometimes type, of soil-profile development. Data that are organized for the soil-association maps are of key importance here.

The geomorphic map will be most meaningful if it is studied in connection with J. W. Hawley's companion article on the geomorphology of northwestern Chihuahua in this guidebook.

Unusual features of the geomorphic map are delineation of Quaternary faults, lava fields, and cinder cones, also classified as to age. The age of Quaternary faults can be estimated from criteria such as the ages of various geomorphic surfaces and deposits that it displaces, ages of younger deposits and surfaces that overlap the fault scarp, and degree of dissection and erosion of the fault scarp. The age of basaltic lava fields and cinder cones can be estimated from the relative differences in their color, soil development, and degree of erosion.

SOIL-ASSOCIATION MAP

The soil-association map, figure 4, is an agronomic-pedologic map, not an engineering soils map. The soils are classified according to their soil-profile characteristics, not primarily by their texture and engineering properties. More detailed, larger-scale remote-sensing studies may later lead to the production of engineering soils maps by the Geological Survey. The present map, nevertheless, does provide considerable information of value to the engineering geologist and engineer.

Soil scientists in the United States usually map soils in terms of units called soil series. A soil series is the fundamental map-unit category for soils, akin to the formation in geologic mapping, and is designed for mapping at a mile to the inch and larger scales. In smaller scale mapping, however, the map units commonly must combine several soil series that occur in such close association that they cannot be mapped separately.. These composite map units are called soil associations. In the exceedingly small-scale maps in this paper the soil-association map units perforce are composites of a large number of individual soil series, and generally of several great groups of soils that occur together in a given kind of terrain unit.

In selecting and defining the map units, primary emphasis is placed on soil characteristics that can be determined from information available from the space photographs, and subordinate emphasis on other soil characteristics that cannot be determined from the photographs but must be inferred from climatic data and terrain analysis, or by extrapolation from available soil reports and maps and from my own ground traverses. Generally, the major categories of map units are mutually exclusive and share as few soil series as possible with other map units. The map-unit classifica-

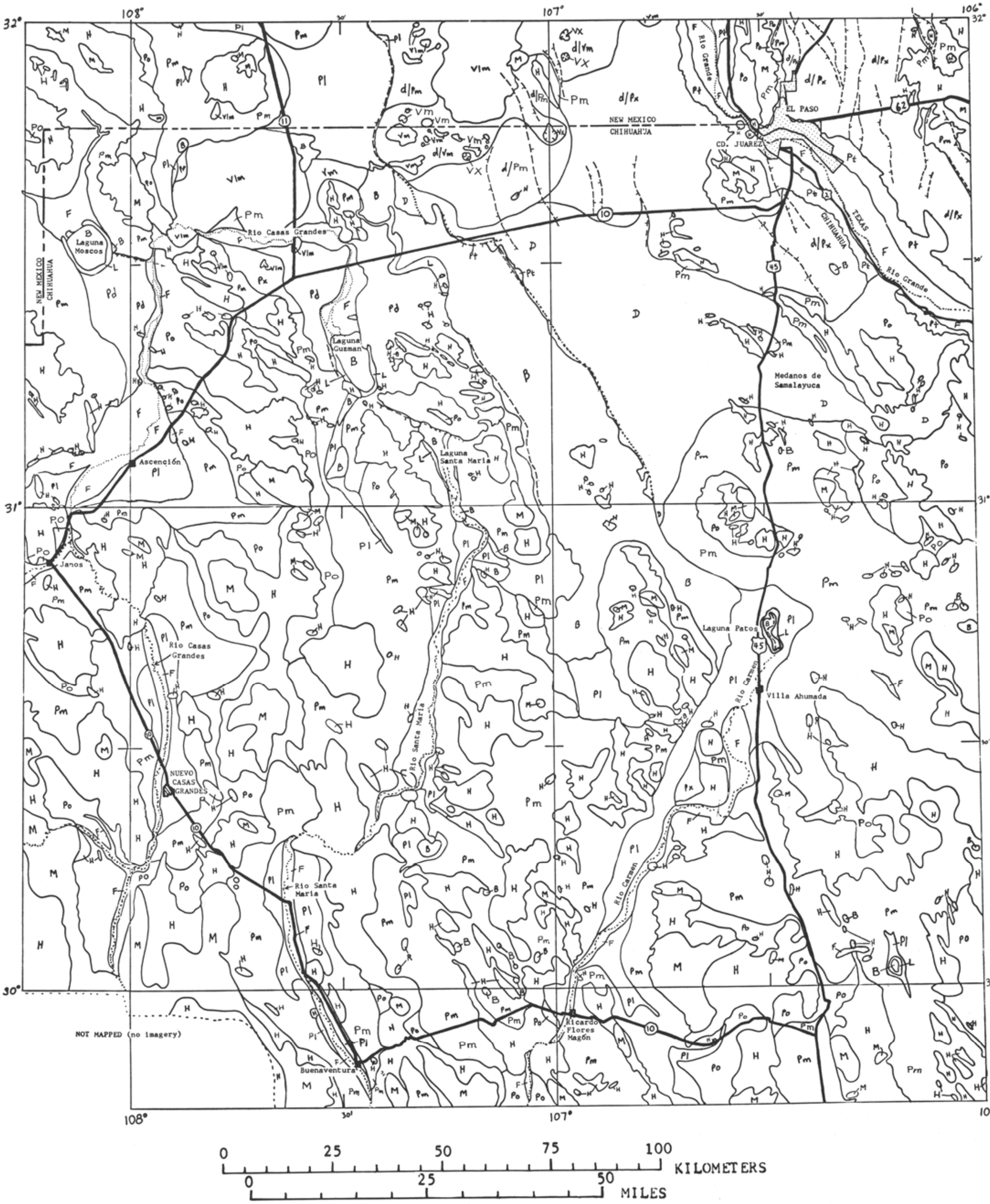

FIGURE 3.

Quaternary geomorphic features of northern Chihuahua and adjoining New Mexico and Texas map. See table 2 for explanation of map.

tion has been structured on geomorphic, geologic, and climatic criteria so as to portray the major pedologic patterns of this region in as much detail as is consistent with the map scale, in order to be most useful to geologists, soil scientists, and geographers and also to be of maximum utility for land-classification studies.

The chief kinds of information obtainable from the space photographs that pertain to the soil mapping are: (1) topographic-geomorphic relations, and (2) color of the ground surface. Thus, topographic-geomorphic features are determined quite readily on the space photographs. An experienced soil photointerpreter, who understands the interrelations of soils and various kinds and ages of land forms under different climatic, geologic, and vegetation conditions, can interpret the kinds of soils that typify a given terrain unit. Certain soils, for example, typify the flood plain of a large river, other kinds of soils a relatively uneroded remnant of an alluvial fan, and still others the more eroded parts of old bajada surfaces—as can be seen from the map explanation for the soil-association map.

Examples of small topographic features that are important aids in the photointerpretation of soils are the small scarps along the dissected edges of geomorphic surfaces of middle and early Pleistocene age. These scarps are caused by the caprock effect of the cemented Cca horizons (Km horizons of Gile et al., 1966) in the pre-Wisconsin soils developed on these surfaces. The outer valley-rim scarps of the Rio Grande Valley are good examples. The space photos clearly show these sinuous scarps along the edges of the oldest geomorphic surfaces, commonly also showing a narrow white line that marks the exposed bare caliche along the top of the scarp.

EXPLANATION

AGE (predominant)	ALLUVIAL UNITS		LACUSTRINE UNITS	EOLIAN UNIT	VOLCANIC UNITS
Holocene	F *Flood plains* (and locally, very young terraces) of rivers and major washes, underlain by alluvial silt and sand, with gravel and clay locally, of Holocene age. Level to gently undulating; local relief < 20 ft.				
Late Quaternary (Wisconsan & Holocene)	Pl Young river terraces and lowermost piedmont toe slopes and flats, underlain by alluvial sand, silt, and gravel of late Quaternary age. Level to gently undulating.		B Barrials ("playas" of customary but incorrect US usage). Level lake floors, usually dry, underlain by lacustrine silt and clay, with sand in places, mostly of late Quaternary age, but locally (where exposed by deflation) of middle Quaternary age.	D Sand dunes, mostly of late Quaternary age. Alluvium and lacustrine sediments of late and middle Quaternary age locally underlie depressions. Local relief generally is less than 50 ft, but attains 550 ft, (170 m) in Medanos de Samalayuca.	Vl Basaltic lava flow of late Quaternary age.
Late & middle Quaternary	Pt Highly dissected areas below Px plains, chiefly bordering the Rio Grande, in alluvium and lacustrine sediments of middle and early Quaternary age, with local terrace-gravel veneers of Illinoian and Wisconsinan age. Local relief 150 to 350 ft.	Px d/Px Alluvial plains, level to gently undulating, of middle Quaternary age (antedating the entrenchment of the Rio Grande), in places veneered with alluvium and/or eolian sand of late Quaternary age. (d/Px symbol indicates areas of eolian sand veneer.)	L Shore zones of pluvial lakes, Underlain by lacustrine sand and gravel of late (and locally middle) Quaternary age. In places includes eolian sand. On west side of Laguna Guzman includes carbonate spring deposits.		Vlm Basaltic lava flows and cinder cones of late and middle Quaternary age. Extensive thin veneer of eolian sand and sandy alluvium.
Middle Quaternary	Pm d/Pm Piedmont alluvial slopes. Principal upland surfaces are veneered by alluvial gravel of middle Quaternary age. They generally are dissected 10 to rarely more than 50 ft into alluvial gravel of middle and/or early Pleistocene (locally perhaps late Pliocene) age. (Symbol d/Pm denotes areas of coppice sand-dune veneer.)	Pd Old deltaic plains of Rio Casas Grandes. Nearly level, underlain by alluvial sand and gravel, probably mainly of late-middle Pleistocene age, with local late Quaternary veneers.			Vm d/Vm Basaltic lava flows and cinder cones of middle Quaternary age. Symbol d/Vm denotes thick veneer of eolian sand. Vx Maare (explosion craters), probably of middle Quaternary age.
Early and/or middle Quaternary	Po Older piedmont alluvial slopes. Underlain by alluvial gravel of early-middle and/or early Pleistocene age. Deeply dissected (50 to > 100 ft.).				
Pre-Quaternary	ROCKLAND AREAS H Hilly, low-mountain, and other rockland areas, with local relief less than 1,000 ft (300 m). Bedrock is widely exposed or is within a few feet of the surface in most places.			M Mountains with local relief greater than 1,000 ft (300 m). Bedrock is widely exposed.	

FAULTS

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Inferred fault, probably of middle Quaternary age (no faults of late Quaternary age have been identified in the map area). Dotted where concealed by younger sediment; queried where problematic. Tick marks indicate down-dropped side.

TABLE 2. EXPLANATION OF SOIL ASSOCIATIONS OF NORTHERN CHIHUAHUA AND ADJOINING NEW MEXICO AND TEXAS

MAP-UNIT SYMBOL	TOPOGRAPHIC-GEOMORPHIC SITUATION	GREAT GROUPS OF SOILS (New US classification. Dominant ones are in italics. See Appendix for definitions and equivalents.)
	LOWLAND GROUP: Young soils of lowlands, with little or no profile development.	
F	Flood plains of rivers and larger washes.	*Torrifluvents*, Torripsamments
B	Barrials. Level, generally dry lake floors—the "playas" of customary but incorrect US usage.	*Torrifluvents*, Torriorthents, Camborthids, Salorthids, Natrargids
L	Shore zones of pluvial lakes.	*Torripsamments*, *Camborthids*, Haplargids
	DUNELAND GROUP: Areas of predominantly eolian sand, generally with distinct dune forms, either active or stabilized. Generally little or no soil profile development.	
D	Duneland. Local relief generally < 50 ft, but as much as 550 ft in Medanos de Samalayuca.	*Torripsamments*
BAJADA GROUP: Alluvial piedmonts (including footslopes and toeslopes); also the badlands and older terraces bordering the Rio Grande. Weak to very strong profile development. The numerals at end of the map-unit symbols indicate degrees of local relief ("slope"), as follows: 1 = level to gentle (< 10%) slopes; 2 = moderate (10-25%) slopes and/or local relief generally 20 to 60 ft (6-18 m); 3 = many steep (> 25%) slopes and/or local relief generally 50 to > 100 ft (15->30 m).		
Pl	Lowermost piedmont toeslopes and, locally, low stream terraces. Level to gently sloping.	*Camborthids* & *Torrifluvents* + Torripsamments, Natrargids, Salorthids
Ps	Deltaic plain of Rio Casas Grandes north of Laguna Guzman. Nearly level.	*Haplargids*, *Camborthids*, Salorthids, Calciorthids, Natrargids
Pb	Piedmonts (footslopes and toeslopes), gently to moderately sloping.	*Camborthids*, *Torriorthents*, *Torripsamments*, Haplargids
Pd	Older deltaic plains and terraces, level to gently sloping.	*Haplargids*, *Camborthids*, Torriorthents, Torripsamments
Ph	Piedmonts (all elements); level to severely dissected.	*Haplargids*, *Calciorthids*, *Paleargids*, *Paleorthids*, Torriorthents, Torripsamments
Pc	Piedmonts (all elements), moderate to severe dissection.	*Calciorthids*, *Paleorthids*, *Torriorthents*, Haplargids, Camborthids, Torripsamments, Paleargids
Pt	Older terraces and badlands, mainly bordering the Rio Grande, cut into the upper part of the Santa Fe Fm.; generally severely dissected.	*Calciorthids*, *Torripsamments*
Pe	Piedmonts (higher portions), moderate to severe dissection.	*Calciorthids*, *Paleorthids*, Camborthids, Torriorthents
ROCKLAND GROUP: Hilly and mountainous areas with much exposed bedrock. Soils generally shallow; profile development weak to very strong. The great groups listed below occur only as inclusions in local areas not dominated by rockland.		
Rh	Lower (and more arid) rockland areas.	*Haplargids*, *Calciorthids*, *Paleorthids*, *Camborthids*, Torriorthents
Ru	Higher (more humid) rockland areas, above about 6000 ft (1,800 m).	*Haplustolls*, *Calciustolls*, Haplargids, Torriorthents
Rc	Arid rockland areas underlain by mainly carbonate bedrock.	*Calciorthids*, *Paleorthids*, Torriorthents

APPENDIX

SUMMARY DEFINITIONS[1] OF ORDERS, SUBORDERS, AND GREAT GROUPS OF THE NEW U.S. SYSTEM OF SOIL CLASSIFICATION

In the new system of soil classification developed by the U.S. Soil Conservation Service, soils are classified into orders, suborders, great groups, and subgroups. Brief definitions through the great group category follow, for those great groups that are represented on the soil association map. Present dominant land use is given for the suborders.

Equivalents also are given, both in terms of the old U.S. (great soil group) classification, and also according to the World Soil Map classification of the Food and Agriculture Organization of the United Nations (the equivalents listed under "FAO =").

ARIDISOLS

Soils that have pedogenic horizons and are low in organic matter and are never moist as long as 3 consecutive months.

Argids

Aridisols that have a horizon in which clay has accumulated with or without alkali (sodium). Used mostly for rangeland and some irrigated crops.

Haplargids:—Argids that have a loamy horizon of clay accumulation, and (in this area) an underlying horizon of calcium carbonate accumulation. Formerly Desert, Red Desert, Sierozem, and some Brown soils (US); FAO = Luvic Ermosols.

Natrargids:—Argids that have a horizon of clay and alkali (sodium) accumulation. Formerly Solonetz soils (US); FAO = Ochric Solonetz.

Paleargids:—Argids that have an indurated (petrocalcic) horizon cemented by carbonates or have a clayey subsurface horizon with or without alkali (sodium) that abruptly changes in texture into an overlying horizon. Formerly Desert, Red Desert, and Sierozem soils (US); FAO = Luvic Ermosols.

Orthids

Aridisols that have accumulations of calcium carbonate, gypsum, or other salts more soluble than gypsum but have no horizon of accumulation of clay. They may have horizons from which some materials have been removed or altered. Used mostly for range and for some irrigated crops.

Calciorthids:—Orthids that have a horizon in which large amounts of calcium carbonate or gypsum have accumulated. Formerly Calcisols (US); FAO = Calxic Ermosols, Gypsic Ermosols.

Camborthids:—Orthids that have horizons from which some materials have been removed or altered but do not have large accumulation of calcium carbonate or gypsum. Formerly some Desert, Red Desert, and Sierozem soils (US); FAO = Calcic Cambisols.

Paleorthids:—Orthids that have a hardpan (petrocalcic horizon) cemented with carbonates. Formerly Calcisols (US); FAO = Calxic Ermosols.

ENTISOLS

Soils that have no pedogenic horizons.

Fluvents

Entisols that have organic-matter content that decreases irregularly with depth; formed in loamy or clayey alluvial deposits. In dry regions used for rangeland and irrigated crops.

Torrifluvents:—Fluvents that are never moist as long as 3 consecutive months. Formerly Alluvial soils (US); FAO = Fluvisols.

Orthents

Loamy or clayey Entisols that have a regular decrease in organic-matter content with depth. In dry regions used for rangeland and (locally) irrigated crops.

Torriorthents:—Orthents that are never moist as long as 3 consecutive months. Formerly Regosols (US); FAO = Rhegosols.

Psamments

Entosols that have textures of loamy fine sand or coarser. Used for rangeland and irrigated crops in arid areas.

Torripsamments:—Psamments that contain easily weatherable minerals; they are never moist as long as 3 consecutive months. Formerly Regosols (US); FAO = Rhegosols.

MOLLISOLS

Soils that have nearly black friable organic-rich surface horizons high in bases; formed mostly in subhumid and semiarid warm to cold climates.

Ustolls

Mollisols that are mostly in semiarid regions. During the warm season of the year, these soils are intermittently dry for a long period or have subsurface horizons in which salts or carbonates have accumulated. Used for rangeland and timberland in map area.

Calciustolls:—Ustolls that are calcareous throughout and have either an indurated (petrocalcic) horizon cemented by carbonates or a horizon in which calcium carbonate or gypsum has accumulated. Formerly Calcisols (US); FAO = Calxic Xerosols.

Haplustolls:—Ustolls that have a subsurface horizon high in bases but without large accumulations of clay, calcium carbonate, or gypsum. Formerly Chernozem, Chestnut, and Brown soils (in part) (US); FAO = Haplic Xerosols, Haplic Castanozems.

[1] From "Soils in the United States" (compiled by the Soil Conservation Service, 1969): National Atlas, sheet 85, 1969, U.S. Geological Survey.

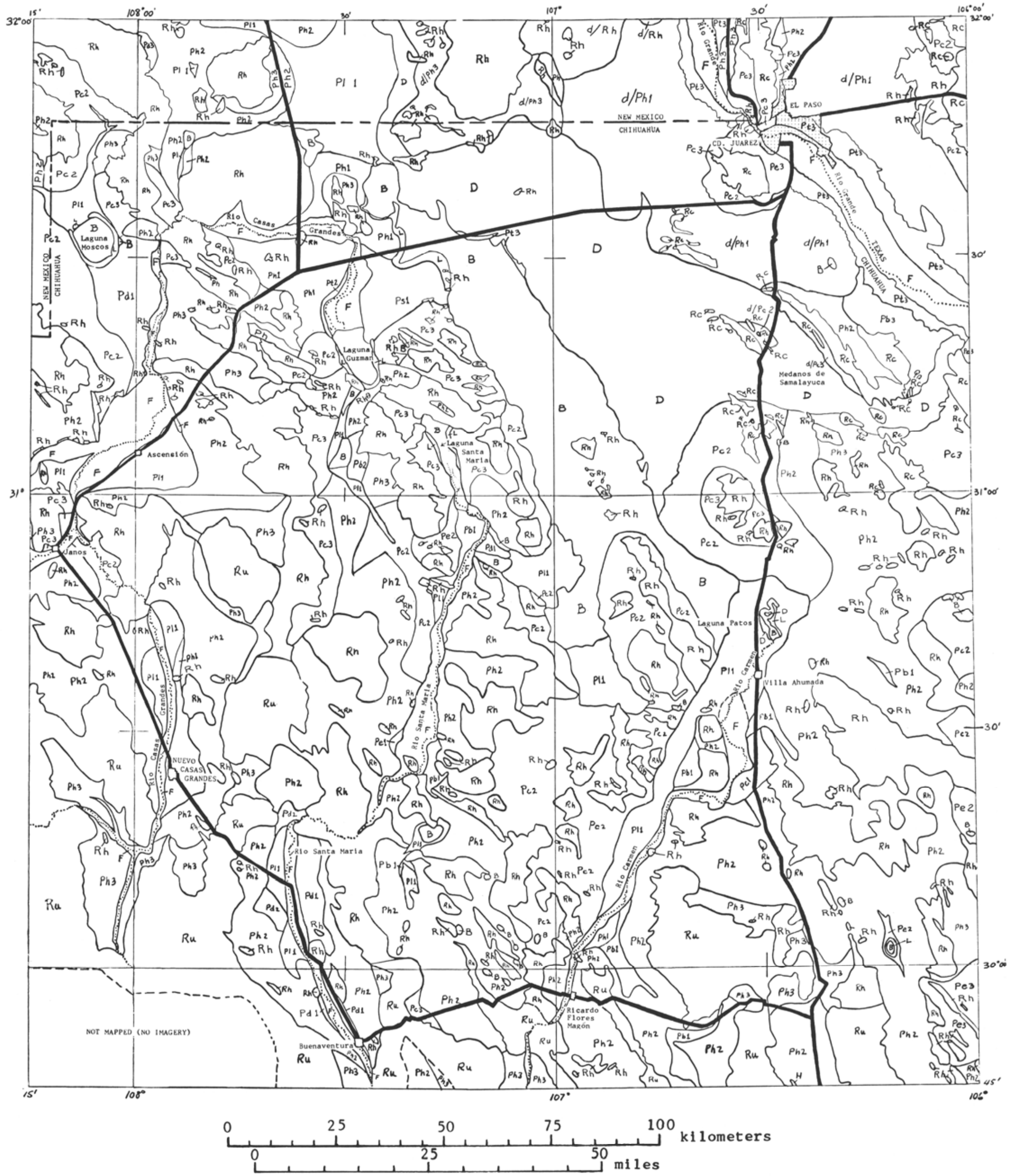

FIGURE 4.
Soil Associations of northern Chihuahua and adjoining New Mexico.

Space photographs in color provide considerably more information about the soils than do black-and-white space photographs, particularly in this warm-arid region, where the upper parts (especially the B horizons) of many of the soils are various shades of red and red-brown. However, the color imaged by a space photograph is not always that of the soil surface; in certain areas the soil color is obscured by grass, brush, or trees. Vegetation shows images in shades of gray, dependent upon its density; for example, forests as dark gray and brush thickets dark to medium gray. In general, however, in all except the forested mountain areas the obscuring effect of vegetation is trivial, and the colors imaged by the space photographs are close to the actual color of the soil surface, especially with the color film used for the Apollo 6, 7, and 9 (hand-held) space photos. The obscuring effect of grass and brush cover usually is much less than it would appear to be to the observer on the ground. Some of the ground-color fidelity of the space photos may be the result of their medium degree of ground resolution, combined with the red-enhancement characteristics of the film, which provides an integrated composite image of the ground color.

As a general rule, the redness, thickness, and clay content of the B horizons of the soils increases with increasing age of the soil. In areas with the same climate, and similar other environmental soil-forming factors such as parent material, the older soils tend to have B horizons that are more clayey and redder in hue and deeper in chroma than the younger soils. This is a general relationship throughout western North America, but it is best displayed in the extreme southwestern US and northern Mexico, because here the soils run the greatest gamut of hues, from 10R to about 10YR of the Munsell color system. This means that this region is an exceptionally favorable one for using color differences, especially in reddish hues, for space-photo-interpretation of soil associations. The special red-enhancing film used for the Apollo color space photographs is a marked advantage over the Gemini photography because it enables the weaker reddish hues to be distinguished, as well as the greatest possible discrimination between various stronger degrees of such hues.

The general rule that the redder soils are the older ones cannot be applied slavishly, however, because of several complicating factors, which is why adequate ground control is essential for accurate mapping of the soils. It is obvious that the reddish B horizons of the older soils, being confined to the upper few inches beneath the land surface, are particularly liable to erosion. The reddest soils are of middle and early Pleistocene age, but they are preserved only where surfaces of this age have remained so little eroded that the B horizons of the soils are preserved. This accounts for the streaky or patchy appearance of many of the older Quaternary surfaces in the space photos, where red patches occur in the relatively uneroded places and gray tones in the places where the B horizon has been removed.

Development of the B horizon is influenced also by the parent material. Strongly calcareous parent material tends to inhibit the development of an illuvial horizon of clay accumulation in the B horizon position. The inhibiting effect of calcareous parent material on B-horizon development becomes especially marked in the parts of this region where the mean annual precipitation is less than about 12 inches; where the mean annual precipitation is less than 10 inches there is virtually no B-horizon development in highly calcareous areas. Parent materials that are relatively high in iron-bearing minerals tend to produce B horizons with redder hues, stronger chromas, and darker values than iron-poor parent materials.

In such arid regions, there is a tendency for calcium carbonate to accumulate in the lower part of the soil profile. Soils having such accumulation are called pedocals; horizons with carbonate concentration are designated as ca horizons. The amount of calcium carbonate accumulation increases with increasing age of the soil, and commonly the soils of middle and early Pleistocene age have strongly developed, even cemented "caliche" horizons (Gile *et* al., 1966) . The degree of calcium carbonate accumulation, however, also is influenced by the parent material. Highly calcareous parent materials, such as alluvium from limestone mountains, promote stronger-than-normal carbonate accumulation for *a* soil of a given age. Conversely, calcium-deficient parent materials result in weaker-than-normal carbonate concentration unless there is an external source of carbonate such as carbonate-laden dust or ground water. Not only does carbonate tend to inhibit the development of a clayey B horizon, there is evidence that after strong carbonate accumulation has taken place the carbonate accumulation may progress upward into and gradually engulf the B horizon (Gile et *al.*, 1966).

Carbonate accumulation in soils is closely controlled by climate. Maximum accumulation occurs in a warm-arid-semiarid climate, neither too dry nor too wet. The upper limit of precipitation is especially critical and a sort of geochemical threshold. In the Basin-and-Range region the local orography is a major control of precipitation, and in a given small area, such as one side of an intermontane basin, with similar parent material, the boundary between pedocal and pedalfer* soils commonly is restricted to an altitude range of several hundred feet; over larger areas, however, it may range several thousand feet in altitude because of varying parent materials and differing local orographic effects. The character of the B horizon also changes markedly at this boundary; it thickens considerably on the pedalfer side of the boundary and it thins on the pedocal side. The thinner and commonly less developed B horizon of pedocals is liable to be truncated by erosion, and in some places so severely that only the more resistant Cca horizon is left. Soils with a Cca horizon but lacking a textural (clayey) B horizon are called Calcisols in the old classification, or Calciorthids, Paleorthids, or Calciustolls in the new classification. Calcisols show on the space photos in shades of gray where they have an A horizon, to white where bare caliche is exposed.

* Pedalfers are formed in relatively humid climates and are characterized by an accumulation of clay minerals and/or hydrolyzates of Fe, Mn, and Al in the B horizon and by the absence of accumulation of alkaline-earth (Ca and/or Mg) carbonates in or below the B horizon.

Where they register grayish they commonly are indistinguishable on the space photos from unweathered alluvium.

An additional complicating factor in use of color differences for photointerpretation of soils is the fact that in some cases comparatively young soils are very red because their parent material includes much reddish sediment, derived either from pre-Quaternary "red beds" or reworked from the red B horizon of an older soil. Striking examples of the latter can be seen in the southern Tularosa Basin north of El Paso, where red eolian sand and alluvium of Wisconsin and Holocene age owe their red color (in places 5YR hues) in large part to having been reworked from the red B horizons of soils of pre-Wisconsin age.

The distinctly reddish soils are confined to the relatively arid lowlands and lower mountains and plateaus, below about 6,000 feet (1,800 m) in this region. In the higher mountains, particularly above 7,000 feet (2,100 m), the increased precipitation causes the surface of the soils to be darker (medium to dark shades of gray) because of increase in organic matter, and the B horizon changes from red-brown to brown (hues 7.5YR and 10YR). Such areas, however, are very limited in the region covered by the soil-association map.

It is obvious from the foregoing discussion of the complexities that beset the photointerpretation of soils that in many cases it is not possible to determine accurately important soil characteristics, such as the character of the B horizon and, if present, the Cca horizon, from just the information available from space photographs. Some ground control is necessary, the amount depending upon the variability of key soil-forming factors, particularly climate and parent material in different parts of the region being mapped, and, of course, the accuracy desired for the mapping.

CONCLUSION

The two maps accompanying this paper demonstrate the practicability of small-scale mapping of geomorphic features and soil associations in an arid region, primarily by photointerpretation of color space photographs, with a minimum of ground control. These are the first systematic maps, in moderate detail, of these features throughout this huge, sparsely populated region, which totals about 20,500 sq mi (53,100 sq km). Except along the Rio Grande, the soils and geomorphic features of this region have not been mapped in comparable detail and accuracy.

A further observation is pertinent: Very little attention has been given to arid-region soils anywhere in the world. This is mainly because these soils have generally not been utilized agriculturally due to lack of water for irrigation. Even in the United States, little detailed information is available about the characteristics and distribution of desert soils—with the notable exception of the intensive studies of the Las Cruces area, New Mexico, by the Desert Project of the U.S. Soil Conservation Service under the leadership of L. H. Gile, J. W. Hawley, and R. V. Ruhe. The soil-association map accompanying this paper is a step toward filling the void on information about the distribution of desert soils in a significant part of the desert region of North America, and it illustrates the possibilities of space-photo-interpretive mapping of soils in other arid regions of the world.

REFERENCES CITED

Davies, M. E., 1967, Big potential for small observation satellites: Astronautics and Aeronautics, v. 5, no. 6, p. 68-72.

Gile, L. H., Peterson, F. F., and R. B. Grossman, R. B., 1966, Morphologic and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, no. 5, p. 347-360.

Lowman, P. D., Jr., 1968, Geologic orbital photography: Experience from the Gemini program: Goddard Space Flight Center (Greenbelt, Md.) Publ. X-644-68-228, 34 p.

Wobber, F. J., 1968, Applications of scientific space imagery: Signal (Journal of Armed Forces Communications and Electronics Assoc.), Oct., 1968.


SIERRA SANTA COTARINA

La Mesa surface from top of East Potrillo Mountains. View SSE to Franklin Mountains in left distance and Juarez Mountains in center distance.
Photo by Sherman A. Wengerd