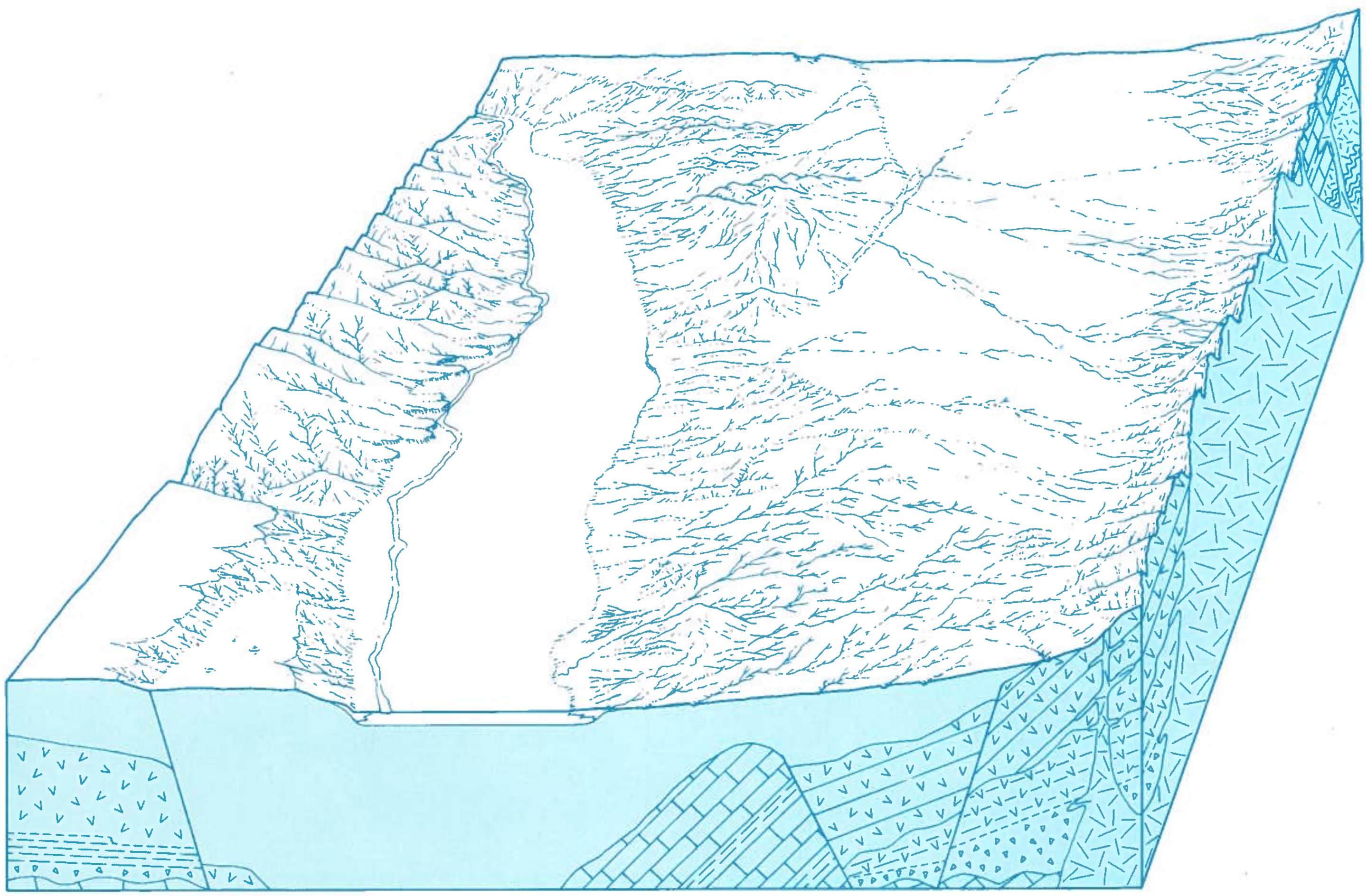
Soils and geomorphology in the Basin and Range area of Southern New Mexico— Guidebook to the Desert Project

by L. H. GILE, J. W. HAWLEY, and R. B. GROSSMAN



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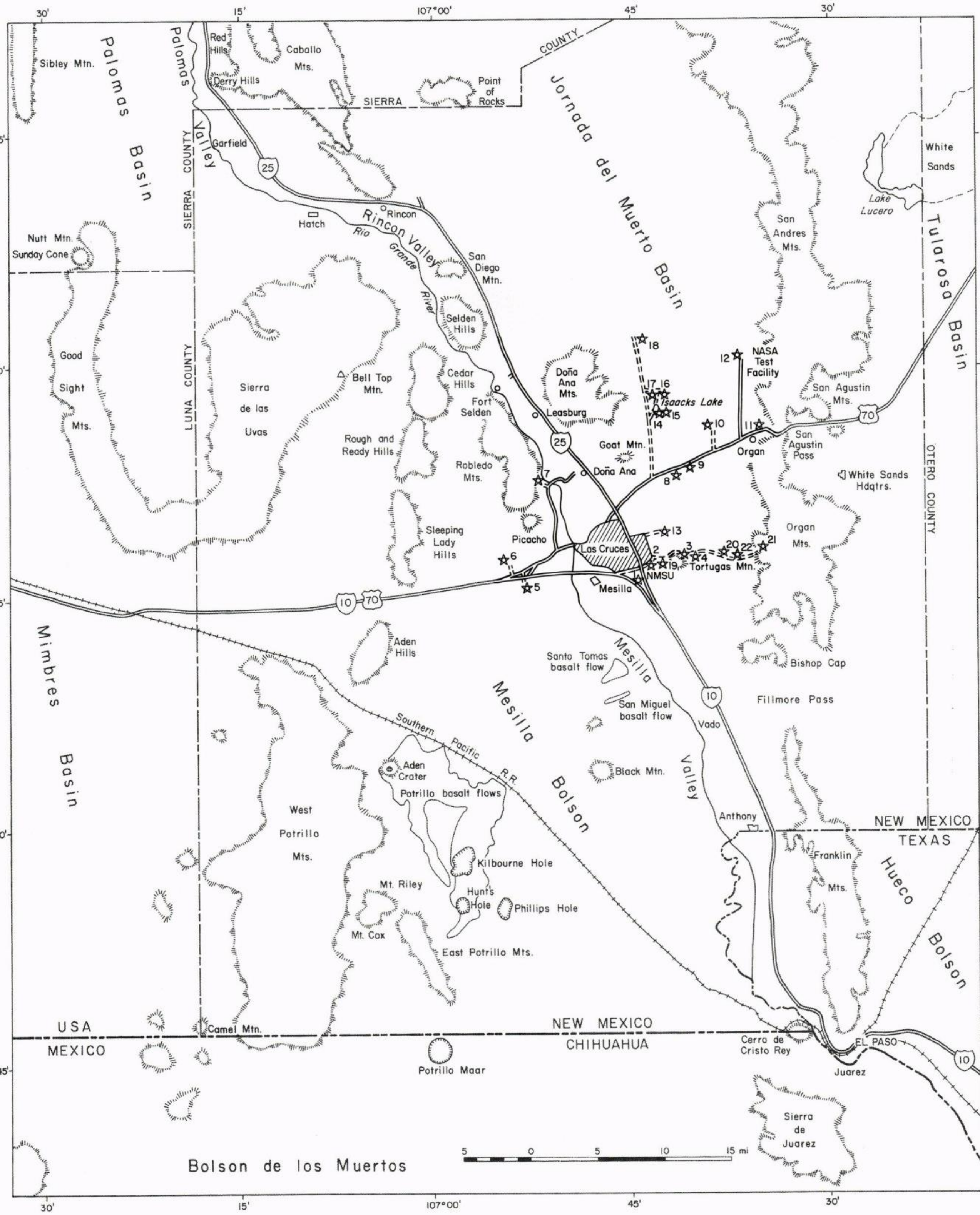
Soils and geomorphology in the Basin and Range area of southern New Mexico— Guidebook to the Desert Project

This book is dedicated to the memory of Guy D. Smith, premier soil scientist, adviser, and friend.

FRONTISPIECE—APOLLO 6 PHOTOGRAPH OF THE DESERT PROJECT, DOÑA ANA COUNTY, AND ADJACENT PARTS OF NEW MEXICO, TEXAS, AND CHIHUAHUA (with index map at right).


Palomas Basin
Palomas Valley
Sibley Mtn.
Red Hills
Caballo Mts.
Derry Hills
Point of Rocks
SIERRA COUNTY
Jornada del Muerto Basin
Garfield
Rincon
Hatch
Rincon Valley
Rio Grande River
San Diego Mtn.
Selden Hills
Nutt Mtn.
Sunday Cone
LUNA COUNTY
Good Sight Mts.
Sierra de las Uvas
Bell Top Mtn.
Cedar Hills
Fort Selden
Leasburg
Doña Ana Mts.
Isaacks Lake
NASA Test Facility
San Andres Mts.
White Sands
Lake Lucero
Tularosa Basin
San Agustin Mts.
San Agustin Pass
Organ
White Sands Hdqtrs.
OTERO COUNTY
Rough and Ready Hills
Robledo Mts.
Goat Mtn.
Doña Ana
Picacho
Sleeping Lady Hills
Las Cruces
Tortugas Mtn.
NMSU
Mesilla
Organ Mts.
Mimbres Basin
Aden Hills
Santo Tomas basalt flow
San Miguel basalt flow
Mesilla Valley
Bishop Cap
Fillmore Pass
Vado
Mesilla Bolson
Southern Pacific R.R.
Aden Crater
Potrillo basalt flows
Black Mtn.
West Potrillo Mts.
Kilbourne Hole
Mt. Riley
Hunt's Hole
Phillips Hole
Mt. Cox
East Potrillo Mts.
Anthony
NEW MEXICO
TEXAS
Franklin Mts.
Hueco Bolson
USA
MEXICO
CHIHUAHUA
Camel Mtn.
Cerro de Cristo Rey
EL PASO
Juarez
Potrillo Maar
Sierra de Juarez
Bolson de los Muertos
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Memoir 39

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Soils and geomorphology in the Basin and Range area of Southern New Mexico—Guidebook to the Desert Project

by L. H. Gile, J. W. Hawley, and R. B. Grossman

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Preface

This book is intended primarily for use in field-study tours of the Desert Soil-Geomorphology Project of the U.S. Soil Conservation Service (informally termed the Desert Project) in Doña Ana County, southern New Mexico (frontispiece). The volume will be useful in the classroom and elsewhere for explanation and study of soil-geomorphic relationships in an arid to semiarid basin-and-range setting. Main purposes are to illustrate major soils and landscapes of the project area, to illustrate principles of soil and landscape evolution in basin-and-range topography, to show the landscape positions in which the soils are most likely to occur, to describe soil development, and to illustrate the United States system of soil taxonomy as it applies to desert soils of the region.

The Desert Project encompasses a 400-sq-mi area studied by a team of soil scientists and geologists from 1957 to 1972. The project was staffed by personnel of Soil Survey Investigations, U.S. Soil Conservation Service; and work was done in cooperation with the Agricultural Experiment Station and Department of Agronomy at New Mexico State University in Las Cruces. Field investigations included mapping the soils, geomorphic surfaces, and surficial deposits at a scale of 1:15,840. In addition, detailed studies at larger scales were conducted along selected transects. Joint laboratory and field investigations included studies of characteristics and genesis of a number of soils and soil horizons, radiocarbon dating of pedogenic carbonates and organic carbon, and studies of the effect of additions from dustfall to soil genesis and morphology. Since 1965, project investigations have been done in cooperation with the New Mexico Bureau of Mines and Mineral Resources; and since 1967, all major reports on geologic phases of the project have been published either by or with support of the Bureau. In 1977 the Desert Project became a formal part of the Bureau's environmental geology program, which includes sponsorship of this and future field-study tours.

The Desert Project has been a good study and training ground for a wide variety of workers. The project area is similar to many arid and semiarid regions in terms of terrain, parent materials for soil, range in age of soils, and general climatic history. Thus principles of soil and landscape evolution worked out in the Desert Project also apply to many areas other than the southwest United States. A number of formal field-study tours were held during progress of the research. Participants included agronomists, anthropologists, archaeologists, biologists, foresters, geomorphologists, geologists, range scientists, and soil scientists. We have received many requests for copies of previous field guides, which were printed only in limited numbers. Supplies of these earlier guides have long been exhausted, and we hope that this volume will be a permanent guide to many of the detailed study sites of the Desert Project.

In addition to this memoir and several journal articles written during progress of the research (see reference list), the Desert Project soil monograph (Gile and Grossman, 1979; Gile, 1981) has been written on the project as a whole. This book may be obtained from the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161 (pub. no. PB80-135304). Complete laboratory analyses, details for methods of analyses reported in this book, many pedon descriptions (including all descriptions of sampled pedons), a list of all soils observed in the project area, and a detailed soil map of the entire project may be found in this monograph. A final report on late Cenozoic geology of the project will be written (by Hawley and others) after detailed mapping of bedrock areas is completed.

Geographic and general measurements in this book are in English units (metric equivalents in parentheses). Geologic and soil-section measurements are in metric (no English equivalents).

ACKNOWLEDGMENTS—We particularly thank Guy D. Smith, under whose general supervision we conducted these investigations, for advice and assistance throughout the existence of the Desert Project. We thank R. V. Ruhe, who—with Guy Smith—made arrangements for establishing the Desert Project, for geomorphic and administrative leadership from 1957 to 1965; F. F. Peterson, for studies of geomorphic surfaces and soils from 1960 to 1962; Warren Lynn, for work on the clay mineralogy; John Cady, for mineralogical studies; L. T. Alexander, for suggestions on C-14 and dust studies; R. C. Vanden Heuvel, who first identified sepiolite in soils of the area; J. L. Gardner and K. A. Valentine for plant identification; and F. E. Kottlowski for steadfast support and assistance in all phases of the geological studies. Others who have contributed to the Desert Project studies include A. L. Metcalf (Quaternary molluscan faunas and stratigraphy), C. A. Wilson, W. E. King, and A. M. Taylor (hydrogeology), W. R. Seager and R. E. Clemons (Cenozoic geology), W. S. Strain (vertebrate paleontology), and C. E. Freeman (Holocene paleobotany).

We are especially grateful to the administration and faculty of New Mexico State University for their generous support of the project, which included providing office and laboratory facilities in the Agronomy Department from 1957 to 1972. Some of our investigations were done on the Jornada Experimental Range of the Agricultural Research Service, U.S. Department of Agriculture. We thank Carlton Herbel and Fred Ares of the ARS staff for their support and cooperation.

The laboratory determinations were made by the U.S. Soil Conservation Service Soil Survey Laboratory, Lincoln, Nebraska. Many of the samples could not be run in standard fashion but required special procedures. We thank R. H. Jordan for supervision of the analyses and data assembly; D. C.

McMurtry for chemical analyses and maintenance of the sample file; L. G. Shields for his interest, suggestions, and maintenance of high standards in the particle-size analyses determinations; R. L. Juve for supervision of the chemical analyses and for his own careful chemical determinations—in particular, for his contributions to the analyses of the small dust samples; Gerald Post for determinations of the calcium-magnesium ratios of carbonate; and J. L. Millet for his overall assistance in the early formulative stages of the analytical work.

Most of the cross sections were prepared by Mark Gower, and most of the block diagrams were drawn by Sam Horn. Special acknowledgment is made to Louise Lee, Joan Hearne, Alice Borden, and Dora Gile for typing and assembling the manuscript. We extend our thanks to LeRoy Daugherty and George Bachman for reviewing the manuscript.

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Abstract

This volume is a comprehensive field guide to the soils, geomorphology, and Quaternary geology of the Rio Grande valley and adjacent intermontane basins near Las Cruces in southern New Mexico. Initially the book was issued for the 1981 tours of the Desert Soil-Geomorphology Project of the U.S. Soil Conservation Service. The first part of the volume includes introductory discussions of the physical setting, geology and geomorphology, and soils of the 400-sq-mi project area in Dona Ana County. The second part includes

detailed commentary on geology and soil-geomorphic relationships at 26 special study sites within the Desert Project. This 4-day tour guide contains maps, cross sections, photographs, and tabular data, as well as connecting road logs between study areas.

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SHEETS *(in pocket)*

1—Lithologic composition
2—Geomorphic surface relationships

Part I

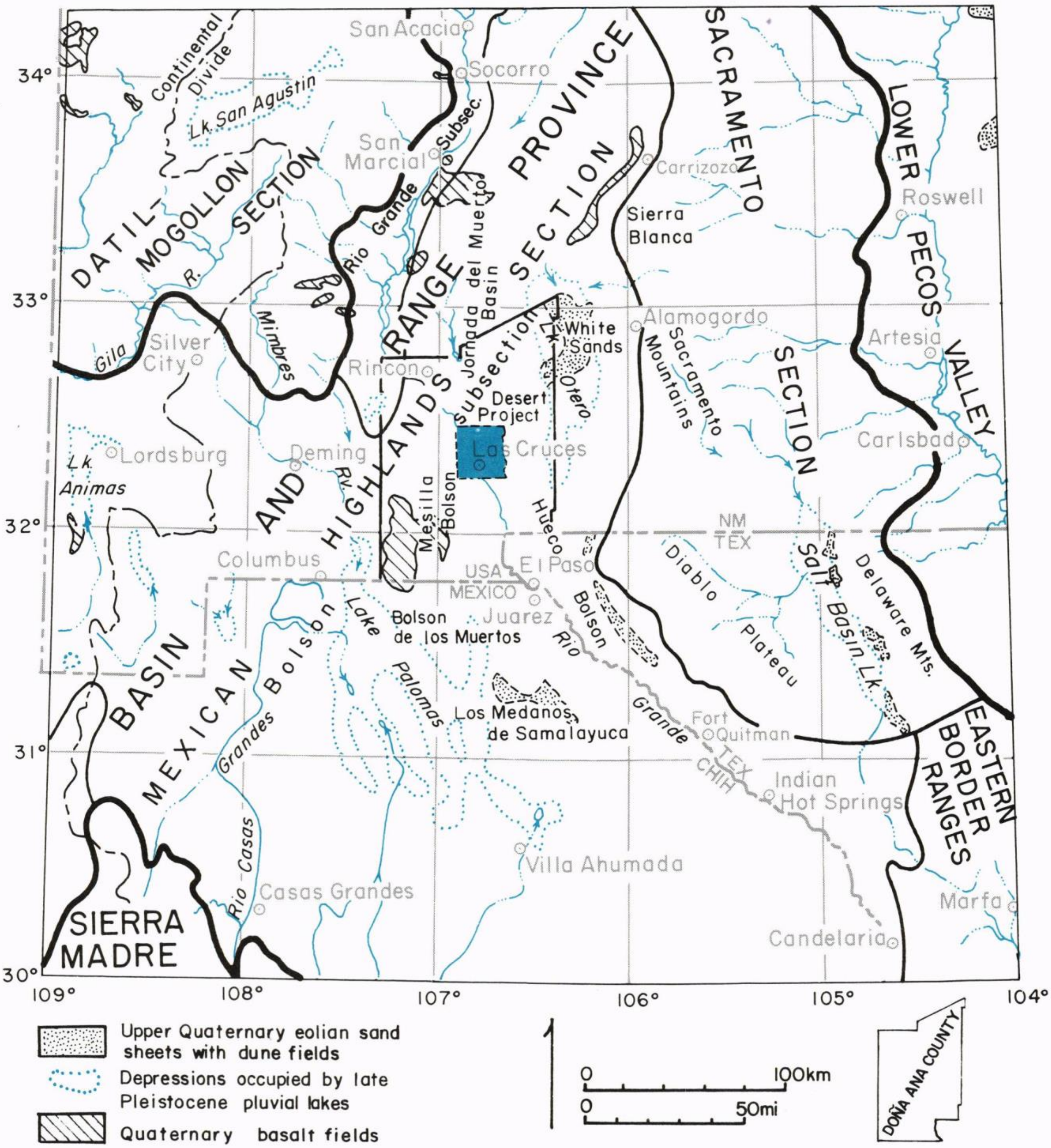

FIGURE 1—Physiographic subdivisions of the Desert Project region, New Mexico, Texas, and Chihuahua, showing major stream systems, pluvial-lake basins, dune fields, and basalt terranes (adapted from Hawley, 1975, fig. 1).

Chapter 1—Introduction

1.1 LOCATION OF INFORMATION

This memoir consists of two parts. Part I comprises three chapters that provide background information on the physiography, climate, vegetation, geology, geomorphology, and soils of the study areas. Chapters are divided into numbered sections, such as 2.14. When these sections are cross-referenced, the number alone is given in parentheses (2.14). Part II consists of a 4-day guided tour through the study areas, with discussions, illustrations, and a road log describing features between specific sites. A map and summary of features discussed in each day's tour are given in the first pages for each day. Table 16 is an index of laboratory data, photographs, and soil discussions arranged by soil classification.

Each detailed study area (Part II) is organized around an exposure of the soils and associated geologic materials. Some study areas are along natural exposures such as arroyos or gullies, whereas others use large trenches. Many of the trenches can be opened temporarily but must be refilled to prevent erosion and sedimentation during rainy seasons. Accessibility of the section (filled trench or open exposure) at each study area is given in the four summary tables at the start of each day's tour.

1.2 SETTING

1.21 Physiography

The Desert Project region (frontispiece, fig. 1, table 1) is located in the Mexican Highland section of the Basin and Range physiographic province (Fenneman, 1931; Thornbury, 1965). Hawley (1975) designated this part of the Mexican Highland as the Bolson subsection. The region is characterized by broad desert basins and discontinuous ranges. Mountains occupy approximately 20 percent of the total area; crest elevations range from 5,709 to 9,012 ft (1,740 to 2,747 m). Intermontane basins extend south into Chihuahua and north into central New Mexico. Through drainage is confined to the Rio Grande system and, for the most part, occupies valleys entrenched well below the floor of two adjacent closed basins, the Jornada del Muerto Basin and the Mesilla Bolson. River floodplain elevations in the project area range from 3,870 to 3,970 ft (1,180 to 1,210 m); minimum elevations of basin floors range from 4,200 to 4,300 ft (1,280 to 1,310 m).

Major physiographic features of the Desert Project (shown in fig. 2) are the prominent mountain masses in the east and northwest parts of the area, intermontane basins (2.21), and the Rio Grande valley (2.22). The major basin landforms are 1) piedmont slopes, consisting of fans, interfan valleys, and

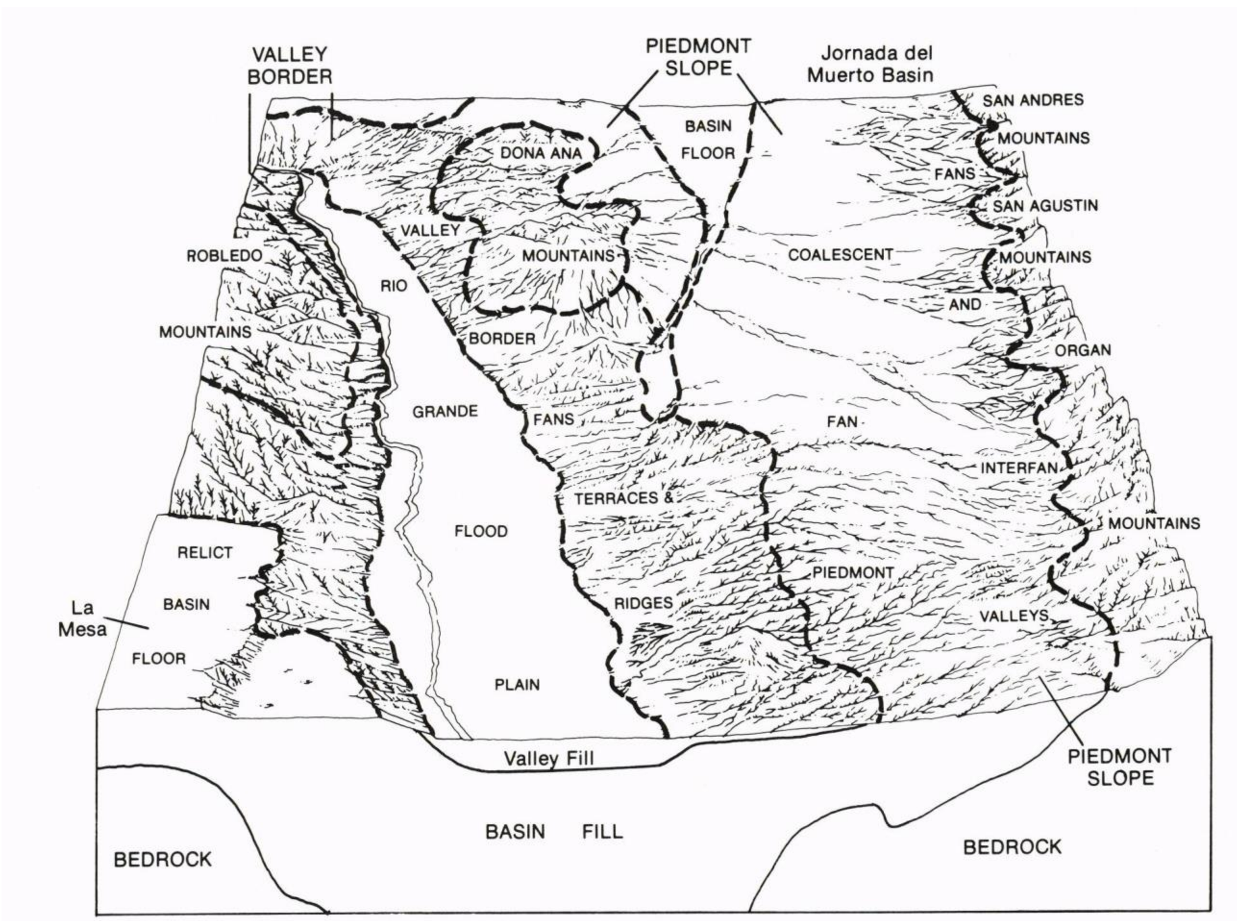

FIGURE 2—BLOCK DIAGRAM SHOWING MAJOR LANDFORMS OF THE DESERT PROJECT (from Gile, 1975, 1977, fig. 1, with permission).

TABLE 1—CHARACTERISTICS OF BASIN AND RANGE PROVINCE SUBDIVISIONS IN THE DESERT PROJECT REGION, NEW MEXICO, TEXAS, AND CHIHUAHUA (adapted from Hawley, 1975, table 1). Numbered references below.

Province	Section	Subsection	Characteristic features
	Datil-Mogollon		*Volcanic upland with basins; dominated by high tablelands, with scattered fault-block ranges and basins and deep canyons. Rhyolitic tuffs and andesites are major upland formers, with pre-Tertiary rocks locally forming highlands (8). Section is transition between Colorado Plateau and Basin and Range provinces (19).* Special features: *Continental Divide (elevation range 2,025–3,050 m, 6,650–10,000 ft); numerous Oligocene volcanic centers (8); San Agustin Plains, a large closed basin (minimum elevation 2,067 m, 6,780 ft) was the site of pluvial Lake San Agustin (27, 30).*
Basin and Range	Mexican Highlands	Rio Grande	*Narrow structural depression, partly occupied by the valley of the Rio Grande, between the Datil-Mogollon section and the Bolson subsection of the Mexican Highlands. The river flows from north to south through an alternating series of broad and narrow valley segments that coincide with an* en echelon *series of structural basins each separated by uplifts of more resistant, Miocene and older rocks (6,7,12). The valley for the most part is incised in intermontane basin fill and associated volcanics of Late Cenozoic age. From the Albuquerque-Belen Basin south, Pliocene to middle Pleistocene (upper Santa Fe Group) deposits form the bulk of the exposed basin fill (13). A stepped sequence of valley-border surfaces, graded to successively lower levels of river incision, is inset below relict basin-fill and piedmont-erosion surfaces of early to middle Pleistocene age (14).* Special features: *Rio Grande floodplain gradient between San Acacia (1,420 m, 4,660 ft) and Rincon (1,231 m, 4,040 ft) is about 0.0009 (4.7 ft/mi). Flood discharge in excess of 1,418 sq m/sec (50,000 cfs) was measured at San Acacia on 9/23/29 (39). Average discharge of San Marcial (40) at the head of Elephant Butte Reservoir is 39 cu m/sec (1,371 cfs) or 121,388 ha-m/yr (992,600 acre-ft/yr).*
		Bolson	*Large area of southwestern New Mexico, extending into Texas, Chihuahua, and Arizona, characterized by broad intermontane basins with internal drainage (= bolsons) and scattered fault-block ranges that occupy about one-fifth of the area (10). Type region of the bolson landform (17, 37). Mountains formed mainly of pre-Tertiary carbonate and clastic rocks, with local Tertiary volcanic and plutonic sequences and Precambrian igneous and metamorphic terranes (12, 36, 38). Quaternary bolson fill, rarely more than 100 m (330 ft) thick, overlies late Tertiary bolson deposits (lower Santa Fe and Gila Group equivalents) that locally exceed 1,000 m (3,300 ft) in thickness (1, 9, 12, 15, 24, 34, 35). Major basin-fill facies are a) piedmont alluvium, including fan deposits and erosion-surface veneers; b) basin-floor sediments, including fine-grained alluvium and lake and playa deposits; c) fluvial sand and gravel of ancient river systems; and d) eolian sand.* *The Rio Grande crosses the southeastern part of the area in a valley entrenched about 100 m (300–400 ft) below remnants of middle Pleistocene bolson plains. As in the Rio Grande subsection to the north, the floodplain is flanked by a stepped sequence of valley-border surfaces. The Gila River crosses the northwest part of the area in a similar setting (29).* Special features: *The Continental Divide (minimum elevation 1,359 m, 4,460 ft) shown on fig. 1 is arbitrarily located along highest drainage divides in a complex of closed basins west of the Rio Grande. The highest peak in the area is Organ Needle (elevation 2,747 m, 9,012 ft). Rio Grande floodplain elevation ranges from about 1,231 (4,040 ft) at Rincon to 853 m (2,800 ft) at Candelaria 400 km (250 mi) downstream. Intermontane basins contain numerous closed depressions, some occupied by perennial lakes during Pleistocene glacial-pluvial intervals (11, 13). The largest late Pleistocene lakes, ranging from hundreds to thousands of square kilometers in surface area, include Lake Animas west of Lordsburg (33), Lake Otero in the Tularosa Basin (14, 16), and Lake Palomas in north-central Chihuahua (31). Major dune fields, White Sands (28) and Los Medanos de Samalayuca (10), have formed on the lee sides of the latter two lake plains. Quaternary basalt fields are locally extensive (26).*
	Sacramento		*Broad, rolling, upland plains,* cuesta-like *mountains with west-facing escarpments, and widely scattered structural basins. Highlands are primarily underlain by Paleozoic carbonate and gypsiferous-clastic rocks that have a gentle eastward dip disrupted by local flexures. The middle Tertiary Sierra Blanca volcanic and plutonic complex (maximum elevation 3,658 m, 12,002 ft) forms the highest part of the section (20, 21, 25, 32). Salt Basin (minimum elevation 1,095 m, 3,590 ft), a large graben complex between the Guadalupe-Delaware uplift and the Diablo Plateau, contains thick late-Cenozoic bolson fill (23).* Special features: *Lacustrine and eolian deposits in Salt Basin are associated with late Quaternary intervals of pluvial lake formation and desiccation (23). Late Pleistocene glacial moraines (minimum elevation 3,050 m, 10,000 ft) have been identified on the north slope of Sierra Blanca (32). High-level remnants of ancient stream deposits (ancestral lower Pecos system) are locally present (4, 5, 13, 18, 20, 21, 25).*
	Eastern Border	Ranges	*Volcanic upland with basins (22). High tablelands and tilted fault-block ranges, including some uplands formed on Cretaceous limestone as well as Tertiary acid to intermediate volcanics; extends south through the Big Bend region into Mexico. The area includes the Davis Mountain volcanic center (3) and exhumed features of the Late Paleozoic* Quachita System *in the Marathon region (22). Alluvial fills in basins and valleys are really extensive (2) but are probably thin except in basin areas northwest of Marfa.*

(1) Akerston, 1970
(2) Albritton and Bryan, 1939
(3) Anderson, 1968
(4) Bachman, 1976
(5) Bretz and Horberg, 1949a
(6) Bryan, 1938
(7) Chapin and Seager, 1975
(8) Chapin and Elston, 1978
(9) Groat, 1972
(10) Hawley, 1969
(11) Hawley, 1975
(12) Hawley, 1978
(13) Hawley and others, 1976
(14) Hawley and Kottlowski, 1969
(15) Hawley and others, 1969
(16) Herrick, 1904b
(17) Hill, 1900
(18) Horberg, 1949
(19) Hunt, 1974
(20) Kelley, 1971
(21) Kelley, 1972
(22) King, 1937
(23) King, 1948
(24) King and others, 1971
(25) Lovelace and others, 1972
(26) Luedke and Smith, 1978
(27) Martin and Mehringer, 1965
(28) McKee and Moiola, 1975
(29) Morrison, 1965
(30) Powers, 1939
(31) Reeves, 1969
(32) Richmond, 1963
(33) Schwennesen, 1918
(34) Seager and Morgan, 1979
(35) Strain, 1966
(36) Texas Bureau of Economic Geology, 1968
(37) Tight, 1905
(38) Twiss, 1971
(39) Water Resources Division, 1965
(40) Water Resources Division, 1970

TABLE 2-AVERAGE **PRECIPITATION AT UNIVERSITY PARK (ELEVATION** 3,881 **FT, IN RIO GRANDE VALLEY) AND BOYD'S RANCH (ELEVATION** 6,200 **FT, IN ORGAN MOUNTAINS).** Values are in inches except for centimeters in parentheses, annual column. Data from U.S. Weather Bureau (1931-1960, 1962-1967) and R. E. Boyd, personal communication.

Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Valley border (University Park, 1892-1966)												
.36	.41	.36	.21	.30	.59	1.47	1.70	1.22	.71	.44	.49	8.26 (21)
Valley border (University Park, 1948-1957)												
.37	.70	.25	.12	.24	.35	1.31	1.02	.58	.84	.12	.29	6.18 (16)
Mountain fronts (Boyd's Ranch, 1948-1957)												
.82	.82	.37	.34	.49	.57	3.29	1.71	.83	1.68	.25	.34	11.49 (29)

minor rock pediments along the mountain fronts and coalescent-fan piedmonts downslope and 2) basin floors, with small playa-lake depressions and extensive alluvial plains. The river valley has floodplain and valley-border components. The latter include arroyo channels, alluvial fans and terraces, structural benches, and complexes of erosional surfaces on interfluve ridges.

1.22 Climate

PRESENT CLIMATE-Two general kinds of climate occur in the project area. Along the Rio Grande valley and in the Jornada del Muerto Basin north of US-70 the climate is arid (Thornwaite, 1948). The climate of the San Andres and Organ Mountains (the highest mountains) is considered (on the basis of limited data) to be semiarid. Short-term records of precipitation at several places in the mountains suggest that the precipitation from 5,000 to 6,000 ft (1,524-1,829 m) ranges from approximately 10 to 16 inches (25-40 cm) annually. Soils at these elevations occur in the mountain canyons and on the high fans along the mountain fronts. A-horizons darken and thicken in many places at approximately 5,000 ft (1,524 m). An increase in density of vegetation commonly occurs at this elevation, and vegetation characteristic of higher elevations (such as blue grama) first appears. Depth of wetting also increases at this elevation. For purposes of this memoir, the general elevation figure of 5,000 ft (1,524 m) is considered to mark the approximate boundary between the arid and semiarid zones.

Precipitation and air temperatures are summarized in tables 2 and 3. Evaporation is more than 10 times the annual precipitation. Wind speeds are highest in the spring, when dust storms are common.

LATE QUATERNARY CLIMATES -In the southern Basin and Range province, times of greater effective moisture occurred during the last full-glacial interval from about 12,500 to 23,000 yrs B.P. (Martin and Mehringer, 1965). Small glaciers formed in nearby alpine areas (Richmond, 1963; Merrill and Pewe, 1978), and perennial lakes occupied numerous closed basins in the region (Hawley and others, 1976). On the southern High Plains, Wendorf (1961) and Reeves (1973) have described a cool-moist interval (the Tahoka pluvial) from 15,000 to 22,500 yrs B.P.

Late Pleistocene climates in the region prior to the last full glacial are poorly documented. An interglacial interval with conditions very similar to those of the last 10,000 yrs (the Holocene) probably occurred about 115,000-125,000 yrs ago (2.7). Quite possibly, long intervals of late Pleistocene time had mild climates relative to either the hot-dry conditions of

TABLE **3-AVERAGE AIR TEMPERATURE (IN °F) AND EVAPORATION AT UNIVERSITY PARK.** Values for evaporation are in inches except for centimeters in parentheses, annual column. Data from U.S. Weather Bureau (1965).

Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Air temperature (1898-1960)												
41.5	45.7	51.6	59.1	67.1	76.5	79.4	77.6	71.0	61.2	48.9	41.6	60.1
Evaporation (1930-1960)												
3.00	4.38	7.77	10.33	12.61	13.77	12.46	10.71	8.70	6.24	3.95	2.74	96.66 (246)

the present or the cold-dry to cool-moist climate inferred for the last full glacial. There is agreement that climatic conditions in the intermontane basins were always arid to semiarid throughout late Quaternary time. Subhumid to humid conditions would only have occurred in higher mountain terrains.

Evidence for more effective moisture in the Desert Project region during the last full glacial is presented by Antevs (1954), Gile (1966b), Metcalf (1967), Harris (1977), Lanner and Van Devender (1981), Van Devender and Spaulding (1979), and Wells (1979). Most detailed studies in the Chihuahua Desert (such as Wells, 1979) suggest that this interval was a pluvial period with increased precipitation, cool summers, and relatively mild winters. However, Galloway (1970) and Brakenridge (1978) speculate that full-glacial intervals were characterized by very cold temperatures and precipitation similar to today's. Even if pluvial precipitation were near the present mean annual value, more moisture would have been available for leaching because of greatly reduced evaporation associated with the lower temperatures of the full glacial.

Archaeological, paleobotanical, and paleontological evidence indicate that the last full glacial was followed by a warmer and drier interval interrupted with short periods of greater effective moisture (Mehringer, 1967; Irwin-Williams and Haynes, 1970; and Van Devender, 1977). Irwin-Williams

TABLE 4—SCIENTIFIC AND COMMON NAMES OF GRASSES AND FORBS, TREES AND SHRUBS in Desert Project region.

Scientific name	Common name	Scientific name	Common name
Perennial grasses			
Aristida divaricata	Three-awn	*Muhlenbergia porteri*	Bush muhly
Aristida pansa	Three-awn	*Panicum obtusum*	Vine mesquite
Bouteloua curtipendula	Sideoats grama	*Scleropogon brevifolius*	Burro grass
Bouteloua eriopoda	Black grama	*Setaria macrostachya*	Bristlegrass
Bouteloua gracilis	Blue grama	*Sporobolus airoides*	Alkali sacaton
Bouteloua hirsuta	Hairy grama	*Sporobolus cryptandrus*	Sand dropseed
Enneapogon desvauxii	Spike pappusgrass	*Sporobolus flexuosus*	Mesa dropseed
Eragrostis sp.	Lovegrass	*Stipa eminens*	Needle grass
Hilaria mutica	Tobosa grass	*Trichachne californica*	Cottontop
Leptochloa dubia	Sprangletop	*Tridens muticus*	Slim tridens
Muhlenbergia emersleyi	Bullgrass	*Tridens pulchellus*	Fluffgrass
Annual grasses			
Aristida adscensionis	Three-awn	*Bouteloua barbata*	Six weeks grama
Forbs			
Allionia incarnata	Trailing four o'clock	*Pectis angustifolia*	Fetid marigold
Astragalus allochrous	Milkvetch	*Perezia nana*	Desert holly
Athysanus pusillus	Mustard	*Phacelia* sp.	Scorpion weed
Bahia sp.	Wild chrysanthemum	*Salsola kali*	Russian thistle
Baileya pleniradiata	Desert marigold	*Verbena* sp.	Vervain
Dithyrea wislizeni	Spectacle-pod	*Verbesina encelioides*	Golden crown-beard
Eriogonum abertianum	Desert buckwheat		
Shrubs and trees			
Acacia constricta	Whitethorn	*Gutierrezia sarothrae*	Snakeweed
Acacia greggii	Catclaw	*Haplopappus laricifolius*	Turpentine bush
Agave palmeri	Century plant	*Helianthus ciliaris*	Blueweed
Artemesia filifolia	Sand sage	*Holacantha emoryi*	Crucifixion thorn
Atriplex canescens	Four-wing saltbush	*Hymenoclea monogyra*	Burro brush
Bacharis pteronoides	Yerba de pasmo	*Juniperus monosperma*	Juniper
Brickellia laciniata	Brickellbush	*Koeberlinia spinosa*	Crucifixion thorn
Ceanothus greggii	Mountain lilac	*Krameria parvifolia*	Ratany
Celtis reticulata	Desert hackberry	*Larrea tridentata*	Creosotebush
Croton corymbulosus	Croton	*Lippia wrightii*	
Chilopsis linearis	Desert willow	*Lycium berlandieri*	Desert thorn
Coldenia canescens		*Nolina microcarpa*	Beargrass
Condalia lycioides	Buckthorn	*Opuntia* spp.	Cholla, prickly pear
Condalia spathulata	Mexican crucillo	*Parthenium incanum*	Mariola
Dalea formosa	Indigo bush	*Pinus edulis*	Pinon
Dalea scoparia	Broomdalea	*Prosopis juliflora*	Mesquite
Dasylirion wheelerii	Sotol	*Quercus* sp.	Oak
Echinocactus wislizenii	Barrel cactus	*Rhus microphylla*	Sumac
Ephredra torreyana	Mormon tea	*Rhus trilobata*	Squawbush
Ephedra trifurca	Mexican tea	*Senecio filifolius*	Threadleaf groundsel
Eurotia lanata		*Yucca baccata*	Yucca
Fallugia paradoxa	Apache plume	*Yucca elata*	Yucca
Flourensia cernua	Tarbush	*Zinnia pumila*	Desert zinnia
Fouquieria splendens	Ocotillo		

and Haynes infer that minor pluvials occurred at approximately 11,000-11,500 yrs B.P., 10,000-10,500 yrs B.P., and 8,000-8,500 yrs B.P. A long, warm interval, the "altithermal," lasted from 7,500 to 4,000 yrs B.P. according to Antevs (1955) and from 7,500 to 5,000 yrs B.P. according to Irwin-Williams and Haynes (1970). Paleobotanical studies by Martin and Mehringer (1965) and Van Devender (1977) show that this interval may have been characterized by intense, warm-season precipitation. The dated stratigraphic record definitely indicates the onset of a major period of landscape instability and erosion-sedimentation during this interval (2.6 and 2.7; Haynes, 1968a).

1.23 Vegetation

Grasses, shrubs, trees, and forbs observed in the Desert Project are listed in table 4.

Chapter 2—Geology and geomorphology

The geomorphic and geologic mapping-unit concepts discussed in this chapter attest to the absence of neat separations between geology, geomorphology, and soil science. Multidisciplinary studies are needed to explain many geomorphic and pedologic features. Specific examples are given in the various study areas (see the summary tables at the start of each day's field-study tour).

2.1 BASIC PRINCIPLES AND TERMINOLOGY

Landforms are features of the earth's surface caused by natural processes. Geomorphology is the earth-science subdivision that deals with the surface geometry, genesis, and age of landforms. It includes studies of a variety of surficial materials, soils, and geologic structures, as well as studies of the processes that formed them.

Landforms in aggregate are landscapes and can be considered at a wide range of scales. The major mountain and basin forms are products of deep-seated earth movements (tectonism) and associated volcanic activity during the past 30-40 m.y. The Rio Grande valley system and the vast constructional surfaces of the intermontane basins are examples of major forms produced jointly by the gradational action of running water and deep-seated forces. The small-scale forms that are superimposed on the major features were produced during the Quaternary Period, primarily by the action of running water, and were locally influenced by mass wasting and wind action. These landforms include pediments, alluvial fans and terraces, gullies, dune fields, arroyos, and structural benches. In terms of soil-geomorphic relationships, the most important landforms are the graded complexes of erosional and depositional surfaces in river-valley and intermontane-basin settings. These surfaces often occur in stepped (topographic) sequences that range from hundreds to hundreds of thousands of years in age. Pleistocene units bear the imprint of local base-level and climate-process controls significantly different from those of the Holocene Epoch (1.22).

2.11 Geomorphic components of hilislopes

The hillslope model, in the context of soil-landscape relationships (Ruhe, 1960; Ruhe and Walker, 1968), provides an excellent means of integrating slope geometry, geologic materials, and geomorphic processes. Ruhe's (1975, figs. 6.2, 6.3) simple hillslope continuum from upland summit to lowland floor (fig. 3), while idealized, is applicable to any landscape where stream erosion is the major geomorphic process. Emphasis here is on hillslope form and process in the Desert Project region; and discussion is limited to a single shoulder-backslope-footslope-toeslope continuum formed by the erosive action of running water and mass wasting. Valleys are occupied by low order, ephemeral streams with gradients exceeding 1 percent; and local relief is in the low to moderate range (less than 330 ft, 100 m).

Ruhe (1975, chapters 6 and 7) describes hillslopes in a variety of physiographic settings, and he discusses their relationship with geomorphic surfaces and soils. His hillslope classification has recently been applied to landforms in the Basin and Range province by Peterson (1981, figs. 15, 17). Dalrymple and others (1968) propose an elaborate, "nine-unit landsurface model" for hillslopes that is useful for soil-geomorphic studies in more humid areas.

The idealized hillslope profile (fig. 3a), between upland summit and the floor of a stream valley or closed depression, has shoulder, backslope, footslope, and toeslope components. However, not all of these must be present in a given slope; or backslope-footslope sequences may be repeated in a complex slope.

Summit is the general term for the top of an upland feature that is flanked by steeper sides comprising the hillslope components. Summits range from narrow ridge crests to broad platforms, such as treads of stream terraces. The *shoulder,* which is convex in profile and degradational in origin, is a transition zone between the summit and the steepest side-slope component of the upland, the *backslope.* Backslopes are

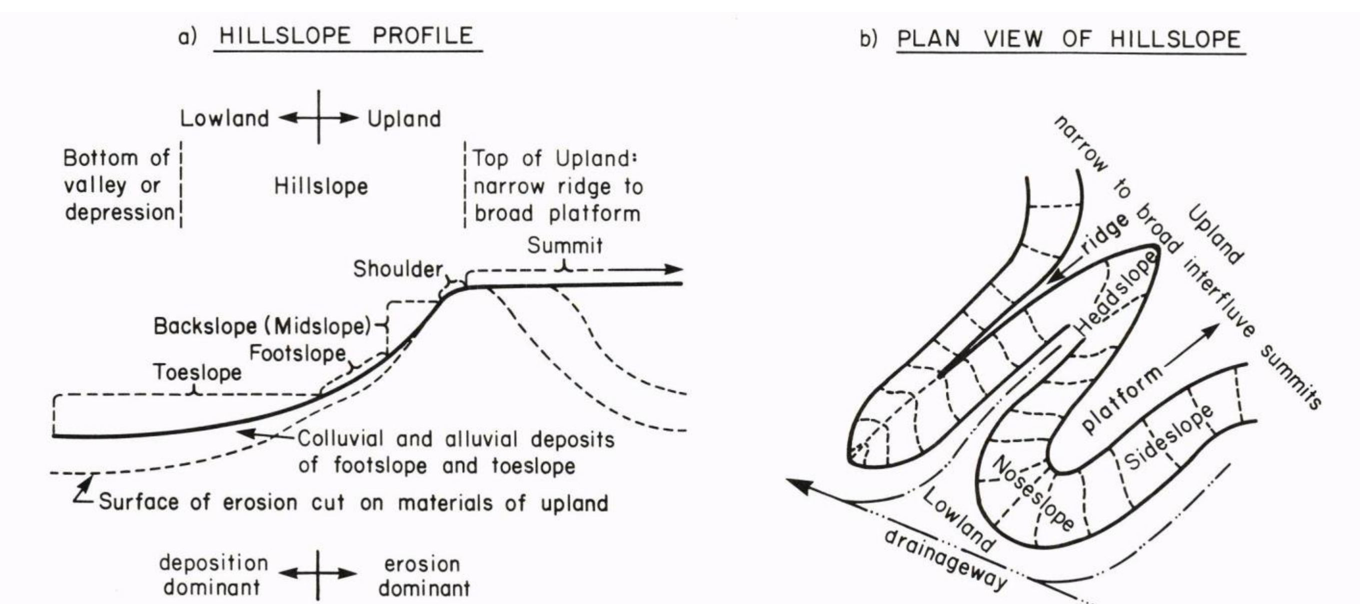

FIGURE 3—GEOMORPHIC COMPONENTS OF HILLSLOPES: a) hillslope components in profile, b) hillslope components in plan view (adapted from Ruhe, 1975, fig. 6.2).

usually linear in profile, but they may include cliff segments alternating with gentler colluvial (debris) slopes. They are dominantly degradational surfaces produced by water erosion and mass wasting. Structural dipslopes cut on gently dipping resistant strata are also called backslopes (for example, cuesta backslopes). Therefore, to avoid confusion, the term mid-slope (Dalrymple and others, 1968) may be used in place of backslope, particularly where a cliff segment is not present.

The *footslope* component is the gently inclined surface at the base of the backslope. Its profile is concave, and it is a transition zone between upslope areas dominated by erosion and downslope surfaces of deposition. The constructional (or alluvial) *toeslope* forms the distal part of the hillslope continuum and its gently sloping profile is linear to slightly concave. It grades to the floor of a stream valley or closed depression.

Fig. 3b is a planimetric diagram showing upland summits and hillslope components in valleys of low-order ephemeral streams. Such tributary systems are typical of the Rio Grande valley border (Part II, study areas 2 and 7). Dashed lines show the changing pattern of shoulder-backslope-footslope profiles across valleys and interfluves. Profile lines converge in valley *headslope* areas, while they diverge on *noseslopes* at the end of interfluves. *Sideslopes* are characterized by roughly parallel profile elements.

2.12 Stratigraphy

Soil-geomorphic investigations must have a firm stratigraphic base. *Stratigraphy* is the subdivision of geology dealing with the origin, composition, age, and correlation of earth materials. The ability to accurately characterize and predict distribution of geologic units, often seen only in limited natural or artificial exposures, is dependent upon the amount of stratigraphic information available.

Geologists define several broad categories of stratigraphic units (American Commission on Stratigraphic Nomenclature, 1970). Where earth materials can be separated from one another and mapped on the basis of distinguishable lithologic properties, they are defined as rock-stratigraphic units. The basic mappable category (usually at scales of 1:24,000 or smaller) is the *formation.* Two or more formations can be combined into a *group,* or a formation can be subdivided into *members* and *beds.* Middle Pleistocene and older sediments and rocks of the project area have been mapped as rock-stratigraphic units. Geochronologic and chronostratigraphic terms used in this report are shown on table 5.

2.13 Geomorphic surfaces and morphostratigraphic units

Age, origin, and physical-chemical properties of surficial materials and land surfaces are rarely shown in enough detail

TABLES—MAJOR GEOCHRONOLOGIC AND CHRONOSTRATIGRAPHIC UNITS; B.P.—before 1950, following the custom for reporting radiocarbon ages; m.y.—millions of years. Quaternary ages are estimated by the authors and subject to revision; see fig. 8 for details of late, middle, and early Pleistocene (adapted from 1980 USGS Geologic Names Committee chart, listed in *Isochron/ West).*

Era or Erathem	Period or System	Epoch or Series	Years B.P.	Started m.y. ago	(est. ranges)
Cenozoic	Quaternary	(Historical	-- 1850 A.D. to present)		
		Holocene	Late 2,500 to present Mid 2,500 to 7,500 Early 7,500 to 10,000	0.010	
		Pleistocene	Late 10,000 to 250,000 Mid	2	(1.7-2.2)
	Tertiary	Pliocene		5	(4.9-5.3)
		Miocene		24	(23 - 26)
		Oligocene		38	(34 - 38)
		Eocene		55	(54 - 56)
		Paleocene		63	(63 - 66)
Mesozoic	Cretaceous			138	(135-141)
	Jurassic			205	(200-215)
	Triassic			~240	
Paleozoic	Permian			290	(290-305)
	Pennsylvanian			~330	
	Mississippian			360	(360-365)
	Devonian			410	(405-415)
	Silurian			435	(435-440)
	Ordovician			500	(495-510)
	Cambrian			~570	
Precambrian			oldest known rocks in U.S.A.	3,600	

(Formation of earth's crust about 4,600 m.y. ago) on conventional geologic maps to help evaluate many pedogenic features. A major effort of Desert Project geologic studies has involved testing of map-unit designs that adequately portray geology and geomorphology at the scale of local soil landscapes (usually 1:24,000 or larger). *Concepts of geomorphic surfaces* (Ruhe, 1975) and *morphostratigraphic units* (Frye and Willman, 1962) originally developed for mapping Quaternary surfaces and deposits in the Midwest, were found to be very useful. They have been adopted as the basic cartographic concepts for illustrating geology-related factors of soil formation in the project area.

Investigators of soil-geomorphic relationships have used the term *geomorphic surface in* a specific context primarily related to soil age and landscape position (Ruhe, 1956, 1969, 1975). Balster and Parsons (1968, p. 2) state that a "geomorphic surface is a land form or group of land forms that represents an episode of landscape development." To Ruhe (1969, p. 5) it is a "portion of the land surface that is specifically defined in terms of space and time." Daniels, Gamble, and Cady (1971, p. 3) stress that a geomorphic surface "is a part of the surface of the land that has definite geographic boundaries and is formed by one or more agencies during a given time span." Unstated but implied in these definitions is the concept that pedogenic features occur in materials immediately underlying a geomorphic surface. In many parts of the world geologists as well as soil scientists have observed that episodes of landscape instability (such as active erosion and sedimentation) were often followed by longer intervals of relative surface stability when weathering and pedogenesis affected earth materials newly exposed or emplaced (Gile and Hawley, 1966). Thus, in this study, geomorphic surfaces are defined in terms of genetic landform components, geologic age, and related pedogenic features.

Most geomorphic surfaces in the region comprise a small group of genetically related landforms that developed during an interval of landscape evolution when local climatic and base-level controls were relatively constant (see 2.32 and following sections for details). Subsequent environmental changes (such as base level, climate, tectonic deformation, and volcanism) have often produced a new generation of landforms that are inset below or overlap the preexisting surface. The most common geomorphic surface in the project area is a hillslope continuum of erosional-depositional surfaces grading from upland-summit remnants of older surfaces through backslopes, footslopes, and toeslopes (2.11) to local valley-floor or depression base levels. Repeated valley incision-aggradation-stabilization cycles along major river systems, including the middle Rio Grande, have produced stepped sequences of geomorphic surfaces. Examples of effects of episodic valley incision on evolution of soil landscapes are illustrated in study areas 2, 3, 4, 7, 12, and 22.

Earth materials genetically related to a constructional phase of a geomorphic surface are often conveniently mapped as a *morphostratigraphic unit.* Frye and Willman (1962, p. 112) propose that this informal stratigraphic term be used to designate "a body of [surficial material] that is identified primarily from the surface form it displays," rather than from some distinguishing lithologic property. They further state that "preservation of original or depositional land forms produced by emplacement of sediments is a characteristic of Quaternary non-marine deposits in many areas. In strati-graphic studies of these surficial materials, in contrast to studies of rocks of greater age, these primary depositional forms have been widely used . . . as a criterion, in most cases the primary criterion, for recognition of the unit being mapped."

Morphostratigraphic units were first used in the Central Lowlands province to map glacial moraines and alluvial terraces (Frye and Leonard, 1965; Willman and Frye, 1970). However, they have since been used in mapping a wide variety of surficial deposits, including fan alluvium, pediment veneers, and coastal-plain deposits. Extent and thickness of units mapped vary widely depending on scale requirements for a particular study. In pedological, archaeological, or paleoecological research, mappable units may be as thin as 20 inches (50 cm) and only a few acres or hectares in extent.

In the project area, basin and valley fills associated with constructional geomorphic surfaces of middle to late Quaternary age are subdivided into six major morphostratigraphic units. Individual geomorphic surfaces and associated sediments have been defined, correlated, and named using type area, landform, and stratigraphic section descriptions (Hawley and Kottlowski, 1969; Hawley, 1975). The placement of various units into relative age categories is based on detailed mapping, usually at scales of 1:8,000 to 1:20,000. This mapping involved physical tracing of deposits, surfaces, and associated pedogenic features and short-distance correlation on the basis of landscape position and lithologic properties. Inset-fill relationships and erosional encroachment of a younger surface on an older one in dissected valley-border terrain are illustrated in study areas 2, 3, 5, 7, 11, and 21. Superposition of fills and burial of surfaces are shown in areas 5, 9, 10, 12, 14, 15, 16, and 20.

Correlation of major units in the project area with similar sequences elsewhere in the Southwest has been based on standard techniques of radiometric dating (C-14 and K-Ar), vertebrate and invertebrate paleontology, pollen analysis, volcanic-ash correlation (tephrochronology), archaeology, and paleomagnetic stratigraphy. In addition, regional reconnaissance mapping of valley- and basin-fill sequences at many places along the Rio Grande, from central New Mexico to Trans-Pecos, Texas, has enabled major stratigraphic units to be traced and correlated throughout a large part of the valley system (Hawley and others, 1976). Details of stratigraphic classification and correlation will be discussed in subsequent sections of this book.

2.14 Concepts of stability, burial, and exhumation

The terms *stable, dynamic, relict, buried,* and *exhumed* may be used to characterize geomorphic surfaces, landforms, and soils with respect to their manner of occurrence and time of development (Ruhe, 1965; Thornbury, 1969; Yaalon, 1971; Birkeland, 1974).

An important aspect of soil-geomorphic research involves an assessment of surface stability—whether or not a given surface has been modified by erosion or deposition. When pedogenic features are being considered, the removal or addition of 1 or 2 inches (2-5 cm) of material can constitute a significant modification. A distinction is made between landform stability and surface stability. The bulk of an original land-form such as an alluvial terrace or fan may exist long after its surficial deposits have been eroded away; but a stable geomorphic surface requires more than simple preservation of the gross topography of a landform. A *stable surface* lacks recognizable drainageways or areas of deposition (area 3a). In Holocene soils, erosion along drainageways only a few centimeters deep and several meters wide can reduce the thickness of thin cambic and argillic horizons so that they are no longer thick enough to be diagnostic. Further, such drainageways locally increase slope and runoff, and hence decrease depth of wetting so that depths of clay and carbonate illuviation are reduced.

In many soils of Pleistocene age, prominent and regularly occurring horizons of clay and/or carbonate accumulation indicate that the surfaces involved must have been sufficiently stable to allow moisture penetration and associated illuviation to a narrow range of depths over a long span of time. Some Pleistocene surfaces are still stable, but others have been dissected. Stages of erosional modification of such surfaces are discussed at area 2.

Several degrees of landscape stability might be recognized; but, for purposes of this discussion, stable surfaces are contrasted to *dynamic surfaces,* in which erosion and deposition are currently active and rapid shifting of surficial materials occurs over a period of a few years or decades. Examples include active meander belts and dune fields, aggrading or degrading parts of piedmont alluvial plains, ephemeral drainageway (arroyo) surfaces, and playa-lake plains. Earth materials associated with dynamic surfaces show little evidence of pedogenesis aside from the accumulation of organic material and occasional disruption of sedimentary strata by soil biota. These materials are commonly of Historical age (table 5).

The term *relict* implies stability over geologic time and may be applied to landforms, soils, and geomorphic surfaces. According to Thornbury (1969, p. 511-512)

> *relict land forms* are paleogeomorphic features which formed on a preexisting landscape and have escaped destruction or burial to persist as parts of the present-day topography. Some relict landforms are products of processes no longer operative in the areas where they exist, as in areas once covered by Pleistocene continental glaciers. . . . Others may be products of processes similar to those still dominant but which operated under climatic conditions or base-level controls different from those presently controlling the geomorphic processes.

A *relict soil* as used here is a soil of the present land surface having some morphological features caused by a soil-forming environment that no longer exists. In the project area, the most common evidence of such environmental change consists of the shallow clay and/or carbonate accumulations of Holocene age in soils of late Pleistocene age or older (see area 3). A *relict geomorphic surface* is one whose associated soils have significant relict features. As a general rule, relict surfaces are those surfaces that have been stable since the end of the Pleistocene Epoch or longer. However, relict surfaces may be as young as several thousands of years, where significant climatic, local base-level, or sedimentologic changes have occurred during the Holocene.

Many geomorphic surfaces, landforms, and soils are *buried,* and some of these once-buried features have been *exhumed* (Horberg, 1952; Ruhe, 1965; Thornbury, 1969). A *buried surface* and landform results when a new body of geologic material is emplaced on a unit previously characterized by surface stability and soil development. With respect to soils, a surface may be buried when as little as 50 cm of new material has been added (3.16; Part II, areas 5 and 9). Stripping of cover from a buried surface without significant truncation of soil horizons present in the underlying materials results in an *exhumed surface.* This phenomenon of selective removal of surficial deposits commonly reflects differences in erodibility between relatively loose younger sediments and more resistant materials of the buried landform and soil.

Relict geomorphic surfaces and soils and their buried counterparts are often found in close association in the project region and elsewhere in the western states (Birkeland, 1974; Birkeland and others, 1971; Hawley and others, 1976). Units many thousands of years old are extensively preserved. Exposed sections of alluvial, eolian, lacustrine, volcanic, and glacial materials throughout the region commonly show multiple sequences of deposits and buried soils; these sequences indicate that episodes of landscape instability alternated with intervals of stability and soil formation at many localities. Exhumed surfaces and soils are present in narrow belts along many hillslopes and scarps but are not areally extensive at the land surface.

2.2 REGIONAL GEOMORPHOLOGY

Landforms of the project region bear the imprint of a complex set of tectonic and gradational processes. The location and gross form of mountain ranges, intermontane basins, and the Rio Grande valley (frontispiece, fig. 2) are controlled by deep-seated processes. This part of North America has been and is being affected by broad-scale structural uplift as well as by localized basin-and-range block faulting (Axelrod and Bailey, 1976; Chapin and Seager, 1975; Hawley, 1978; Seager and Morgan, 1979). Volcanic activity has occurred in the relatively recent geologic past. Total tectonic displacement of lower Pleistocene strata and surfaces along folds and high-angle faults may locally exceed 300 ft (90 m). Significant displacement (as much as 30 ft, 9 m) of upper Quaternary units has been documented in a few places; however, fault scarps produced by historic earthquakes have not been recognized in the project region (fig. 1) except in northeastern Sonora, Mexico (DuBois and Smith, 1981; Sanford and others, 1981).

Structural deformation has been the major factor influencing erosion and deposition on a regional scale during time spans measured in hundreds of thousands to millions of years. However, short-term fluctuations in regional climate, as evidenced by the waxing and waning of mountain glaciers and pluvial lakes, have usually been the primary factor controlling gradational processes in individual basin and river-valley segments.

Depositional and erosional landforms record episodes of landscape instability that alternate with intervals of surface stability and soil formation. Concepts introduced here are discussed in detail in 2.6 and 2.7. These episodes usually reflect climatic cycles (periods of thousands to tens of thousands of years) that control the nature of local hydrologic regimes and vegetative cover. Waxing parts of glaciations and related pluvial phenomena appear to be associated with episodes of increased river discharge, entrenchment of major valleys, and flooding of basin floors to form perennial lakes. However, large areas of piedmont and valley-border slopes were stable during waxing and full glaciations because of increased effectiveness of vegetative cover. The transition from glaciation to interglaciation was marked by a variety of local environmental changes including increased aridity and stress on plant communities. Deterioration of vegetative cover and possible shifts in local precipitation patterns to higher intensity events resulted in widespread erosion and sedimentation on formerly stable slopes. Concurrent decrease in river discharge combined with greater sediment production from ephemeral tributaries led to encroachment of arroyo-mouth fans onto the floodplain as well as valley-floor aggradation. Deflation or eolian deposition also affected large areas during early parts of interglaciations, particularly in and near river valleys and depressions with desiccating lakes. Ancient soils that developed throughout the region, largely during intervals of widespread surface stability, are prominent as both relict and buried features.

During the past century many genetic concepts and terms have been introduced by geologists and physical geographers in order to better characterize the great variety of landforms that compose the landscape of the Basin and Range province. A recent detailed treatment of intermontane-basin forms by Peterson (1981) specifically relates landform analysis to soil surveys. The following discussion (2.21, 2.22) emphasizes the development of geomorphic concepts and terms that prove to be very useful for soil-landscape characterization in many parts of the western states. The transverse profiles in fig. 4 illustrate genetic landform groupings, as well as individual forms, in two major types of terrain: a) intermontane basins (bolsons) with central plains of aggradation, including lake and alluvial basin floors; and b) river valleys entrenched into older basin fill and rocks of mountain uplands. Desert pavements, coppice dunes, and scarplet erosion surfaces (common micro- to low-relief forms) are described in Part II (areas 2, 5, and 16, respectively).

2.21 Landforms of intermontane basins

Closed or partly closed intermontane basins of the Desert Project region served as a model for the classic descriptions of bolson landscapes by Hill (1896, 1900), Tight (1905), and Tolman (1909). In a review of topographic terms with long-established use in Spanish America, R. T. Hill (1896, p. 294-295) described *bolsons* as "[flat-bottomed] basin valleys which have not, or originally had not, any outflowing drain-

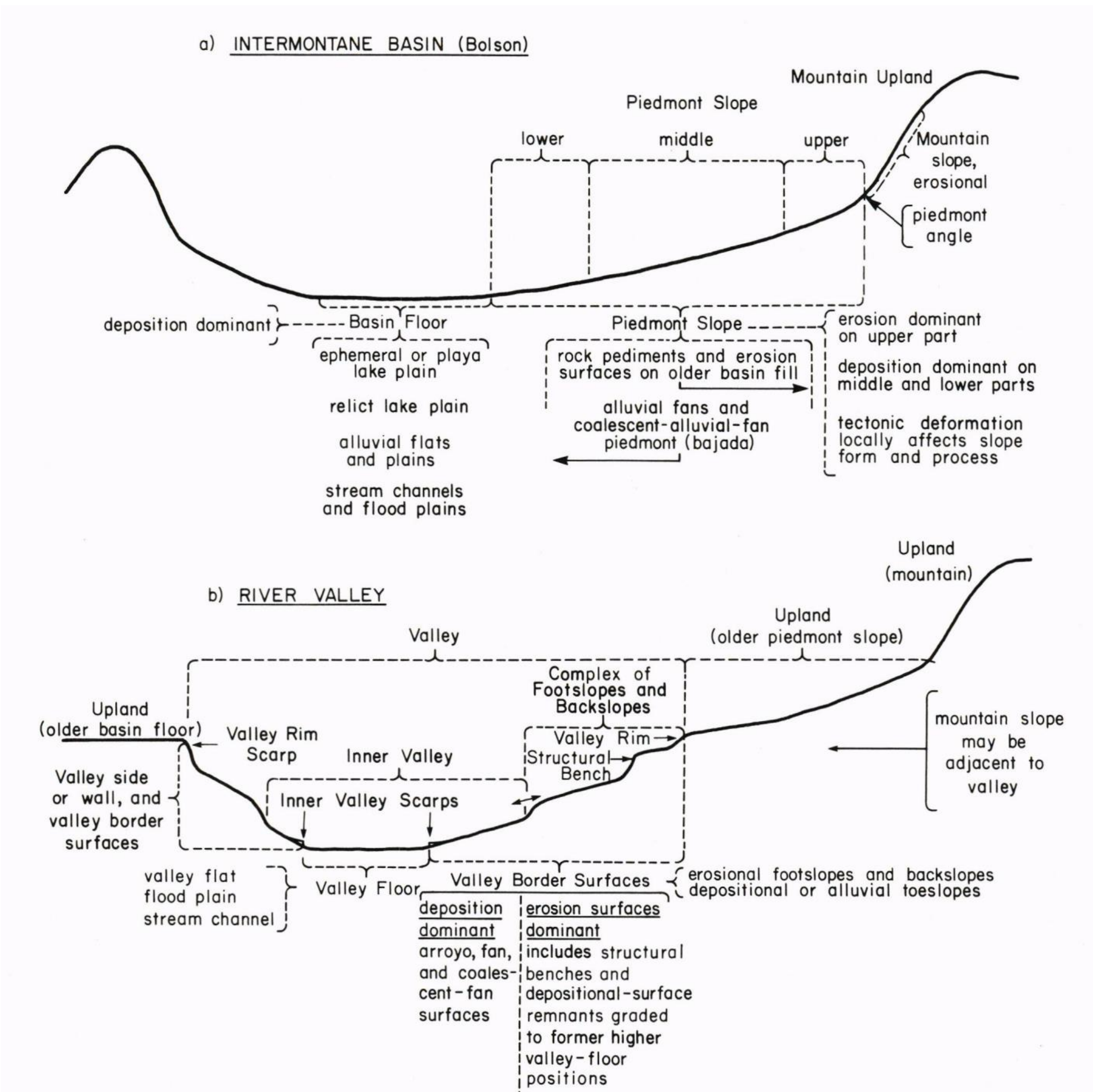

FIGURE 4—LANDFORM PROFILES IN THE BASIN AND RANGE PROVINCE: a) intermontane-basin landforms, b) river-valley landforms.

age and are lined with sedimentary debris derived from the surrounding country." According to Tolman (1909), the three main components of a bolson are 1) erosional slopes cut on rocks of the surrounding mountains, 2) flanking detrital slopes of aggradation, and 3) a central, ephemeral lake plain (playa).

In this report *intermontane basin* (or *basin)* is used instead of *bolson in* most cases. The two major basin subdivisions are *piedmont slopes* and *basin floors* (Thornbury, 1969, p. 271), illustrated in figs. 2 and 4 and a number of other diagrams and maps in this guidebook. *Piedmont slopes* are gently to moderately sloping, graded surfaces extending from mountain fronts to nearly level, central-basin areas. Dominant slope orientation is perpendicular to range and basin-axis trends. Longitudinal gradients usually range from 0.5 to 8 percent but may be as much as 15 percent contiguous to the steep mountain fronts. There is usually a distinct break in slope, or *piedmont angle,* at the piedmont-slope-mountainfront junction. *Basin floors* are essentially level alluvial and lacustrine plains occupying central basin areas. Major gradient components and drainage trends are oriented roughly parallel to long axes of basins and have slopes of less than 0.5 percent.

Width of piedmont slopes in the project region (frontispiece and fig. 1) ranges from slightly less than 1 mi to about 13 mi (1-20 km), while basin floors range from narrow drainage-ways several hundreds of feet (about 100 m) wide to broad plains 20-30 mi (30-50 km) across. Major controls on size and relative proportion of these forms include 1) overall basinand-range geometry, with size and relief of source-mountain watersheds being a very important factor, and 2) amount of contribution of basin-fill materials from external sources (such as ancestral Rio Grande system) relative to contributions from local upland masses. Excellent reviews of the geomorphology and hydrology of intermontane desert basins have been prepared by Lustig (1968) and Cooke and Warren (1973).

PIEDMONT FORMS—Individual landforms on piedmont slopes include well-defined rock pediments, alluvial fans, and coalescent-fan complexes, as well as some widespread units of both erosional and depositional origin that do not always neatly fit into geometric and genetic categories. In an internally-drained basin landscape, such as the Jornada del Muerto Basin or Mesilla Bolson, aggradational piedmont forms (fans and coalescent fans) are dominant and original depositional surfaces are extensively preserved. Landforms of erosional origin (pediments and dissected alluvial slopes) are present in zones immediately adjacent to mountain fronts. In geomorphic settings where mountains are adjacent to major through-drainage systems such as the Rio Grande, erosional forms occupy large areas.

A *pediment,* as used here, is a piedmont erosion surface of low relief that "cuts across the rock formations of the mountain ranges. It slopes away from the residual mountain and is commonly fringed by an alluvial apron or by a degradational surface developed on old alluvium" (Tuan, 1959, p. 3). An excellent example of this erosional landform is located in study area 11 at the foot of the San Agustin Mountains.

A major process involved in the development of piedmont erosional forms in the project region is the action of concentrated runoff in stream systems of the large (in both area and relief) mountain-drainage basins (Lustig, 1968, p. 191). Weathering and erosional processes on upland interfluves and footslopes adjacent to mountain fronts also play an important role (Moss, 1977). Mountain-mass reduction and pediment formation in many parts of the region have involved progressive burial of the piedmont erosion surface as mountain fronts were worn back. Extensive pediment components of the present landscape display evidence of being exhumed landforms, initially developed and buried in later Tertiary to early Quaternary time (Oberlander, 1974). These existed as *suballuvial benches* (Lawson, 1915) until their partial exhumation with some regrading in middle to late Quaternary time. Some pediment segments, therefore, may be the result of processes of mountain reduction acting in environments considerably different from those of the past million years.

An *alluvial fan in* a piedmont setting (figs. 2, 4a) has been described by Bull (1968) as "a body of stream deposits whose surface approximates a segment of a cone that radiates down-slope from the point where the stream leaves a mountainous area." A more general definition is used here that is applicable to upland areas with less than "mountainous" local relief (less than 1,000 ft or 300 in). Individual fans of many different scales will be described that range from large "mountain front" features more than 40 sq mi (100 sq km) in areal extent and hundreds of feet thick to tiny arroyo- and gully-mouth fans occupying areas of a fraction of a square mile and comprising deposits less than 10 ft (3 m) thick.

The most extensive piedmont surface in the project region is the *coalescent-alluvial-fan piedmont,* or simply *fan piedmont* (figs 2 and 4a), formed "where alluvial fans coalesce laterally downslope" (Ruhe, 1962, p. 162). It is equivalent to the term *bajada,* as used by geologists and physical geographers. Fan-piedmont components are illustrated in areas 9 to 12.

Interfan valleys (area 12) are locally prominent landforms at the upper edge of the fan piedmont between the strongly convex, *proximal* parts of individual fans that debouch from major canyons and opposite intercanyon mountain fronts. These roughly triangular-shaped lowlands (area 12) have drainage lines converging towards a trunk drainageway at the upper end of the fan-coalescence zone and are occupied by smaller landforms that comprise basin-fill and bedrock erosion surfaces and valley-fill units including fans and terraces.

The distinct, undulatory feature of fan piedmonts in transverse profile, imparted by the convexities of individual fans, disappears basinward due to progressive flattening of cross-fan profile (Bull, 1964, p. 114). The very gently inclined, lowermost piedmont-slope component merges upslope with the *distal* parts of distinct fan forms and may continue as a transversely nearly level surface unit for several miles down-slope to the zone of mergence with the basin floor. In this report piedmont slopes of this type will be considered as lowermost *(distal)* parts of fan-piedmont surfaces (fig. 4a).

Three basic types of entrenched piedmont-channel and valley systems occur in internally drained basins of the project region; most are confined to upper piedmont slopes. The first of these systems is the typical *fanhead trench* (Eckis, 1928), which is an extension of the source mountain canyon cut through the proximal parts of a fan. The second type occurs in the interfan lows just described and usually heads in smaller mountain-front drainage basins between the major feeder canyons of the larger fans. The third type comprises swales and incised channel systems that head on piedmont slopes. Particularly extensive features are systems of discontinuous gullies with associated fans and headcuts (Heede, 1974; Leopold and others, 1964, p. 448-463; Patton and Schumm, 1975).

In broad basins like the Jornada del Muerto, with a stable or very slowly aggrading local base level, entrenchment of various drainageway types usually dies out on the middle piedmont slopes in the zone of major fan coalescence. The mouths of the incised reaches in turn become apex areas for smaller-scale fan deposits that mantle much of the middle to lower parts of the fan-piedmont landscape. Development of entrenched channel and valley systems and shifts in loci of alluvial deposition on piedmont slopes have been controlled by a variety of geomorphic processes acting individually or in combination. The two major influencing factors are structural deformation (Seager and Morgan, 1979) and episodic, climate-vegetation-controlled shifts in water and sediment discharge.

Sedimentological properties of fan alluvium and associated piedmont-slope deposits (such as pediment veneers and other bodies of alluvium without fan form) must be considered in a local source-drainage-basin setting. Piedmont deposits generally coarsen towards the mountains or exhibit considerable variation in textures and sedimentary structures due to the wide range in sediment-to-water ratios (stream flows to mudflows) observed in piedmont sediment-transport systems (Bull, 1962, 1972). However, bedrock lithology, area-altitude relationships, and such factors as hydrologic and biologic regimes of the source watersheds are the basic controls in texture, mineralogy, and fabric of the downslope piedmont deposits. For example, if a sediment source area furnishes little or no gravel, then fan deposits derived from that area will contain little or no gravel. Specific examples of source-area lithologic and geomorphic controls on the character of piedmont- (and valley-) slope deposits will be discussed in 2.4, 2.52, and 3.2, and at most of the study areas.

BASIN-FLOOR FORMS—Individual landforms of intermontane basin floors include ephemeral lake plains, relict forms of ancient perennial lakes, both recent and ancient features of alluvial origin (plains, flats, and axial drainageways), and a variety of sand-dune types and other eolian forms.

Lake plains of the region are not presently sites of permanent flooding, but they do contain ephemeral water bodies ranging up to approximately 10 sq mi (26 sq km) in area. Flooding intervals usually last weeks to months following major storm-runoff episodes, and dry intervals may last several years. These essentially level and barren plains are designated *playas* in the southwest United States (Davis, 1905; Tolman, 1909; Bryan, 1923; Motts, 1970).

Ephemeral and relict (pluvial) lake plains of the Jornada del Muerto and Mesilla Bolson occupy a very small part of the total basin-floor surface. The individual, circular to linear playas of the present landscape, such as Isaacks Lake in area 14, rarely exceed 1 sq mi (2.6 sq km) in area. Flooding occurs solely as the result of surface-runoff events because depression floors are usually at least 150 ft (46 m) and may be more than 300 ft (91 m) above the regional water table. In marked contrast to many other basins in the region, the subsurface flow regime in the immediate area of the Desert Project is part of a deep, open circulation system reflecting 1) the incised-valley base level of the Rio Grande, 2) relatively high basin-fill permeabilities, and 3) low recharge capability of local watersheds (King and others, 1971). Playas discharge water by downward percolation as well as by evapotranspiration. Appreciable salt accumulations have not been noted in sediments of this type of playa.

The *alluvial plain* is the dominant basin-floor landform in parts of Jornada del Muerto and Mesilla Bolson shown in fig. 2. Most of the surface consists of a relict floodplain to delta complex of the ancestral river system that emptied into closed basins of the Chihuahua and Trans-Pecos Texas region prior to incision of the present Rio Grande valley (2.52, 2.71). The other important (but locally much less extensive) alluvial feature of the basin-floor landscape comprises the broad and nearly level, graded surfaces that carry storm runoff from adjacent piedmont slopes and slightly higher basin-floor components to or towards playas. These surfaces, here designated *alluvial flats*, range from a few hundred feet (100 m) to approximately 2 mi (3 km) in width and are generally underlain by several feet (1 m) or more of fine-grained sediments. In elongate basins such as the Jornada del Muerto, drainageway orientation is more or less parallel to the basin axis and terminal piedmont-slope zones. Sheet floods and broad, shallow stream floods are major active processes in these areas. The *axial drainageways* are a third type of alluvial landform and are locally important features in the basin-floor landscape. They occupy narrow belts that separate the toes of opposing piedmont slopes by only a few hundred feet (less than 100 m) and occasionally carry storm runoff from these slopes towards the alluvial flats or playas to which they are graded.

2.22 Landforms of river valleys

Large, deeply incised valleys of major throughgoing river systems, such as the Rio Grande or Colorado, are very extensive landscape features in many parts of the Basin and Range province (Hunt, 1974; Thornbury, 1965). Smaller but still extensive valley systems have been cut by streams that ultimately terminate in closed basins. Leopold and others (1964) and Leopold and Bull (1979) give excellent reviews of geomorphic research in stream valleys of the Southwest.

River valleys are complex geomorphic units in comparison to many intermontane basin landscapes. This difference reflects the basic depositional nature of the latter and erosional origin of the former. Valley-erosion-surface morphology reflects the variation in lithologic and structural properties of the materials eroded, as well as variation, in both space and time, of the effectiveness of agents (mainly running water) doing the work. The subordinate, but locally extensive, depositional features superimposed on the dominant erosional forms impart further complexity to valley landscapes. Deep-seated (tectonic and volcanic) processes have had significant effect on the morphology of many valleys in the Basin and Range province. Structural features (such as faults and flexures) affecting Quaternary stratigraphic and geomorphic units in the project area are discussed in subsequent sections.

A typical Basin and Range river valley, with the exception of narrow canyon segments, has two major geomorphic subdivisions: 1) a nearly level *valley floor* with large areas subject to periodic flooding prior to dam closure and 2) complex, gentle to very steep sideslopes, designated *valley borders* (Ruhe, 1962) (figs. 2 and 4b). Valley morphology in cross section ranges from narrow, sideslope-dominated segments to broad, floor-dominated segments. In plan view, the boundary between valley and intermontane basin landscapes ranges from relatively straight and abrupt, where tributary drainage is poorly developed, to irregular and indistinct, where adjacent upland and valley terrains interfinger because of tributary valley incision.

VALLEY FLOORS—The Rio Grande in the project region (cover, frontispiece) can be classed as an alluvial river (Schumm, 1977). Most reaches of the Rio Grande channel are formed in alluvium; and, in most valley segments, the late

Quaternary alluvial fill is inset against older nonindurated valley and basin-fill units rather than against bedrock. Schumm's (1965, 1968, 1972) discussions of alluvial channels are particularly pertinent because of his emphasis on rivers of semiarid and arid regions. Channel forms (which may be single or multiple) range from relatively narrow, deep and sinuous (meandering) "suspended-load channels" to relatively wide, shallow and straight "bedload channels." The former is characterized by fine-grained channel perimeter and floodplain sediments and the latter by medium- to coarse-grained materials in these zones. Braided channelway and bar complexes may occur within "bedload" or intermediate, "mixed-load" channel forms (Schumm, 1968, p. 40; 1972, p. 99).

A complete range of these channel types can be found in the Rio Grande valley. However, in the project region, man's activity during the past century has apparently shifted the balance away from sinuous suspended-load towards straighter mixed-load or bedload channels. Channels may comprise essentially all of the valley floor, or they may be flanked by floodplains ranging from narrow strips to broad flats. The wider areas, rarely exceeding 5 mi (8 km) along the Rio Grande, may contain one or more abandoned channel zones (such as earlier meander belts) and scattered small lakes in former channel segments (such as oxbows and sloughs). In larger stream valleys, longitudinal floodplain slopes are usually less than 0.2 percent. The river-valley slope in the project region is slightly less than 0.1 percent.

VALLEY BORDERS—In many areas along the Rio Grande valley, as well as in other major river valleys in the province, a prominent stepped sequence of geomorphic surfaces (and associated deposits) occurs between the river floodplain and valley rims. These relict surfaces, graded to a complex succession of river base levels, are designated *valley-border surfaces* (Ruhe, 1962). The best preserved members of the stepped sequence are fans and terraces associated with large ephemeral tributaries. These surfaces are graded to former valley-floor positions that may have persisted as relatively stable base levels for thousands of years. A special class of valley-border surfaces are *river terraces*, including former floodplains with thick fills as well as river-cut features with thin alluvial veneers. The only extensive river terraces preserved in the project area are the rock-defended surfaces near Fort Selden (frontispiece).

Along most of the river's course through the area (figs. 2 and 4b), the boundary between the valley floor and sideslope is marked by a low bluff or scarp, here designated the *inner-valley scarp.* This erosional landform is the product of river trimming of the valley sides whenever the laterally shifting channel or flood flow impinges upon them. The outer limits, or *rims,* of the valley vary considerably in terms of distinctness and regularity. In many areas the valley is flanked by undissected, level to gently sloping basin (floor and piedmont-slope) surfaces, which produce very little runoff in this region. In such places a short, very steep backslope component, or *valley-rim scarp,* usually marks the outermost edge of the valley. These scarps may be very prominent and nearly vertical where indurated soil-carbonate horizons form caprock zones in surficial basin-fill materials. Regularity and distinctness of valley rims decrease with increased dissection of valley-border surfaces by tributary streams. Areas of maximum slope dissection occur where river valleys are close to mountains and their flanking piedmont surfaces. Locally, valley and basin forms may be transitional with one another. In such areas landscape-dissection patterns are in early stages of development; and geomorphic evidence indicates that a river tributary has recently captured former segments of an internally-drained basin system.

The term *arroyo* is used throughout the project region (and in many parts of the Southwest) to designate the channels of ephemeral streams, particularly those with broad, flat floors and vertical walls several feet (1 m) or more in height (Antevs, 1952; Bryan, 1923; Tuan, 1966). This use corresponds with Hill's (1896, p. 298) definition of an arroyo as "a streamway, ordinarily dry, in which water occurs only immediately after a torrential rainfall." Valleys of these tributary streams comprise the dominant landforms of dissected terrains adjacent to the river floodplain, and they are here termed *arroyo valleys.*

Extensive valley-border areas are composed of erosional-depositional surfaces of Holocene age graded to a local base level near that formed by the present river floodplain. These surfaces comprise the typical hillslope geomorphic continuum (2.11) of erosional backslopes and footslopes grading to alluvial toeslopes (fig. 3). In the tributary-arroyo valleys of the project area, hillslope components include erosional slopes on older alluvial fill or bedrock, valley-floor depositional forms, and valley-mouth alluvial fans graded to the Rio Grande. Gentlest longitudinal gradients of arroyo valley floors and valley-mouth fans are 1-2 percent and contrast markedly with the less than 0.1 percent slope of the river floodplain.

The stepped sequence of relict surfaces above present valley floors reflects several intervals of significant regional instability in the fluvial system during the time of valley formation. These intervals include episodes of major degradation with subsequent periods of aggradation. The intervals may be correlated with parts of major glacial-interglacial cycles when significant discharge and base-level changes are known to have occurred (2.7). However, much of the complexity of valley morphology is caused by graded surfaces that are superimposed on and affected by a variety of lithologic types and structural features. For example, nearly horizontal layers of resistant materials such as gravel or rock have been exposed during valley incision. The terrace-like erosional platforms supported by such resistant layers are designated *structural benches* (Thornbury, 1969, p. 111). Such stripped structural surfaces may be confused with footslope and toeslope components of a graded hillslope continuum. Hillslopes usually form during short spans of geologic time, while structural benches usually exhibit a long, complex history of surface exposure. Soil-geomorphic relationships on a structural bench are illustrated at area 13.

2.3 INTRODUCTION TO PROJECT AREA GEOLOGY AND GEOMORPHOLOGY

The major subdivisions of the Desert Project landscape have been briefly described in the section on physiographic setting (frontispiece and fig. 2). The project area includes parts of two structural and topographic basins, Jornada del Muerto and Mesilla, which have been depressed by faulting and warping relative to the mountains during the past 26 m.y. The tectonic evolution of these low-lying segments of the Rio Grande rift zone (Chapin and Seager, 1975; Seager and Morgan, 1979) has been accompanied by extensive erosion of adjacent ranges and deposition of thick basin fills. Recent basin investigations have emphasized areal and structural geology (Seager and Hawley, 1973; Seager and others, 1971, 1975, 1976); geomorphology (Ruhe, 1962, 1964, 1967; Hawley, 1965, 1969, 1972); hydrogeology (King and others, 1971; King and Hawley, 1975); and stratigraphy (Metcalf, 1967; Hawley, 1975; Hawley and Kottlowski, 1969; Hawley and others, 1969, 1976).

Detailed geologic studies with emphasis on mapping of bedrock units, description of stratigraphic sections, and structural geology are listed by mountain area: San Andres Mountains—Bachman and Myers (1969) and Kottlowski and others (1956); southern San Andres, San Agustin, and Organ Mountains—Seager (1981); southern Organ Mountains and Bishop Cap—Seager (1973); Doila Ana Mountains—Seager and others (1976); Robledo Mountains—Seager and others (1981); and Tortugas Mountain—King and Kelley (1980).

A basic general reference on the geologic setting is the New Mexico Geological Society *Guidebook of the Las Cruces Country,* edited and compiled by Seager, Clemons, and Callender (1975). This well-illustrated book contains detailed road logs covering much of Doña Ana County and 36 technical papers devoted to many aspects of geology, hydrology, paleoecology, and geography.

Much of the groundwork for Desert Project geological and geomorphological studies was done by K. C. Dunham (1935) and F. E. Kottlowski (1953, 1958, 1960). They continued investigations initiated in the region by Hill (1900), Herrick (1904a, 1904b), Tight (1905), Lee (1907), Meinzer and Hare (1915), Darton (1928, 1933), and Bryan (1938). Along with Kirk Bryan (1938), Dunham and Kottlowski developed many of the basic concepts on late Cenozoic geomorphic history that are emphasized in this book.

2.4 MOUNTAINS AND BEDROCK UNITS

Sheet 1 (in pocket) summarizes the distribution of major bedrock types exposed in upland source areas of the Desert Project, and general classification of igneous rocks is given in table 6. Most of this general information is derived from detailed maps cited above. Composition of major basin-fill subdivisions, which are mainly derived from local mountains, is also shown on sheet 1.

Bedrock units of local mountains and valleys are of twofold importance in soil-geomorphic investigations. First, these rocks and their weathering products form soil parent materials in place. Second, they serve as source material for a variety of colluvial and alluvial deposits in and adjacent to the mountains. Except for minor volumes of eolian sediments, all piedmont-slope deposits and some river-valley and basin-floor sediments are ultimately derived from local bedrock units. Only Rio Grande (fluvial) deposits have a significant amount of material from upriver sources. Effects of relief, size, and climate of mountain drainage basins must always be evaluated as part of the assessment of how various rock types and derived sediments behave during weathering, erosion, and transportation to depositional sites. The influence of source-area factors on deposits and soils is discussed in more detail in 2.52 and 3.2; and in individual study areas (Part II).

2.41 San Andres, San Agustin, and Organ Mountains

The southern San Andres, San Agustin, and Organ Mountains form a continuous range in the east part of the project area. The range is a complex of tilted fault blocks with a core of Precambrian igneous and metamorphic rocks and large igneous intrusive masses of Tertiary age (Seager, 1981).

The southern San Andres Mountains consist of a thick section of upper Paleozoic and Mesozoic sedimentary rocks with some intrusive bodies of Tertiary rhyolite (table 6). East of Gardner Spring, study area 12, a large thrust block of Precambrian granitic rock overrides younger units. Sedimentary rocks in the San Andres-northern San Agustin segment of the range are mainly marine carbonate rocks (limestone and dolomite), in part cherty, with interbedded clastic rocks comprising shale, mudstone, siltstone, and sandstone. Thick gypsum beds are locally present. Clastic units are partly calcareous and include nonmarine red beds (Permian) as well as marine rocks. Lithologic character of rocks in the southern San Andres Mountains is described in detail by Kottlowski and others (1956).

The San Agustin Mountains are a transitional upland unit between the dominantly sedimentary rock terrane to the north and monzonitic rocks of the Organ Mountain intrusive complex to the south. San Agustin Peak (east of area 11) marks the northern end of the intrusive mass. The west spur of the mountains, between areas 11 and 12, is fronted by a large block of intermediate volcanics (table 6), the Orejon Andesite of Dunham (1935), that is faulted against upper Paleozoic carbonate and clastic rocks.

The Organ Mountains are a particularly rugged landform with very high local relief. Elevation differences of 2,000-3,000 ft (600-900 m) within 1 mi (1-2 km) horizontal distance are common in many parts of the range. Dunham (1935, p. 150) pointed out that the highest peaks are associated with particularly resistant monzonite phases, while lowlands are formed on zones of rocks weakened by faulting and on lithologic units that are particularly susceptible to weathering. The latter include shale, intermediate volcanic and volcaniclastic rocks, poorly welded rhyolite tuffs, and parts of the quartz-bearing monzonite phase (area 11).

The northern Organ Mountains, from San Agustin Pass to Fillmore Canyon, are mainly composed of monzonitic rocks of the Organ batholith (Dunham, 1935). Monzonites are alkali-feldspar-rich plutonic rocks with a coarsely crystalline (granitic) texture and accessory amounts of quartz, iron-rich micas, and heavy minerals (table 6). Quartz-bearing monzonites (phase III of Dunham) at San Agustin Pass have recently been dated radiometrically (K-Ar) at approximately 32 m.y. (Seager, 1981). The high spires of the central Organs are formed on erosion-resistant quartz monzonites (table 6, phase II of Dunham). The batholith intrudes a thick sequence of older rocks that is locally exposed beneath a cap of piedmont-slope alluvium along the west base of the mountains. These Precambrian, Paleozoic, and lower Tertiary rocks are similar to the units described in the southern San Andres-northern San Agustin segment of the range (Seager, 1981). Rocks in the contact zone between the intrusive mass and older sedimentary and igneous rocks have been hydrothermally altered, with zones of intense silicification, sericitization (mica formation), and heavy-metal-baritefluorite mineralization being common. The northern end of the intrusive contact zone will be crossed in study area 11.

The southern Organ Mountains, near study areas 21 and 22, consist almost entirely of rhyolitic volcanics. The dominant unit, the Soledad Rhyolite of Dunham (1935) is a middle Tertiary sequence of flows and welded tuffs that attains maximum thicknesses of approximately 10,000 ft (3,000 m) over much of a very rugged outcrop area about 20 sq mi (50 sq km) in extent. A poorly welded ash-flow tuff, the Cueva Tuff (Dunham, 1935), forms the base of the rhyolitic sequence. The volcanics form the bulk of the fill of a large *cauldron,* the zone of structural subsidence associated with a major volcanic center (Seager, 1981).

TABLE 6—SIMPLIFIED CLASSIFICATION OF IGNEOUS ROCKS (derived from Peterson, no date, and Williams, Turner, and Gilbert, 1954; see these references for accessory mineral [such as micas, amphiboles, pyroxenes, olivines] composition).

Feldspar[1]		Quartz >10% Coarse	Quartz >10% Fine		Quartz or feldspathoids <10% Coarse	Quartz or feldspathoids <10% Fine	Feldspathoids[2] >10% Coarse	Feldspathoids[2] >10% Fine
Alkali feldspar >2/3 of total feldspar		* Granite	** Rhyolite	** Common pyroclastic varieties	* Syenite	* Trachyte	Feldspathoidal syenites	Phonolite
Alk. feldspar >1/3 <2/3 of feldspar	Intermediate to sodic plagioclase dominant	** Quartz monzonite	* Rhyodacite (quartz latite)		** Monzonite	** Intermediate volcanics: *Latite (trachy-andesite); *Andesite		
Alk. feldspar >1/10 <1/3 of feldspar		Granodiorite Quartz diorite (tonolite)	* Dacite		* Diorite	*Basaltic andesite		
Alk. feldspar <10% of feldspar	Calcic-intermediate plagioclase	Quartz gabbro			Gabbro Anorthosite	Diabase * Basalt		
Alk. feldspar >10% of feldspar	Calcic-sodic plagio-clase					Trachybasalt	Feldspathoidal basic and ultramafic rocks (with or without olivine)	
No feldspar					Peridotite (olivine-pyroxene) Hornblendite			

[1]Alkali feldspars: albite (sodium plagioclase), potash feldspar (including orthoclase, microcline and sanidine), and perthites (Na and K feldspar mixtures). The plagioclase series comprises sodic (albite and oligoclase), intermediate (andesine and labradorite), and calcic (bytownite and anorthite) feldspars. [2]Aluminosilicates of K, Na, or Ca with insufficient silica to form feldspars; absent in rocks with quartz.

*present in Desert Project area. **common in Desert Project area.

2.42 Doña Ana Mountains

The Doña Ana Mountains comprise a group of peaks and ridges, similar to the Organs in general lithologic composition but of much lower relief. The maximum elevation of this isolated upland area located between the Jornada del Muerto and the northern Mesilla Valley is 5,829 ft (1,777 m). Late Paleozoic carbonate and clastic rocks crop out in the northern part of the mountains and on valley-border slopes. To the south these rocks are in contact with a complex mass of lower to middle Tertiary volcanics of intermediate and rhyolitic composition. Seager and others (1976) have identified the roots of a large andesitic volcano of Eocene age, which is the probable source of many of the coarse volcaniclastic rocks in the area. As in the southern Organs, thick rhyolite lavas and tuffs fill a cauldron formed by volcano-tectonic collapse of older volcanic and sedimentary rocks. The highest peaks are formed by large dikes and sills of monzonitic to syenitic composition (table 6). Numerous remnants of small rhyolite intrusions form hills in the southern part of the mountains. The rhyolitic to monzonitic intrusive rocks and associated tuffs have K-Ar ages ranging from 33 to 37 m.y. (Seager and others, 1976). They were therefore emplaced at approximately the same time as the Soledad Rhyolite and Organ Mountain monzonite.

2.43 Robledo Mountains

The Robledo Mountains form the west rim of the northern Mesilla Valley and the northwest part of the project area (Seager and others, 1981). This wedge-shaped uplift is bounded by major fault zones that converge towards the north. The local relief between Robledo Peak (elev. 5,876 ft; 1,791 m) and the river floodplain, 1.5 mi (2.4 km) to the east, is almost 2,000 ft (600 m). Paleozoic carbonate rocks, with some mudstone and sandstone clastic units, are dominant. At the north end of the mountains a thick lower to middle Paleozoic sequence of dolomite, limestone, and shale is intruded by Tertiary rhyolite sills. To the south upper Paleozoic limestones with a thick tongue of red-bed clastics are dominant. West of area 7 these rocks are locally intruded by small rhyolite dikes and sills and basalt plugs. At the south end of the mountains, Paleozoic limestones and red beds are overlapped by gypsiferous sedimentary rocks and intermediate volcanics of early Tertiary age. The latter include volcaniclastic mudflow (Lahar) facies.

2.44 Outlying peaks

In addition to major mountains, with local relief well over 1,600 ft (500 m), three small outlying peaks have summits only about 1,000 ft (300 m) above adjacent parts of the river floodplain. Picacho Mountain, southeast of the Robledos between areas 6 and 7, is capped by a large mass of intrusive rhyolite (Seager and others, 1981). This rock penetrates a volcaniclastic sequence that has been dated radiometrically (K-Ar) at about 43 m.y. (Seager and others, 1975, p. 35). Goat Mountain, on the east rim of the valley south of the Doña Anas, is an intrusive mass of a very fine-grained (micro)-syenite (table 6; Seager and others, 1976, p. 3). The third isolated uplift, Tortugas (or "A") Mountain is a small fault block of limestone located on the valley border southeast of Las Cruces, between areas 2, 3, and 19 (King and Kelley, 1980).

2.5 OLDER DEPOSITS AND SURFACES OF INTERMONTANE BASINS

This section deals with development of a regional system of through drainage and culmination of widespread basin aggradation in Pliocene to middle Pleistocene time. Middle to late Quaternary entrenchment of the Rio Grande valley and contemporaneous evolution of closed-basin landscapes are discussed in 2.6 and 2.7.

2.51 Santa Fe Group

The Sante Fe Group is the rock-stratigraphic unit that comprises the bulk of intermontane-basin deposits along the Rio Grande rift (Hawley and others, 1969). The lower limit of the group in the project region is at the top of igneous and volcaniclastic rocks emplaced just before and during early stages of basin-and-range faulting in middle Tertiary time. These rocks include the plutonic and volcanic units of the San Agustin, Organ, Dona Ana, and Robledo Mountains. The top of the Santa Fe is the youngest basin-fill surface predating initial entrenchment of the Rio Grande valley. Major subdivisions of the group are briefly described in table 7. These comprise three formations in the lower Santa Fe Group (basal unnamed unit, Hayner Ranch, and Rincon Valley) and the upper Santa Fe-Fort Hancock and Camp Rice Formations. Dating of deposits is based on 1) K-Ar ages of basaltic rocks that underlie, intertongue with, and overlap the group and 2) regional correlations of volcanic ashes and vertebrate faunas in the upper part of the group.

Lithologic characteristics of various basin-fill facies demonstrate that depositional environments included both internally drained and open hydrologic systems (Bryan, 1938). Typical bolson environments, with central playa-lake plains and peripheral aggrading piedmont slopes, prevailed regionally for a period of about 20 m.y. beginning in early Miocene time (Seager, 1975). Thousands of feet (more than 1,000 m) of lower Santa Fe basin fill were deposited, and structural deformation continued throughout this interval. Major differential movements between basins and ranges culminated in Late Miocene to Pliocene time after emplacement of the Selden Basalt, dated radiometrically (K-Ar) at 9-10 m.y. This interval was marked by coalescence of fills of individual basins and isolation of many mountain uplifts by partial burial. By late Pliocene, a regional drainage system, the ancestral upper Rio Grande, had developed along the axes of a chain of structural depressions extending from southern Colorado to northern Mexico (fig. 5).

The ancestral river may have originally terminated in rapidly subsiding segments of the Mesilla, Hueco, and Los Muertos Bolsons near El Paso (figs. 1, 5; Hawley, 1975). Thick deposits accumulating in these sink areas, collectively designated the Lake Cabeza de Vaca basin by Strain (1966), graded from deltaic to lacustrine sediments. The lacustrine unit includes playa deposits and intertongues with piedmont-slope alluvium. This bolson-facies assemblage forms the upper part of the Fort Hancock Formation of Strain (1966). Deposits of perennial streams, such as the ancient Rio Grande, form a very distinctive basin-fill facies. They are here designated *fluvial* deposits, and they contrast markedly with alluvium of the high-gradient ephemeral streams of tributary systems.

2.52 Camp Rice Formation (upper Santa Fe Group)

From late Pliocene (2-3 m.y. ago) to middle Pleistocene, rapid fluvial deposition prevailed throughout the entire

TABLE 7—OUTLINE OF SANTA FE GROUP SUBDIVISIONS IN AND NEAR THE DESERT PROJECT AREA.

Camp Rice Formation (Strain, 1966, 1969a, 1969b; Hudspeth County, Texas, Hueco Bolson —type area). Reference area in Dona Ana County is east and southeast of San Diego Mountain (Seager, Hawley, and Clemons, 1971); maximum measured thickness about 300 ft (100 m), but probably at least 600 ft (200 m) thick in the west-central Mesilla Bolson.

Basin-floor facies—mainly river sand and gravel (ancestral Rio Grande *fluvial facies);* generally nonindurated with discontinuous zones of lime cementation, but locally well-cemented with carbonate (major), silica, iron oxide, or iron-manganese oxide (minor). The unit laterally intertongues with and is overlapped by:

Piedmont-slope facies—primarily gravelly alluvial-fan, coalescent-fan, and pediment-veneer deposits; nonindurated to locally indurated, cemented with carbonate (major), silica, iron oxide, or iron-manganese oxide (minor).

The Camp Rice is late Pliocene to middle Pleistocene; it contains late Blancan and Irvingtonian vertebrate faunas and lenses of rhyolitic volcanic ash. The ashes are air-fall units derived from Yellowstone, Wyoming, and Bishop, California eruptive centers. Yellowstone ashes are dated at 0.6 and 2 m.y., and Bishop ash is dated at about 0.7 m.y. (Izett and others, 1970, 1972). Basal contact ranges from angular unconformity to disconformity on:

Rincon Valley Formation (Seager, Hawley, and Clemons, 1971).
Type area—Rincon Valley; type section in basin south of Tonuco uplift (San Diego Mountain). Partial thickness 535 ft (165 m) in southeastern Rincon Valley.

Basin-floor facies—fine- to medium-grained deposits of ephemeral(?) lakes and broad alluvial flats, locally gypsiferous, generally weakly indurated, with local nonindurated to well-indurated zones (gypsum and carbonate cements); laterally transitional to:

Piedmont-slope facies—(Selden Canyon conglomerate member-informal name)—Dominantly coarse-grained fan alluvium, with zeolitized sand to clay matrix; weakly to moderately indurated.

The Rincon Valley Formation is thought to be of late Miocene age. The *Selden (olivine) Basalt Tongue* (Kottlowski, 1953) in the Selden Canyon Member has a K-Ar age of 9-10 m.y. Basal contacts range from conformable to angularly unconformable on:

Hayner Ranch Formation (Seager, Hawley, and Clemons, 1971).
Typearea—Tonuco, Selden, and Rincon Hills uplifts; type section—south flank of Tonuco uplift (San Diego Mountain). Partial thickness 2,622 ft (807 m) in southeastern Rincon Valley. Primarily conglomeratic sandstone, conglomerate, sandstone, and minor mudstone; well consolidated to weakly consolidated. Miocene. Conformable to disconformable basal contact on rocks of early(?) H iocene to Oligocene age.

Notes 1) The above three formations are described in detail by Seager, Hawley, and Clemons (1971), Seager and Hawley (1973), and Hawley and others (1969, Appendix, measured sections 1 and 2). In the 1969 report, the Hayner Ranch Formation is designated by units A-E, *the* Rincon Valley by unit F, and the Camp Rice by units G and H. Measured thickness of the Santa Fe exceeds 3,567 ft (1,098 m) near Tonuco.

2) The terms "upper" and "lower" Santa Fe Group, respectively, designate the Camp Rice Formation and Rincon Valley- Hayner Ranch Formations. The lower Santa Fe Group represents the major period of deposition associated with formation of the present basins and ranges at the southern end of the Rio Grande depression.

3) The basin-floor facies of the Rincon Valley Formation may be partly equivalent in age to the lower part of the Fort Hancock Formation in its type area in Hueco Bolson, Hudspeth County, Texas (Strain, 1966). However, the Rincon Valley Formation cannot be physically traced as a continuous unit into the Fort Hancock type area or, for that matter, with certainty into the Mesilla Bolson. During deposition of the Rincon Valley Formation, the Jornada-Rincon-Palomas Basins and the Mesilla-Hueco Bolsons may still have been essentially separated by now-buried bedrock highs.

4) The upper units of the Camp Rice basin-floor (fluvial) facies can be physically traced into the southern Mesilla and Hueco Bolsons, where they demonstrably comprise basin-fill units identified as Camp Rice Formation by Strain (1966, 1971). The lower part of the Camp Rice as described in the Rincon-Selden area appears to intertongue with (or grade to) upper Fort Hancock Formation strata described near Anapra by Strain.

southern Jornada del Muerto, Mesilla, and Hueco Bolson region. The Camp Rice Formation of Strain (1966) includes deposits associated with this ancestral Rio Grande system. River distributaries fanned out from apex areas on narrow basin floors north of Rincon and built a broad fluvial to deltaic plain exceeding 40 mi (65 km) in width near El Paso (fig. 5). Hundreds of feet (more than 100 m) of predominantly sandy sediments were deposited on basin floors, resulting in their expansion at the expense of more slowly aggrading piedmont slopes. Basal slopes of a number of highlands, including the Doña Ana, Robledo, and Franklin Mountains, were progressively buried by fluvial to deltaic deposits. Aggradation proceeded to elevations as much as 550 ft (168 m) above present floodplain level. Ultimately, integration of upper and lower Rio Grande segments and establishment of through-flowing drainage to the Gulf of Mexico resulted in rapid valley entrenchment. Widespread aggradation of basins ceased in many areas due to diversion of mountain runoff into an expanding network of river-valley tributaries. Upper Santa Fe Group deposition probably terminated in the project area about 300,000-400,000 yrs ago in the late middle Pleistocene.

Figs. 6 and 7 illustrate major stratigraphic units and facies subdivisions of the Camp Rice Formation and their relationship to older and younger units. Both the piedmont and fluvial facies of the Camp Rice form extensive surficial deposits in the project area. The general position of the zone of fluvial-facies pinchout against piedmont deposits is also shown on sheet 1. Fig. 6 is a diagrammatic cross section of the project area along US-70 (areas 5-6 to 8-11) showing general facies relationships and water-table position (2.8) in basin and valley fills. Fig. 7 shows stratigraphic units, detailed facies distribution, and geomorphic surfaces between New Mexico State University and the Organ Mountains (areas 1-4, 20-22).

CAMP RICE FLUVIAL FACIES (Qcrf, figs. 6, 7)—The fluvial facies forms one of the major parent-material units in the project area, particularly beneath basin-floor plains of the Mesilla and Jornada Basins (see La Mesa geomorphic surface, 2.53). The ancient river deposits are also well exposed or only shallowly buried on upper sideslopes of the Mesilla Valley, especially below valley rims south of Goat Mountain and Picacho, and northwest of the Doña Ana Mountains. Very extensive areas exist where the original (or near original) depositional surfaces of the fluvial unit are preserved. These surfaces are relict basin floors still unaffected by erosional encroachment of valley tributaries or emplacement of piedmont-slope, alluvial-flat, and playa deposits. Geomorphic surfaces associated with Camp Rice basin fills will be discussed in 2.53.

Sandy to gravelly river-channel deposits are the dominant component of the fluvial facies. Thin, fine-grained units that represent overbank (floodplain) deposits are also locally pres-

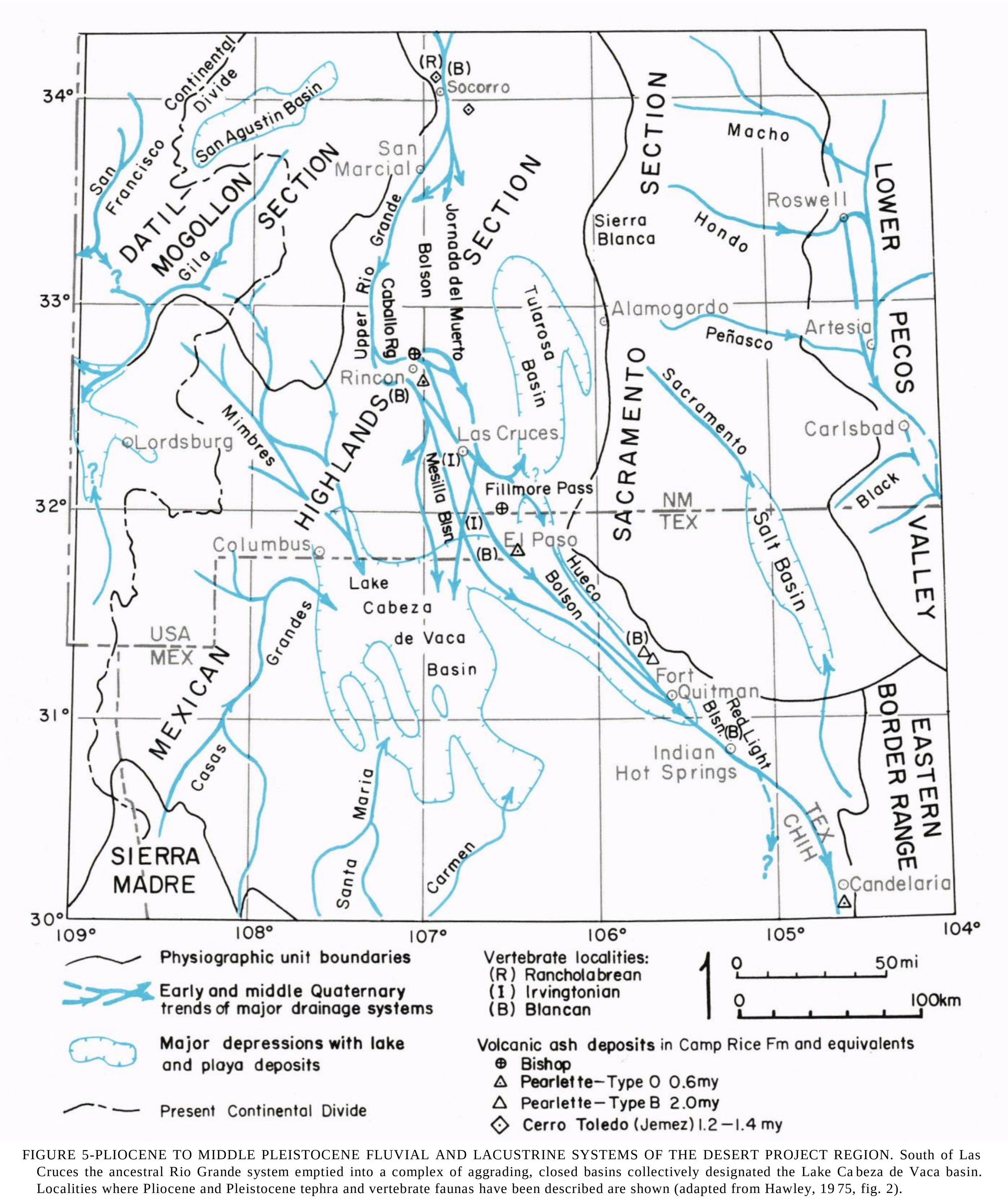

FIGURE 5-PLIOCENE TO MIDDLE PLEISTOCENE FLUVIAL AND LACUSTRINE SYSTEMS OF THE DESERT PROJECT REGION. South of Las Cruces the ancestral Rio Grande system emptied into a complex of aggrading, closed basins collectively designated the Lake Cabeza de Vaca basin. Localities where Pliocene and Pleistocene tephra and vertebrate faunas have been described are shown (adapted from Hawley, 1975, fig. 2).

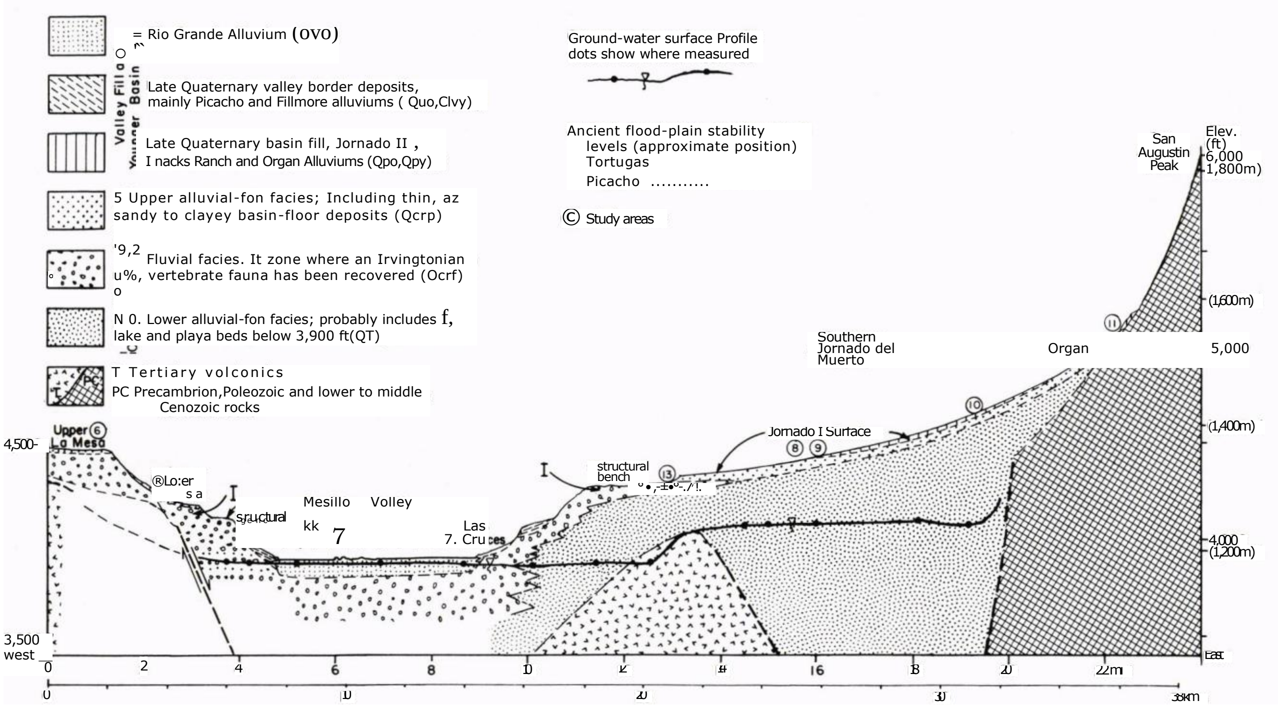

FIGURE 6—DIAGRAMMATIC CROSS SECTION OF THE DESERT PROJECT, along US-70 from upper La Mesa (west) to San Agustin Pass (east), showing general distribution of bedrock units, facies relationships in basin and valley fills, water-table position, and geomorphic surfaces. Detailed soil-geomorphic relationships along this section are illustrated at study areas 5, 6, 8, 9, 10, and 11 (adapted from Hawley and others, 1969, fig. 3).

ent. The youngest gravelly to very gravelly subfacies is particularly resistant to erosion and forms prominent structural benches and ridges where it crops out on uppermost valley sides (area 13). Gravel clasts are relatively well rounded and mainly of pebble size. They include a mixture of resistant rock types derived from distant (upstream) as well as local sources. Clasts of carbonate-rocks are rare, and beds containing cobble-size mud balls are common. Sands are quartz-rich, feldspathic, and usually free of silt-clay matrix. Sand and gravel units are well bedded and contain very thick sets of trough cross-stratification. Beds are usually nonindurated, but discontinuous layers of sandstone and conglomerate are present that are well cemented with sparry calcite.

The fluvial facies thickens towards the basin centers. Within the project area it wedges out against the piedmont-slope facies (and locally older units) in a zone with maximum elevations ranging from 4,225 to 4,500 ft (1,285-1,370 m). Much of the unit has been removed by erosion in the Mesilla Valley. However, original maximum thickness near the southern project boundary seems to be approximately 700 ft (210 m; King and others, 1971).

Vertebrate fossils have been collected from the younger gravelly subfacies of the unit in several of the sand and gravel pits located east of Las Cruces (along US-70 and Lohman Avenue) near the outer valley rim (fig. 6; Ruhe, 1962; Hawley and others, 1969). The *Mammuthus*, *Cuvieronius*, and *Equus* assemblage recovered to date clearly indicates that the upper part of the Camp Rice Formation was deposited during part of the Pleistocene Irvingtonian land-mammal age. The time span represented by this assemblage probably ranges from about 1.8 million to several hundred thousand years ago (2.7). The oldest isotope-dated units that mark early stages of valley incision are basalt flows near San Miguel, 10 mi (16 km) south of Las Cruces. These flows have K-Ar ages of approximately 500,000 yrs (R. Marvin, USGS, personal communication, May 1979).

CAMP RICE PIEDMONT FACIES (Qcrp, Qcrc, and Qcru, fig. 7)—The piedmont facies is primarily a gravelly fan and coalescent-fan deposit that intertongues with and overlaps parts of the fluvial facies. It also includes thin pediment veneers in areas contiguous to mountain fronts. In the project area this unit comprises the entire Camp Rice Formation mountainward from the previously mentioned 4,225-4,500 ft (1,285-1,370 m) wedge-out zone of the fluvial facies (figs. 6, 7; sheet 1). The piedmont deposits locally extend into mountain canyons and valleys as alluvial terraces. Fills of the latter type are particularly prominent in Ice and Soledad Canyons in the central Organ Mountains (areas 21 and 22). The facies has two major subdivisions: 1) a basal, generally indurated, unit (Qcrc in fig. 7) that probably was deposited penecontemporaneously with the lower part of the fluvial facies and 2) a younger, generally nonindurated unit (Qcrp in fig. 7) that intertongues with or overlaps the river deposits and overlaps or is inset against the basal (Qcrc) unit.

The basal piedmont subdivision, here referred to as the conglomeratic unit (Qcrc, fig. 7), is a pebbly to bouldery sandstone to mudstone, mainly cemented with calcium carbonate, that is as much as 200 ft (61 m) thick. Cementation is probably related to circulation of carbonate-rich ground water in the deposits prior to middle Pleistocene valley incision. The conglomeratic unit is deeply buried beneath younger fills in most of the project area. It is extensively exposed in only two geomorphic settings. One is the deeply dissected river-valley terrain that extends onto mountain blocks at the south and west edges, respectively, of the Robledo and Dam Ana Mountains. The other setting is on the uppermost piedmont slopes of the central Organ Mountains in deeply trenched proximal fan areas. Both settings exhibit effects of Pleisto-

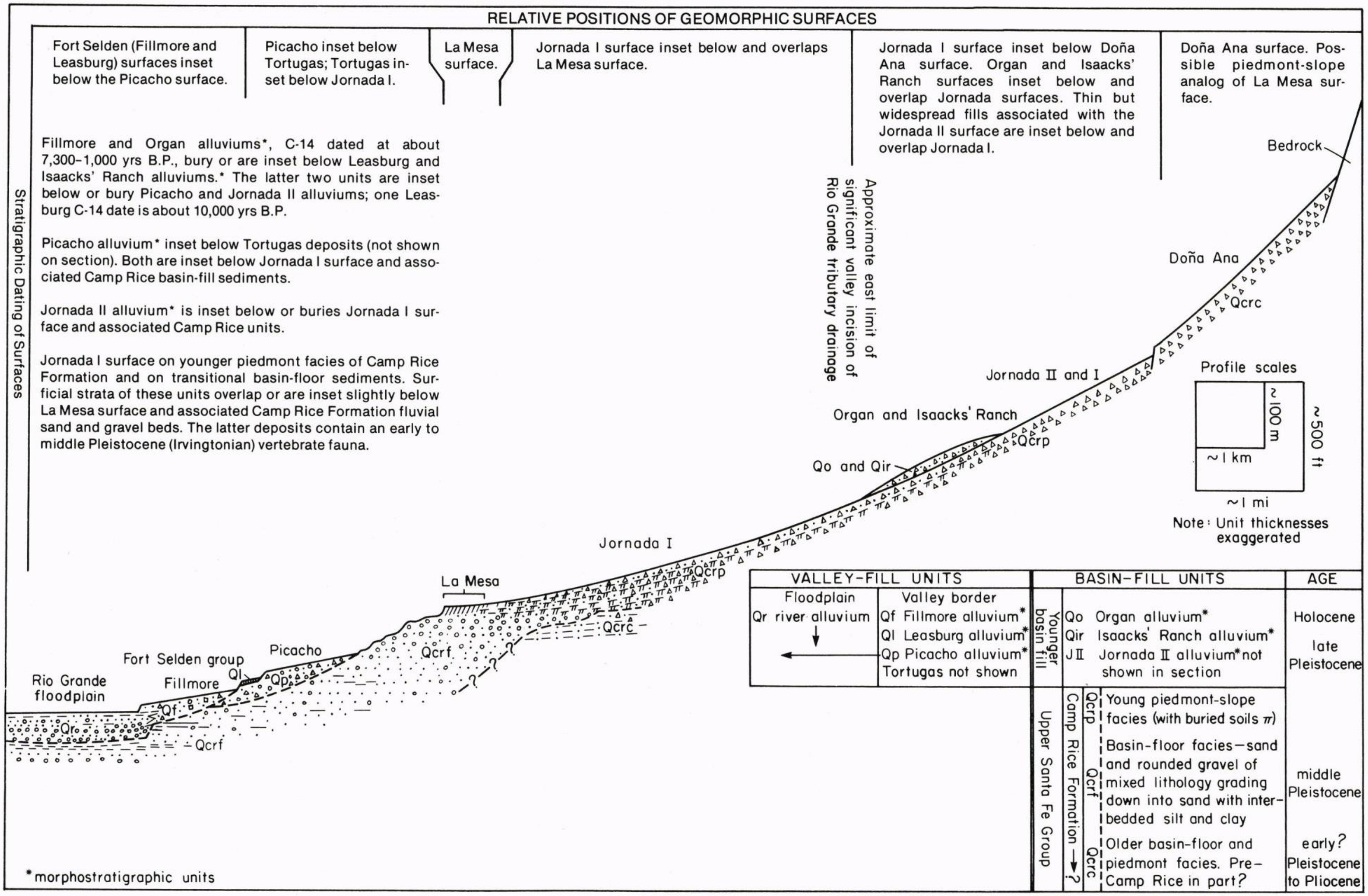

FIGURE 7—DIAGRAMMATIC CROSS SECTION OF VALLEY BORDER AND PIEDMONT SLOPE EAST OF LAS CRUCES, showing stratigraphic units, facies distribution in basin and valley fills, and geomorphic surfaces. Detailed soil geomorphic relationships along this section are illustrated at study areas 1, 2, 3, 4, 19, 20, 21, and 22 (adapted from Hawley and Kottlowski, 1969, fig. 2). West to east section looking north.

cene warping or faulting associated with uplift and tilting of mountain blocks. On the southern slopes of the Robledos and the valleyward slope of the Dona Anas, the erosion-resistant basal conglomerate has been partly exhumed from beneath a cover of fluvial facies and younger piedmont deposits during valley incision. In these areas the conglomeratic unit locally forms prominent structural benches and ridges that have been misinterpreted as remnants of original constructional surfaces. The best exposures of the basal piedmont (Qcrc) unit along the Organ Mountain front are north of study area 22 and west of the mouth of Ice Canyon. Thick, partly indurated, fan-gravel deposits are exposed in the walls of deep fanhead trenches cut below the highest and oldest member of a stepped sequence of fan-piedmont surfaces (see Doña Ana surface).

The basal conglomeratic unit (Qcrc) illustrates an important process of piedmont alluvial-fan deposition that can be observed or inferred in many parts of the Basin and Range province (Hawley and Wilson, 1965), as well as in other tectonically active mountain and basin areas like the California Central Valley (Bull, 1964, p. 106-109). As fans and associated upper-piedmont landforms develop through time along the margins of structural basins, proximal segments often show evidence of progressive (continuous or episodic) differential elevation relative to distal segments. In many cases rapid stream erosion of mountain-valley and upper-fan areas during and after uplift results in formation of deep fanhead trenches and basinward shifting of loci of fan deposition. Distal parts of fans (and piedmont slopes) thus continue to expand and aggrade while proximal segments become more and more dissected. Ultimately the latter are preserved (if at all) only as scattered high-level remnants. In aggrading bolson settings the distal-slope deposits can only be observed in subsurface borings. However, in deeply eroded axial river-valley areas such as between Doña Ana and Rincon, parts of the basal Camp Rice conglomerates are commonly well exposed and form structrual benches. This sequence has been described by Seager (1981) and Seager and others (1975, 1976).

The younger and areally most widespread piedmont-facies subdivision (Qcrp, figs. 6, 7) marks the culmination of basin aggradation in many areas near the mountain fronts. The unit is shallowly buried on most middle and lower piedmont slopes of closed basins such as the Jornada del Muerto. In valley areas dissected by arroyos tributary to the Rio Grande (such as the east side of Mesilla Valley near area 4), the facies has been partly to completely eroded and is exposed or only shallowly buried on interfluve sideslopes and summits. Good exposures are usually of small extent because of general lack of induration.

In the central Jornada del Muerto Basin the younger piedmont facies either wedges out over the ancient river facies at the toe of the piedmont slope or grades to thin, fine-grained alluvial-flat deposits associated with very shallow drainageways inset below remnants of sandy to pebbly fluvial deposits. The unit pinches out mountainward against and partly buries, bedrock and older basin-fill units (such as Qcrc). Locally it extends up mountain canyons and slopes as alluvial and colluvial fills. Estimated maximum thickness from subsurface borings in the project area is approximately 150 ft (45 m). Maximum measured thickness where the unit overlaps the edge of the fluvial facies in the valley-rim area east of Las Cruces (figs. 6, 7) is approximately 75 ft (23 m).

Basic relationships between source-rock lithology and piedmont-facies composition are summarized in sheet 1; and they have been described in detail by Ruhe (1964, 1967). The major texture-lithology groups are represented in the piedmont alluvium flanking the San Andres-Organ chain. The carbonate-dominated sedimentary rock sequence of the southern San Andres-northern San Agustin Mountains (locally with appreciable amounts of sandstone-mudstone, granite, rhyolite, and andesite) produced calcareous fill units that are very gravelly near the mountains but primarily loamy to silty with gravelly interbeds in basinward areas. Gravel zones range from common and coarse (pebbles to cobbles) in a middle fan-piedmont position to widely spaced fine pebbly layers near basin floors.

The monzonite terrane of the southern San Agustin-northern Organ Mountains is the source of widespread, low-gravelly, very coarse sandy to loamy fills across almost the entire fan piedmont. However, this bedrock unit is also the source of a narrow belt of very gravelly alluvium, with clasts ranging up to extremely large boulders at the base of very steep mountain fronts. Volcanic terranes are sources of a variety of particle sizes in piedmont alluvium. The Soledad Rhyolite of the southern Organs and other rhyolitic lava and strongly welded tuff units in the area produce pebbles and cobbles that persist as common alluvial constituents completely across the fan piedmont. Even though there is not a marked decrease in maximum clast size of Soledad-derived gravel, the proportion of very gravelly zones decreases markedly from a middle piedmont to toeslope position. Loamy interbeds are dominant in the latter area but are uncommon in middle to upper piedmont settings. The less extensive intermediate volcanic types (andesite-latite) in the central Organ Mountains tend to produce a wide range of particle sizes, but the bulk of the alluvium is in the loam to pebble-gravel range. Basalts are not common in the project area; where present, they are also a source of very resistant gravel.

The younger piedmont subdivision is basically distinguished from older Santa Fe Group deposits of similar origin by 1) its general lack of induration and 2) its grossly stratified appearance, related to multiple-graded (fining-upward) depositional units with buried soils (2.14) of varying degrees of development and prominence (see areas 4 and 13).

The overall geometry of the younger piedmont facies is a major feature that distinguishes it from the post-Camp Rice basin and valley fills that overlap or are inset against it (2.61). All Camp Rice units in the project area are part of a very widespread basin-fill sequence, associated for the most part with the progressively rising local base level that resulted from construction of the fluvial plain of the ancestral Rio Grande. The coalescent-fan deposits that make up the bulk of the younger piedmont facies are products of sedimentation on relatively smooth, gently sloping surfaces graded to an aggrading and expanding basin-floor terrain. Post-Camp Rice fills of internally drained basins like the Jornada del Muerto are usually associated with local drainageway depressions in the basin topography and are of relatively limited areal extent in comparison with Camp Rice beds. In addition, they are graded to a local base level that has been nearly static (except in areas of tectonic movements and drainage-divide shifts) since cessation of the fluvial-facies deposition. These post-Camp Rice fills in valleys of the Rio Grande system show even more contrast because they are confined to relatively narrow, inset strips of alluvium that are clearly graded to members of the stepped sequence of valley-border surfaces.

2.53 Geomorphic surfaces associated with Camp Rice Formation

Areas where the original surface of the Camp Rice Formation (or a close approximation of it) is preserved represent remnants of a vast basin-fill plain that developed over a long span of early to middle Pleistocene time. In places erosional surfaces graded to this plain extend onto adjacent mountain blocks as rock pediments. In other areas upper piedmont erosional surfaces were also cut across older Santa Fe Group alluvial fills flanking the ranges. General distribution of these and younger surfaces is shown in sheet 2. Age ranges and landform components of geomorphic surfaces are given in table 8.

LA MESA SURFACE (LM, sheet 2)—La Mesa surface (areas 5 and 6) was initially defined by Ruhe (1964, 1967) as a widespread basin (-floor) surface that is underlain by a thin veneer of loamy sediments on middle Pleistocene rounded gravels and sands of mixed composition (now recognized as being part of the Camp Rice fluvial facies, Qcrf). Ruhe recognized that the surface predated formation of the present river-valley

TABLE 8—ESTIMATED AGE, LANDFORM, AND MATERIALS ASSOCIATED WITH GEOMORPHIC SURFACES AND THEIR SOILS. The age of a geomorphic surface and its soils is considered to be the same. On a constructional surface, for example, all would date from the approximate time that sedimentation stopped and soil development started.

Geomorphic surface	Physiographic location and soil age (yrs B.P. or epoch)	Landform and material
	The valley border	
Arroyo channels	Historical (since 1850)	Arroyo; alluvium
(Coppice dunes)*	Historical	Dune; eolian sediments
Fillmore	100 to 7,000	Fan, ridge remnant, terrace; alluvium; colluvium
Leasburg	Earliest Holocene-latest Pleistocene (8,000-15,000)	Fan, ridge remnant, terrace; alluvium
Fort Selden	(Fillmore and Leasburg--undifferentiated)	Fan, ridge remnant, terrace; alluvium; colluvium
Picacho	Late Pleistocene (25,000-75,000)	Fan, ridge remnant, terrace; alluvium; colluvium
Tortugas	Late to middle Pleistocene (150,000-250,000)	Fan, ridge remnant, terrace; alluvium; colluvium
Jornada I†	Late middle Pleistocene (250,000-400,000)	Fan-piedmont, ridge; alluvium remnant
La Mesa†	Early to middle Pleistocene (400,000-1,500,000)	Basin floor; alluvium
	The piedmont slope	
Arroyo channels	Historical	Arroyo; alluvium
(Coppice dunes)*	Historical	Dune; eolian sediments
Whitebottom**	Historical	Small fan, drainageway; alluvium
Organ	100 to 7,000	Fan, fan-piedmont, terrace, drainageway, valley fill, ridge; alluvium; colluvium
III	100(?) to 1,100	Gully fill at Gardner Spring
II	1,100 to 2,100	Valley fill and terrace at Gardner Spring
I	2,200 to 7,000	Valley fill at Gardner Spring, extensive elsewhere in landforms noted for Organ
Isaacks' Ranch	Earliest Holocene-latest Pleistocene (8,000-15,000)	Fan, drainageway, ridge; alluvium
Jornada II	Late Pleistocene (25,000-75,000?)	Fan, fan-piedmont, terrace, ridge; alluvium; colluvium
Jornada I	Late middle Pleistocene (250,000-400,000)	Fan, fan piedmont, ridge remnant, terrace
Jornada	(Jornada I or Jornada II, undifferentiated)	As for Jornada I and II
Doña Ana	early to middle-Pleistocene (greater than 400,000)	Fan, ridge remnant; alluvium
	Basin floor north of US-70	
Lake Tank	Present to Late Pleistocene	Playa; alluvium, lacustrine sediments
Petts Tank	Late Pleistocene (25,000-75,000)	Basin floor; alluvium (lacustrine in part?)
Jornada I	Late middle Pleistocene (250,000-400,000)	Basin floor; alluvium
La Mesa	Middle Pleistocene (greater than 400,000)	Basin floor; alluvium
Jornada I-La Mesa	(Jornada I or La Mesa, undifferentiated)	Basin floor; alluvium
	-------------------------	
Mountain slopes and summits (undifferentiated)		

Coppice dunes have not been formally designated a geomorphic surface but are considered separately here because of their extent and significance to soils of the area.

t The Jornada I and La Mesa surfaces are not formally considered a part of the valley border. They are included here because they form part of a stepped sequence with the valley border surfaces.

**The Whitebottom surface is recognized in the silty, highly calcareous sediments northeast of Isaacks Lake Playa. Associated sediments are generally only a few cm thick.

system and was locally structurally deformed. The type area is La Mesa, the broad plain forming the Mesilla Bolson floor west of the Mesilla Valley (fig. 6, sheet 2). This geomorphic mapping unit also includes plains of similar age and origin in parts of the Hueco Bolson and Jornada del Muerto and Palomas Basins (fig. 1). In the latter two basins, the La Mesa surface includes parts of bolson plains previously referred to as the Jornada and Palomas surfaces, respectively (Kelley and Silver, 1952; Kottlowski, 1953).

Various parts of the La Mesa surface stabilized at different intervals within the broad span of early to middle Pleistocene time (tables 5 and 8). Faulting and warping of Camp Rice strata occurred both during and after deposition of the formation and stabilization of various parts of La Mesa. Most of the surface as defined (that is, predating initial valley entrenchment) seems to be older than emplacement of the oldest (San Miguel) basalts in the Mesilla Valley about 500,000 yrs ago.

Doña ANA SURFACE (part of DJ, sheet 2)—As originally defined by Ruhe (1964), the Doña Ana surface comprised 1) small remnants of fan surfaces preserved near the Organ Mountain front and 2) pediments and fans in the Dona Ana and Robledo area, both in high-level piedmont-slope positions. The relict-fan surface adjacent to the Organ Mountains (fig. 8) is best preserved at the mouth of Ice Canyon, north of areas 20 and 22. It includes very small remnants of the original depositional surface of the basal member of the Camp Rice piedmont facies described previously (Qcrc-fig. 7). These remnants occupy broad interfluve summits often flanked by terraced valleys containing evidence of several intervals of post-Doña Ana fan trenching.

The Doña Ana Mountain piedmont area includes a prominent stepped-sequence of erosional surfaces on bedrock (mainly limestone) and conglomerate that Ruhe (1967) subdivided into three major pediment mapping units with the Doña Ana surface as the highest and oldest. In this report such rockcut surfaces are combined into an undifferentiated mapping unit because the erosional and structural history of these forms is too complex to permit their placement in a simple chronological sequence. Major complicating factors in the western Doña Ana-northern Mesilla Valley area include the local exhumation of the rockcut surface on which the basal Camp Rice (Qcrc) unit was deposited and the erosion-resistant nature of this basal conglomeratic facies. Some so-called Pleistocene pediment forms thus include exhumed (possibly late Pliocene) suballuvial benches on bedrock as well as stripped structural benches on conglomeratic phases of early fan-piedmont deposits.

JORNADA I SURFACE (JI, sheet 2)—The Jornada I surface (areas 4, 8, 9, 17, 18, 21; Gile and Hawley, 1968) is the youngest geomorphic surface on the Camp Rice Formation that predates incision of major valleys (figs. 6, 7). This surface, whose type area is the Desert Project segment of the Jornada Basin, comprises 1) remnants of original depositional surface of the younger Camp Rice piedmont facies (area 4), 2) piedmont erosion surfaces graded to it that are cut on bedrock and basin fill (area 1), and 3) alluvial-flat surfaces that are associated with thin basin-floor fills inset against the fluvial-facies sand and gravel unit (areas 17 and 18). The latter type of surface, which is inset only a few feet below or very locally overlaps La Mesa remnants, apparently developed during an interval of unknown duration between the time of abandonment of the ancient Jornada del Muerto river course and initial trenching of the Mesilla Valley. The bulk of the original Jornada I landscape was a fan and coalescent-fan complex. On the upper piedmont slopes extensive Jornada I fan remnants are commonly preserved as transversely level summits of interfluves between fanhead trenches, interfan valleys, and many smaller entrenched drainageways. Near areas 20 to 22 and at several other places along the Organ Mountain front, the surface is inset against basal Camp Rice fan deposits and remnants of the Doña Ana surface. In most areas the Jornada I is the highest and oldest member of the geomorphic surface sequence along the mountain fronts.

Along the Mesilla Valley rims south of the Doña Ana Mountains, the Jornada I surface—along with La Mesa—forms the highest of the stepped sequence of valley-border surfaces, including the inset Tortugas, Picacho, and Fort Selden units discussed in section 2.62 of this chapter. In the area of deep arroyo-valley dissection along the eastern valley rim south of US-70, ridge remnants of the Jornada I surface occupy narrow interfluve summits formed on distal alluvial deposits of the Camp Rice piedmont facies (unit JIF, sheet 2).

Camp Rice deposits and associated geomorphic surfaces (that is, La Mesa, Doña Ana, and Jornada I) have been dissected or buried in some parts of the project area but are well preserved as relict forms at other localities. Such variations result from the general lack of development of well integrated tributary drainage even after formation of a deeply entrenched river valley. This lack of incised drainageways reflects the arid to semiarid climatic regime, the complete absence of perennial stream systems other than the river, and the presence of large, topographically closed basins and relatively small highland masses. In this setting the several-hundred-thousand-year period since final establishment of through drainage has not been long enough for major landform modifications to have occurred except in areas immediately adjacent to the river or with high local relief.

Soils of the Jornada I surface reflect a very long interval of general landscape stability. These soils and the underlying sequence of multiple Camp Rice buried soils merge downslope as the stack of individual fan-piedmont deposits thins and finally wedges out. In areas where the Jornada I and La Mesa surfaces are preserved as a distal piedmont-slope to basin-floor continuum (Day 2, mile 9 discussion stop), the compressed and coalescing pedogenic features of the piedmont alluvial wedge can be observed to merge with soils of the La Mesa surface (Ruhe, 1964).

2.6 YOUNGER DEPOSITS AND SURFACES—UNITS POSTDATING RIVER-VALLEY ENTRENCHMENT

This section deals with evolution of closed basin and stream-valley landscapes since onset of Rio Grande valley incision in the middle Pleistocene. Stratigraphic units comprising post-Santa Fe basin and valley fills (outlined in table 9) are related to geomorphic sequences of both constructional and erosional origin.

2.61 Basins not integrated with Rio Grande valley

The episodic erosion-sedimentation, surficial stability, and soil formation that characterized later stages of Camp Rice Formation deposition continued in many watersheds not integrated with the evolving river-valley system. Four major morphostratigraphic-geomorphic surface units—Jornada II, Petts Tank, Isaacks' Ranch, and Organ—have been delineated in parts of the Jornada and Mesilla Basins. These map-

TABLE 9—OUTLINE OF POST-SANTA FE GROUP STRATIGRAPHIC UNITS IN BASIN AND VALLEY FILLS OF THE DESERT PROJECT; all units postdate formation of the Jornada I and La Mesa geomorphic surfaces.

Basin fill in areas unaffected by Rio Grande activity

Ephemeral-lake-plain (playa) sediments—Basin-floor sediments, (fine-grained) primarily lacustrine; maximum thickness to more than 15 ft (4.5 m). Youngest deposits associated with late Holocene Lake Tank geomorphic surface, but unit probably includes sediments of late Pleistocene age associated with older ephemeral and perennial(?) lakes.

Arroyo and gully (channel and fan) alluvium—Piedmont-slope channel fills, including arroyo- and gully-mouth fans and sediments derived from broad belts of erosional scarplets (Whitebottom surface). Thickness generally less than 6 ft (2 m). Historical age (post-1850 A.D.). Sediments locally inset below or overlap:

Organ alluvium—Piedmont-slope deposits, including fan, terrace, and undissected drainageway fills, associated with the Organ geomorphic surface. Maximum thickness about 10 ft (3 m). Middle to late Holocene (less than 7,000 yrs B.P., prehistorical). Sediments locally inset against or overlap:

Isaacks' Ranch alluvium—Piedmont-slope deposits, including fan, terrace, and undissected drainageway fills, associated with the Isaacks' Ranch geomorphic surface. Maximum thickness about 7 ft (2 m). Late Wisconsinan to early Holocene (greater than 8,000 yrs B.P.). Sediments locally inset against or overlap:

Jornada II alluvium—Piedmont-slope deposits associated with constructional parts of the Jornada II geomorphic surface, including 1) fan, terrace, and undissected drainageway alluvium and 2) undifferentiated but very extensive sheets of coalescent-fan alluvium. Maximum thickness probably about 15 ft (4.5 m). Late Pleistocene (greater than 25,000 to 250,000 yrs B.P.). Sediments locally inset against or overlap the Camp Rice and older formations, and they grade laterally into:

Petts Tank sediments—Basin-floor deposits (silty, very calcareous) associated with the Petts Tank geomorphic surface that comprises broad alluvial flats grading to playa-lake depressions in parts of the southern Jornada del Muerto Basin; primarily alluvium, but possibly including some ancient lacustrine sediments. Maximum thickness about 10 ft (3 m). Late Pleistocene (general age equivalent to Jornada II alluvium).

Rio Grande valley fill

Rio Grande (fluvial channel and floodplain) deposits—Maximum thickness about 80 ft (24 m). Late Wisconsinan through Holocene.

Arroyo (channel and fan) alluvium—Maximum thickness 10-15 ft (3-4.5 m) in small fans along floodplain border, generally less than 6 ft (2 m) on valley slopes. Historical age (post-1850 A.D.). Sediments partly fill channels cut into:

Fort Selden alluviums—undifferentiated—Valley-border (alluvial toeslope) deposits, and alluvial-colluvial veneers (generally less than 6 ft, 2 m thick) on erosion surfaces; associated with landscapes graded to local base levels ranging from as much as 30 ft (9 m) above to below present river valley floor. Maximum thickness as much as 110 ft (36 m) beneath toes of valley-sideslopes along floodplain borders; generally less than 15 ft (4.5 m) on main part of valley slopes. Late Wisconsinan through Holocene. Sediments locally inset against or overlap Picacho and older deposits and are differentiated into the Leasburg and Fillmore units in basins of tributary arroyos.

Fillmore alluvium (morphostratigraphic unit)—Fan and terrace deposits associated with constructional parts of the Fillmore geomorphic surface and alluvial-colluvial veneers on erosion surfaces graded to local base levels near the present floodplain level. Thickest and most extensive fills of this unit are located on lower slopes of major arroyo systems (maximum thickness about 45 ft, 16 m; usually less than 15 ft, 4.5 m). Middle to late Holocene (less than 7,500 yrs B.P., prehistorical). Sediments locally inset against or overlap:

Leasburg alluvium (morphostratigraphic unit)—Fan and terrace deposits associated with constructional parts of the Leasburg geomorphic surface and alluvial-colluvial veneers on erosion surfaces graded to local base levels slightly above present river-valley floor. Maximum thickness probably to about 15 ft. Late Wisconsinan to early Holocene (less than 25,000 to about 8,000 yrs B.P.). Sediments locally inset against or overlap:

Picacho alluvium (morphostratigraphic unit)—Fan and terrace deposits associated with constructional parts of the Picacho geomorphic surface and erosion-surface veneers, with upper surfaces in most areas graded to local base levels 60 to 80 ft (18 to 24 m) above the present river flood-plain. Thickest (as much as 70 ft, 21 m) and most extensive fills occur in lower parts of major tributary drainage basins near the floodplain margins and locally include tongues of ancient Rio Grande (fluvial) deposits. Late Pleistocene (greater than 25,000 to less than 150,000 yrs B.P.), partly fills valleys cut into:

Tortugas alluvium (morphostratigraphic unit)—Fan and terrace deposits associated with constructional parts of the Tortugas geomorphic surface and erosion-surface veneers, with upper surfaces graded to local base levels 110 ft or more above the present river floodplain, but below Jornada I and La Mesa surfaces. Thickest fills (as much as 125 ft, 38 m) occur in lower parts of major tributary basins and locally contain tongues of ancient Rio Grande deposits; they are associated with ancient floodplain stability levels less than 130 ft (40 m) above the present river floodplain. Late Pleistocene (150,000 to 250,000 yrs B.P.); partly fills valleys cut into Camp Rice and older formations.

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ping units (table 9) form the material record of surface instability-stability cycles on mountain and piedmont slopes, and basin floors. Three geomorphic-surface units comprise landforms of very recent age that are dynamic components of the basin landscape. The first is the *Lake Tank* unit, which comprises playa-lake plains and associated sediments. The second is the *Whitebottom* unit, a complex scarplet-erosion surface locally formed on silty to loamy piedmont-slope alluvium (Organ and Jornada II) derived from calcareous sedimentary rock source areas. The third unit is an unnamed complex of small-scale erosional and depositional forms associated with arroyo channels and discontinuous gullies. The second and third types seem to be primarily associated with Historical, man-influenced patterns of landscape instability. Many coppice-dune forms (described in area 5) also date from this period. Playa depressions have continued as sites of ephemeral lakes during the Historical interval, but these are ancient features that have probably existed in the southern Jornada Basin since diversion of the ancestral Rio Grande (fig. 5) from the basin axis.

The climate-process model that seems to best fit the ages and facies of Jornada Basin fills is one that places major landscape stability and soil-forming periods within pluvials. C-14 dating and pollen analyses have established that the bulk of the Organ alluvium was deposited during an arid, middle Holocene interval downslope from local erosional areas characterized by relatively poor vegetative cover (Freeman, 1972). Parts of previous warm-dry intervals also may have been characterized by environmental conditions that favored development of erosional source areas and placement of similar depositional forms. Pedogenic features that can only be explained by relatively moist soil-climate regimes and long intervals of landscape stability are discussed in chapter 3. C-14 dating of inorganic carbon from soil carbonates, as well as age of organic carbon engulfed by soil carbonates, is also discussed in chapter 3. This dating provides the only semi-quantitative information available on absolute ages of late Pleistocene units in the closed basins (2.73).

JORNADA II DEPOSITS AND SURFACE (JII, sheet 2)—The Jornada II morphostratigraphic and geomorphic surface units (areas 8, 9, 12, and 15) are the product of one or more episodes of piedmont-slope gradation following a long interval of general landscape stability represented by the Jornada I surface and its associated soils. The type area is the eastern piedmont slope of the Jornada Basin flanking the southern San Andres-San Agustin-northern Organ range. The Jornada II morphostratigraphic unit, herein termed the *Jornada II unit,* predates Isaacks' Ranch deposition (2.61). The original depositional surface of the Jornada II alluvium is designated the *constructional phase* of the Jornada II geomorphic surface. An *erosional phase* of this surface, cut on older basin fill and bedrock, is also locally preserved in sideslope and foot-slope positions of tributary valleys. The geomorphic surface is no younger than middle Wisconsinan (about 25,000 yrs B.P.), as discussed in 2.73.

The bulk of the Jornada II unit is a sheet-like fan-piedmont deposit that forms a thin (usually less than 10 ft or 3 m) but nearly continuous mantle on piedmont slopes flanking the San Andres-northern Organ range and the northeast Doña Ana Mountains (sheet 2). This mantle buries the upper Camp Rice piedmont facies and Jornada I surface. The broad area along the Organ-San Andres piedmont where the unit is nearly continuously present, either at the surface or shallowly buried, ranges to 6 mi (10 km) wide and extends from the basin floor to an upper piedmont zone of dissected Jornada I fans. Longitudinal slopes range from 1 to 3 percent. The unit wedges out basinward and laterally against Camp Rice sediments. Northeast of Isaacks Lake playa (areas 14 and 15 to 16) it grades to fine-grained alluvial-flat deposits of the Petts Tank morphostratigraphic unit. Mountainward, Jornada II fan-piedmont alluvium grades to individual fan deposits that generally head in upper piedmont valleys cut in Camp Rice (Qcrp) alluvium. Jornada II fan deposits in turn grade to source-valley fills, some extending into mountain canyons. These comprise alluvial terraces and a variety of small-scale alluvial and colluvial deposits veneering backslope and foot-slope erosion surfaces.

Lithologic characteristics are similar to those of underlying and laterally adjacent bodies of the Camp Rice piedmont facies. Very gravelly deposits occur in the upper piedmont zone. Basinward, Jornada II alluvium grades to a fining-upward, gravelly to loamy depositional sequence on the middle to lower piedmont slopes. The topography of basal and upper contacts is usually smooth; but locally, narrow, gravelly to sandy channel-fill zones occur in drainageway forms cut in older alluvium.

The depositional environment of the widespread fan-piedmont facies of the Jornada II and also of much of the succeeding Isaacks' Ranch and Organ units represents two contiguous but contrasting settings. Narrow belts of relatively active erosion and sedimentation alternate with broader areas characterized by uniform sedimentation on an uneroded surface. The belts of more active cut and fill, here termed channel zones, range in width from approximately 10 to more than several hundred ft (3 to more than 100 m) and are located primarily in central parts of broad drainageways. These zones are characterized by alluvium that shows considerable variation in texture and thickness. Basal gravelly sand that fills channels grades upward into low-gravel loamy sediments. Crossbedding and cut-and-fill structures, as well as relatively flat bedding are common in the basal zone. The upper sediments are massive to very weakly stratified. Thickness of this upward-fining sequence is usually no more than 5-8 ft (1 1/2-2 1/2 m). The stratigraphic record in the areas adjacent to the channel zones is characterized by thinner, more uniform and generally low-gravel loamy materials that represent lateral extensions of the upper sediments of the channel-zone sequence. These sheet-like bodies may extend laterally for several thousand feet from channel zones without showing much change in thickness.

Bull's (1962) threefold classification of fan deposits into braided-stream, intermediate, and mudflow types can be applied to the sequence just described. The gravelly channel zones are considered to represent braided, bed-load-type (Schumm, 1963, 1977) stream deposits. The upper low-gravel units are of an intermediate type interpreted as being deposited by channel-topping sheet floods with relatively high sediment to water ratios. Sedimentary structures of channel zones indicate that they were produced by transitional and upper-flow-regime discharge events (Harms and Fahnestock, 1965).

PETTS TANK DEPOSITS AND SURFACE (Pt, sheet 2)—The Petts Tank geomorphic surface and morphostratigraphic units (area 16) comprise a large part of the alluvial flat northeast of Isaacks Lake playa and underlying basin-floor deposits transitional to the Jornada II unit (Hawley and Gile, 1966). Sediments are fine grained and calcareous, reflecting the southern San Andres-northern San Agustin Mountain carbonate-rock source area of much of the material. The maximum thickness of Petts Tank deposits is approximately 10 ft (3 m). The two major facies are 1) an upper alluvial zone transitional to the main body of Jornada II toeslope deposits and 2) a lower zone of possible lacustrine origin occupying an early-stage basin-floor depression overlapped on the east by Jornada II alluvium. The lower zone is usually more silty than the upper part and is commonly gypsiferous. Remnants of a primary laminated fabric are also locally present. The Petts Tank surface is locally veneered with deposits associated with Holocene (Organ and Whitebottom) episodes of erosion of adjacent piedmont slopes. Petts Tank sediments bury the Jornada I (basin-floor) surface and soil.

The mergence zone of piedmont-slope and basin-floor land-forms is described in Part II (areas 16 and 17). Detailed studies at those sites show that the basin-floor area of the Jornada del Muerto that developed during final stages of Camp Rice fluvial deposition (La Mesa-Jornada I) was much broader than at present. Moreover, the lowest part of the ancient basin plain was located almost 3,000 ft (900 m) east of the present basin axis in parts of the project area north of Isaacks Lake. Because of greater drainage-basin area and relief in the San Andres-Organ Range as compared to the Doña Ana Mountains and possible structural tilting, expansion of piedmont slopes has occurred much more rapidly on the eastern (San Andres) than on the western (Dona Ana) side of the Jornada Basin during middle to late Quaternary time. During the intervals of Jornada II-Petts Tank deposition, the basin axis has been gradually forced westward; and some minor aggradation of alluvial flats and the playa has taken place. However, piedmont-slope deposits derived from the Doha Ana and San Andres-San Agustin Mountains still have not extended to the point where they merge and completely bury the ancient basin-floor plains.

ISAACKS' RANCH DEPOSITS AND SURFACE (part of 01r, sheet

2)—The Isaacks' Ranch morphostratigraphic unit and geomorphic surface (areas 9 and 14) seem to be the product of one or two episodes of piedmont-slope gradation after an interval of general landscape stability represented by the Jornada II surface and associated soils. The type area is the middle piedmont slope of the Jornada Basin flanking the San Agustin-northern Organ Range. The Isaacks' Ranch surface stabilized and associated soils developed during an interval of unknown length before 7,000 yrs B.P. (time of earliest Organ deposition).

The Isaacks' Ranch morphostratigraphic unit has been mapped in detail in only a few localities within the project area (such as area 9). This unit, with the original depositional surface preserved essentially intact, forms a very discontinuous cover on the Jornada II surface in several parts of the fan piedmont west of the Organ-San Agustin range. It is essentially confined to broad, shallow drainageways on the Jornada II surface. Individual bodies of Isaacks' Ranch alluvium have maximum mapped widths of approximately 0.6 mi (1 km) but are generally much narrower. Maximum thickness noted is approximately 7 ft (2 m).

The unit exhibits the same fining-upward, channel-zone to sheet-like facies distribution as the Jornada II alluvium. The Isaacks' Ranch also includes small lobate deposits composed primarily of sandy to pebbly sediments that form small topographic highs on the fan piedmont. These grade upslope to inset channel-zone deposits on the Jornada II surface. They represent small fans that apex at the mouths of gully systems cut into Jornada II and possibly Camp Rice units. Fossil pollen recovered from one section of Isaacks' Ranch alluvium (near area 9) indicates that during at least part of the depositional interval, vegetative communities similar to those of the warm-dry, middle to late Holocene were dominant (Freeman, 1968). Soils associated with relict and buried components of the Isaacks' Ranch surface exhibit horizons of clay and carbonate accumulation intermediate in development between soils of the Jornada II and Organ surfaces.

ORGAN DEPOSITS AND SURFACE (part of Oh, sheet 2)—The Organ geomorphic surface (Ruhe, 1964, 1967) is the youngest major depositional surface of the post-Camp Rice piedmont sequence. Associated sediments form the Organ morphostratigraphic unit (areas 8, 10-12, 14-16, 20-22). The type area is the western piedmont of the southern San Andres-Organ range. These deposits are middle and late Holocene in age, based on C-14 dating of buried charcoal at two sites on the middle and upper piedmont slope west of the southern San Andres-San Agustin range (table 10). Initial deposition started before 6,400 yrs B.P. (area 12; Gile and Hawley, 1968). Final stages of deposition occurred after 1,100 yrs B.P. Dating of charcoal near Gardner Spring as well as at the Isaacks' radiocarbon site (area 10) on the middle piedmont slope indicates that the bulk of Organ alluvium was deposited between 6,400 yrs B.P. and 2,200 yrs B.P. The general depositional chronology of the Organ alluvium fits well with the southwest alluvial chronology described by Haynes (1968a, 1970) (2.73). The youngest Organ deposits and surfaces predate gullies and arroyo channels incised since the first land survey in 1858. The uppermost limit of the unit has not been dated but is considered to be prehistorical in age.

Organ alluvium can be observed as both an inset till against eroded Isaacks' Ranch alluvium and a mantling deposit on the uneroded Isaacks' Ranch surface. The more extensive areas of Organ depositional-surface distribution are shown in sheet 2. Deposits rarely exceed 10 ft (3 m) in thickness. Facies composition and distribution pattern is like that of the older piedmont units except that the loci of Organ deposition are commonly offset (laterally) into a new series of drainageway swales formed between Isaacks' Ranch and Jornada II aggradational highs. Because the Organ is the youngest major unit of the piedmont-slope depositional sequence, primary surface forms are particularly well expressed.

Fossil pollen distribution in the main body of Organ alluvium near Gardner Spring has been studied by Freeman (1972). Pollen counts indicate that vegetation communities during Organ deposition differed somewhat, but not greatly, from present vegetation patterns observed in this region (York and Dick-Peddie, 1969). However, Freeman did note a shift from dominantly shrub to dominantly grass cover during an interval starting shortly before 4,500 yrs B.P. and culminating some time (probably no more than 1,000 yrs) after that date. This shift in vegetation indicates a change from less favorable to more favorable soil-moisture conditions, but no precise statement on temperature and precipitation distribution can be made on the basis of the pollen count.

ARROYO AND GULLY UNITS—During the Historical interval a number of piedmont-slope areas have been unstable. Many landforms, such as arroyo channels and gullies, can be classed as dynamic (2.14). Erosion of middle Pleistocene to Holocene piedmont alluvium and concurrent downslope deposition has been significant at a number of places. Intensive human activity, particularly after 1847, involving livestock introduction and development of roads, has been a major factor in the genesis of many of the unstable areas (Buffington and Herbel, 1965; York and Dick-Peddie, 1969).

Arroyo channels and associated deposits in the Jornada Basin are usually confined to the upper piedmont zone, and incised channel forms disappear within 3-4 mi of the mountain fronts. Small fans head at the ends of many channels. Discontinuous gullies formed along old roads are present on middle and lower piedmont slopes in the area of monzonite-derived alluvium southeast of Isaacks Lake and west of Organ. The "Highway 70 Gully" (areas 8 and 9) has been described by Gile and Hawley (1966).

Individual gully segments have a flatter longitudinal profile than do the adjacent piedmont slopes—except for steep headcuts at their upslope termini. Channel incision gradually dies out downslope, and the end of the gully is the apex area of a small gully-mouth fan. As headcuts retreat mountainward, lower parts of the gully systems may be backfilled, and proximal areas of the small fans tend to shift upslope. The resultant depositional unit, with an overthickened axial channel zone and a relatively widespread sheet-like fan cover, is a very small scale analogue of major depositional units making up the Jornada II, Isaacks' Ranch, and Organ sequence.

WHITEBOTTOM SURFACE—Historical erosion of the calcareous silty to loamy facies of alluvium derived from the southern San Andres-northern San Agustin Mountain source area has locally produced a striking scarplet-erosion surface that has been designated the Whitebottom surface (Ruhe, 1964, 1967). Units affected include Organ alluvium and the uppermost parts of Jornada II and Petts Tank sediments. Associated deposits are generally less than 1 ft (30 cm) thick and are discontinuous in areal extent. These deposits can be shown on cross sections (see area 16) but are generally not mappable except on very large scale photo maps (1:8,000). The White-bottom landscape is characterized by repeated sequences of low scarps or scarplets (ranging from less than 1 ft to rarely more than 6 ft, about 0.2 to 2 m in height), miniature foot-

TABLE 10—RADIOCARBON DATES FROM CHARCOAL AND WOOD IN THE DESERT PROJECT AND ADJACENT PARTS OF THE RIO GRANDE VALLEY; dates are in years B.P. (before 1950). GX = Geochron Laboratories, Inc.; I = Isotopes, Inc.; W = USGS, Washington, D.C. Depths given are distances below constructional surface. All sites in Organ alluvium except those designated IRS (Isaacks' radiocarbon site) are at the Gardner Spring radiocarbon site (Gile and Hawley, 1968).

Fillmore alluvium (Mesilla Valley slopes)		Organ alluvium (Southern Jornada Basin)	
		I-292 Organ III	1,130 ± 90 (51-55 inches, 130-140 cm)
		I-290 Organ II	2,120 ± 110 (20-32 inches, 51-81 cm)
W-819 Fillmore Arroyo	2,620 ± 200 (44-52 inches, 112-113 cm)	I-2225 Organ II	2,220 ± 95 (32-39 inches, 80-99 cm)
I-294 Shalam Colony	2,850 ± 120 (38-41 inches, 96-104 cm)		
I-1741 Chamberino	3,750 ± 115 (23-24 ft., 7-7.3 m)		
I-2736 Altimira #2	3,960 ± 150 (40-44 inches, 102-112 cm)	I-2902 Organ I	4,035 ± 115 (IRS) (17-21 inches, 43-53 cm)
		I-4282 Organ I	4,200 ± 105 (IRS) (39-42 inches, 99-107 cm)
		I-1795 Organ I	4,570 ± 120 (50-60 inches, 127-152 cm)
		I-291 Organ I	4,640 ± 180 (90-98 inches, 229-249 cm)
		I-1794 Organ I	4,700 ± 225 (91-101 inches, 231-257 cm)
I-295 Shalam Colony	4,910 ± 225 (92-95 inches, 234-242 cm)	I-1740 Organ I	4,960 ± 130 (about 60 inches, 152 cm)
		I-4281 Organ I	6,400 ± 110 (about 102 inches, 260 cm)
I-4282 Chandler Tank Arroyo	7,340 ± 285 (about 80 inches, 201 cm)		

Miscellaneous materials	
I-2226	< 195
Altimira #1	(36-37 inches, 91-94 cm) Rio Grande floodplain alluvium
W-703	320 ± 160
Cottonwood Springs Pueblo -- corn cob -- surface sample	
I-3784	9,360 ± 150
Garfield site (about 16 ft., 4.9 m below Fillmore surface, and 5 ft., 1.5 m below base of Fillmore alluvium). Leasburg floodplain alluvium.	
GX-2258	280 ± 90
Burn Construction Co., sand and gravel pit west of Las Cruces. Slab of wood from log in Rio Grande (abandoned) channel deposits, about 15 ft (4.6 m) below floodplain surface.	
GX-2259	<200
Same site as GX-2258. Slab of wood from log in Rio Grande (abandoned) channel deposits about 22 ft. (6.7 m) below floodplain surface.	
GX-2260	3,180 ± 130
Same site as GX-2258. Large wood fragments from large mudball in Rio Grande (abandoned) channel deposits, about 27 ft (8.2 m) below floodplain surface.	

slope erosion surfaces, alluvial toeslopes, and intervening smooth grass-covered surfaces. The latter receive increments of Whitebottom sediments from upslope erosion, and, downslope, form uplands for headward encroaching scarplets. Major Whitebottom areas are shown on sheet 2 as map unit JIIw. The surface will be described further in study area 16.

LAKE TANK SURFACE (Lt, sheet 2)—Two playas within the southern Jornada del Muerto Basin are located in the project area. Isaacks Lake playa, the ephemeral-lake plain forming the lowest point in the Jornada del Muerto (elevation, 4,2854,289 ft; 1,310 m), is the type area of the *Lake Tank geomorphic surface* (Ruhe, 1964, 1967; study area 14). Extensive and long-term flooding of this playa has occurred only six times in the 1957-1979 period (1957, 1959, 1963, 1967, 1972, and 1978). Maximum observed flooding occurred in the late summer and early fall of 1967 when about 200 acres (80 hectares) of the lake plain were temporarily flooded. Closure of the Isaacks Lake depression and the southern end of the Jornada Basin is primarily due to early to middle Pleistocene uplift of the Doña Ana-Tortugas Mountain block relative to flanking basin areas. Sometime during the late Pliocene to middle Pleistocene interval this part of the basin floor was occupied by an aggrading, ancestral river channel.

Fine-grained sediments (primarily clay) of the *Lake Tank* *morphostratigraphic unit* form a relatively thin, lenticular body that probably does not exceed 15 ft (4.5 m) in thickness. The unit rests on sandy to gravelly fluvial deposits of the Camp Rice Formation. The playa unit comprises a wide range in ages of sediments washed into the depression from adjacent piedmont slopes and tributary alluvial flats. The potential source watershed area is about 170 sq mi (440 sq km). Some eolian material may also have been contributed to the fill. Churning of playa sediments during alternating desiccation and wetting episodes over a long time interval has resulted in obliteration of primarily lacustrine bedding forms.

2.62 Rio Grande valley and tributary arroyo systems

The Rio Grande valley floor ranges from 300 to 500 ft (91152 m) below remnants of the Jornada I and La Mesa basin surfaces (figs. 6 and 7). It is underlain by as much as 80 ft (25 m) of river deposits laid down during and subsequent to the last major episode of valley entrenchment. An undifferentiated river-channel and floodplain unit occupying the valley floor constitutes an informal morphostratigraphic category.

Evidence of earlier episodes of valley entrenchment and aggradation is preserved in a few river terraces in Selden and El Paso Canyons and elsewhere in extensive stepped sequences of erosional and constructional surfaces associated with tributary drainage systems. Remnants of ancient graded surfaces associated with former Rio Grande base levels are best preserved in valleys of the larger arroyo systems that head in nearby mountain uplands (such as Tortugas and Fillmore Arroyos in areas 1-4 and area 7).

Three valley-border surfaces and associated morphostratigraphic units, representing major intervals of valley entrenchment and partial backfilling, have been delineated and formally named in the Las Cruces area. In order of decreasing age and surface elevation they are the Tortugas, Picacho, and Fort Selden units. The Fort Selden has been further subdivided into two members: Leasburg and Fillmore. Ruhe (1962, 1964, and 1967), F. F. Peterson (unpublished work 19591962), and Hawley (1965) developed the geomorphic surface concepts and names used here. Metcalf (1967) proposed that the deposits associated with constructional elements of geomorphic surfaces be recognized as morphostratigraphic units. He described fossil molluscan faunas recovered from a number of these deposits in the project area. Hawley and Kottlowski (1969) formally named the Tortugas, Picacho, and Fillmore morphostratigraphic units and described their type areas and representative sections. Seager and Hawley (1973) proposed two informal rock-stratigraphic map units; *older valley alluvium* and *younger valley alluvium.* The former comprises the Picacho and Tortugas morphostratigraphic units, while the latter includes Fort Selden as well as river-channel and floodplain deposits. These two rock-stratigraphic units are designed for general geologic quadrangle mapping at scales of 1:24,000 or smaller, and they will eventually receive formal formation names.

Each major geomorphic-surface unit includes several member surfaces graded to a relatively limited range of local base levels. Individual surfaces seem to have been the product of gradational activity by the river and tributary drainage systems over relatively short spans of geologic time (possibly several thousands to a few tens of thousands of years). They normally include the four hillslope components (2.11, fig. 3) that formed below and at the expense of uplands comprising older basin or valley fills and bedrock. Erosional shoulders and backslopes grade to footslopes and alluvial-toeslopes (fan and coalescent-fan surfaces). Valley floors include arroyo channel, floodplain, and terrace surfaces (figs. 2, 4).

Constructional elements of valley-border surfaces cap fills that range to 125 ft (38 m) in thickness and have two major facies subdivisions: axial river (channel and floodplain) deposits and alluvium of tributary drainage systems (mainly arroyo deposits). Medium- to coarse-grained river deposits are primarily sand and gravel and contain a mixture of resistant rock types derived from distant upstream as well as local sources. Sands are quartz rich, feldspathic, and usually free of silt-clay matrix. Carbonate rocks are uncommon, even in deposits contiguous to ranges with much limestone and dolomite. Gravel clasts are relatively well rounded and rarely larger than the pebbles. Beds containing cobble-size mud balls are common. Sand and gravel units exhibit a variety of cross-bedding and planar bedding and locally grade upward into medium- to fine-grained floodplain sediments. The river deposits are essentially identical to the Camp Rice fluvial facies except for their confined distribution pattern within the central zone of the Rio Grande valley and general lack of cementation. However, thin, discontinuous zones of carbonate cementation are present in soils associated with relict late Pleistocene surfaces.

Axial river deposits intertongue laterally with locally derived alluvium and colluvium of tributary drainage systems. These sediments vary in lithology because they reflect the bedrock, basin-fill, or older valley-fill composition and the hydrologic characteristics of the local-source watersheds. In this respect they are similar to the piedmont-slope facies of the Santa Fe Group. The only extensive areas where valley-fill alluvium is relatively uniform in composition occur in places where the material is principally derived from reworking of the fluvial facies of the Camp Rice Formation. Widespread cementation has been noted only in the piedmont facies of the oldest valley fill (Tortugas) adjacent to the Robledo Mountains. This alluvium is composed primarily of carbonate rock clasts; and prior to valley incision it was saturated with carbonate-rich ground water.

TORTUGAS DEPOSITS AND SURFACE (part of TP, sheet 2)—The Tortugas geomorphic surface (Ruhe, 1962, 1967) comprises erosion surfaces on bedrock and basin fill adjacent to the mountains and constructional terrace and fan surfaces in central valley positions. Sediments associated with depositional elements compose the Tortugas morphostratigraphic unit (Hawley and Kottlowski, 1969). In the type area east and southeast of Las Cruces, the Tortugas surface as originally defined (Ruhe, 1962) included small remnants of erosion surfaces (structural benches, 2.22) cut on older basin fill and a few arroyo terrace and fan surfaces in the stepped sequence between the Jornada I and Picacho surfaces on the flanks of Tortugas Mountain (areas 1-3). As used in this report, the Tortugas surface refers primarily to constructional surfaces and not to structural benches.

North of Las Cruces, on the piedmont slopes of the Robledo and Dona Ana Mountains, extensive areas of Tortugas fan and terrace surfaces are preserved between Jornada I and Picacho surfaces (TP, sheet 2; north of area 7). At several places the Tortugas surface extends to elevations as low as 125 ft (38 m) above the present floodplain and caps prominent bluffs flanking the valley floor. The surface is warped and faulted along the east boundary fault zone of the Robledo Mountains (the Robledo fault) and elsewhere is possibly locally deformed. Differential displacement along individual faults has not been accurately measured but appears locally to exceed 30 ft (9 m). The amount of deformation due to warping has not been determined.

East of the Robledo Mountains in the upper Mesilla Valley, the lower extremities of the Tortugas fan deposits intertongue with one or two wedges of river sediments, but no remnants of ancient Tortugas floodplain surfaces are preserved as relict landforms. However, in Selden Canyon remnants of Tortugas river terraces are preserved that have summit elevation approximately 120 ft (36 m) above the floodplain, and associated fills are locally as much as 100 ft (30 m) thick. Detailed studies of valley-fill alluvium associated with the Tortugas surface (Metcalf, 1967, 1969; Hawley and Kottlowski, 1969; Seager and Hawley, 1973) indicated that early episodes of river incision resulted in cutting of a wide ancestral valley with a floor slightly above the present floodplain level. Subsequently, the central part of the valley was backfilled at least 100 ft (30 m) before surface stabilization and renewed valley incision occurred.

In lower Mesilla Valley, Selden Canyon, and Rincon Valley, one or two graded erosion surfaces occur between the main Tortugas level surface just described and the ancient basin floors (Hawley, 1965). These erosion surfaces are considered to be erosional members of the Tortugas surface complex formed during earliest stages of valley incision. Temporary base-level controls may have resulted from a number of possible causes, including presence of resistant rock units in valley walls, tectonism, or fluctuations in climate.

PICACHO DEPOSITS AND SURFACE (P, sheet 2)—The Picacho geomorphic surface has a type area extending along the eastern base of the Picacho-Robledo Mountain uplift at the north end of the Mesilla Valley. As originally defined by Dunham (1935) and mapped by Kottlowski (1953, 1960), this unit included the Tortugas surface. However, Ruhe (1962, 1964, 1967), Hawley (1965), Metcalf (1967), and Hawley and Kottlowski (1969) have restricted the Picacho to the lower level of the stepped sequence of surfaces that lies between the Jornada I and Fort Selden units (fig. 7). The Picacho geomorphic surface has the same basic elements as the Tortugas surface. Erosion surfaces along the mountain fronts grade out to constructional terrace, fan, and coalescent-fan surfaces towards the valley axis. Associated deposits form the Picacho morphostratigraphic unit. In the low bluffs flanking the floodplain in the upper Mesilla Valley (area 7), the Picacho fan alluvium overlaps and intertongues with ancestral river sediments (gravels to clays) at a number of places. Studies of well-preserved remnants of river terraces in Selden and El Paso Canyons show that the Picacho surface developed during a time of relative stability (or slow aggradation) of the ancestral Rio Grande floodplain when it was about 70 ft (21 m) above the present valley floor.

As with the Tortugas, deposition of the Picacho morphostratigraphic unit and stabilization of the Picacho surface were preceded and succeeded by major episodes of valley entrenchment (areas 2, 3, and 7). Remnants of Picacho fills in lower valley-border areas attain thicknesses of 50-70 ft (15-21 m). These thicknesses indicate that the inner valley (fig. 2b) of post-Tortugas-pre-Picacho age was cut to about the level of the present valley floors and then partly backfilled (Hawley and Kottlowski, 1969). There is no direct evidence of significant structural displacement of the Picacho surface except along the Robledo fault, between Shalam Colony and Picacho Mountain, and in the Leasburg-Radium Springs area of the northern Mesilla Valley. In these areas the surface and associated fills seem to have been offset as much as 30 ft (9 m) by faulting and warping.

FORT SELDEN UNITS (S, F, L, sheet 2)—Ruhe (1962, 1964) proposed the name *Fort Selden* for the complex of fan and terrace surfaces terminating in low scarps that rise 5-45 ft (1.5-13 m) above the floodplain. On the basis of detailed mapping (Hawley, 1965) a twofold subdivision of the Fort Selden was made to separate member surfaces of middle and late Holocene age from those of possible late Wisconsinan age. The older unit was designated *Leasburg* and the younger, *Fillmore*. Valley fills associated with constructional elements of these two surfaces respectively compose the Leasburg and Fillmore morphostratigraphic units (Hawley and Kottlowski, 1969). Arroyo-channel deposits of Historical age are excluded from the Fort Selden.

LEASBURG DEPOSITS AND SURFACE (L, sheet 2)—The Leas-burg surface type area is along the northern Mesilla Valley border. The surface commonly consists of one or two minor erosional benches cut into Picacho fan and river deposits before deposition of Fillmore alluvium. In several places the Leasburg also comprises graded fan and arroyo-terrace surfaces of post-Picacho-pre-Fillmore age. Associated thin alluvial fills form the Leasburg morphostratigraphic unit.

Major excavation of the valley of the Rio Grande and lower reaches of tributary arroyos occurred during at least part of the interval represented by the Leasburg unit. Charcoal recovered from an older floodplain deposit near Garfield in the southern Palomas Valley segment (frontispiece) has been dated at 9,360± 150 yrs B.P. (table 10; Metcalf, 1969). This deposit, which may correlate with a younger part of the Leas-burg unit, is essentially at modern flood level. It is inset below Picacho alluvium and is buried by Fillmore fan alluvium.

FILLMORE DEPOSITS AND SURFACE (F, sheet 2)—The Fill-more surface represents the culmination of prehistoric activity of arroyos that were graded to local base levels in positions near the present valley floor. The surface is a major component of the valley landscape. Backslope and footslope erosion surfaces in the upper parts of tributary watersheds grade to constructional (terrace and fan) surfaces on the floors and at the mouths of arroyo valleys. Older arroyo fan and terrace deposits make up the bulk of the Fillmore morphostratigraphic unit. Fan deposits adjacent to the inner valley scarp range up to 45 ft (14 m) in thickness. C-14 dating of charcoal recovered from five sites in the Mesilla Valley (summarized in table 10) shows that deposition of Fillmore fans and terraces commenced approximately 7,500 yrs B.P. and continued after 2,600 yrs B.P. Fillmore fan alluvium fills shallow channels cut into the dated floodplain section near Garfield mentioned in the preceding paragraph. Archeological studies in the Las Cruces-El Paso area show that large areas of the Fillmore surface had stabilized by 1,000 yrs B.P. because Indians of that period were already using these valley-border fans as dwelling sites (Gile and others, 1969). Distribution of Fillmore constructional surfaces indicates that the middle and late Holocene was a time of significant encroachment of fans of tributary arroyos onto the Rio Grande floodplain, as well as a time of relative equilibrium or very slow aggradation of the valley floor itself (areas 1 and 7).

ARROYO UNIT—Arroyos are the products of minor episodes of channel erosion that have occurred on valley slopes since deposition of the Fillmore unit. Much channel incision has occurred in Historical time. The present arroyo system is entrenched from about 3 to as much as 40 ft (1-12 m) below the Fillmore surface. Lateral shifting of the Rio Grande channel during the past several centuries (U.S. Reclamation Service, 1914), resulting in removal of fan-toe segments when the river occasionally impinged on the inner valley borders, has caused some of the observed arroyo incision.

RIO GRANDE VALLEY-FLOOR DEPOSITS AND SURFACES (RG, sheet 2)— Maximum entrenchment of this reach of the Rio Grande valley apparently occurred in late Wisconsinan time after stabilization of the Picacho surface and prior to deposition of lower Holocene floodplain deposits with a C-14 age of about 9,300 yrs (table 9). Subsurface information summarized by King and others (1971) indicates that river-channel deposits associated with the last major episode of valley cutting rest on a broad, nearly level erosion surface (cut into Santa Fe Group basin fill and older rocks) from 60 to 80 ft (18-24 m) below the present valley floor. The basal 30 ft (9 m) or so of this inner-valley fill contains numerous zones of pebble to cobble gravel, while the upper part is non- to low-gravelly, with cobble-size material generally absent except in local areas at the margin of the valley. Sur ficial floodplain deposits that appear to be time correlatives of Fillmore and Historic arroyo fans are probably no more than 30 ft (9 m) thick.

The river has remained in approximately the same position since 1865, and it has been straightened and diked since initiation of the Elephant Butte Project in 1915. The gradient of the floodplain in the Mesilla Valley is 4.5 ft/mi (0.085 percent). The gradient of the pre-1865 meandering channel was as low as 1.4 ft/mi and its maximum sinuosity (channel length/ meander wave length) was about 2.5 (U.S. Reclamation Service, 1914). Measured peak discharges during the floods in 1904 and 1905 in the San Marcial-El Paso Reach ranged from about 24,000 cu ft/sec (El Paso 6/12/05) to 50,000 cu ft/sec (San Marcial 10/11/04). Maximum discharge since Elephant Butte Dam was closed in 1915 has been generally less than 10,000 cu ft/sec (Water Resources Division, 1965, 1970). Wood specimens from logs in pre-1865 (1844?) river-channel deposits near Las Cruces, at depths of 15 and 22 ft (4.5 and 6.7 m) below floodplain level, have C-14 ages of less than 200 yrs (table 10). The depth of river scour during major river-discharge events of Historic time probably has not greatly exceeded 25 ft (7.7 m).

2.7 LOCAL AND REGIONAL QUATERNARY HISTORY

Major advances in the past decade in tephrochronology, radiometric dating, magnetic-polarity stratigraphy, vertebrate paleontology, soil geomorphology, and detailed field investigations have contributed significantly to the understanding of Quaternary history in the Southwest. Dating and correlation of deposits and surfaces in the project region reflect recent work done in many of these specialties. Tephrochronology (volcanic-ash dating and correlation) has been especially important in establishing absolute age ranges of a number of stratigraphic units and geomorphic surfaces. Widespread air-fall deposits of ash derived from explosive (caldera-forming) eruptions of volcanic centers at Yellowstone National Park (Pearlette ashes); Long Valley, California (Bishop Tuft); and the Jemez Mountains, New Mexico (Bandelier Tuft) have been identified and dated by petrographic and radiometric methods (Christiansen and Blank, 1972; Doell and others, 1968; Izett and Naeser, 1976; Izett and others, 1981; Smith and Bailey, 1968). Discovery of these ashes at many vertebrate-fauna localities has resulted in considerable refinement in dating of land-mammal (provincial) ages and stratigraphic correlation (Lindsay and others, 1976; Berggren and Van Couvering, 1974; Izett and others, 1972; Naeser and others, 1973). Present time-stratigraphic concepts are further supported by magnetic-polarity stratigraphy of dated volcanic units in New Mexico (Doell and others, 1968) and of ash-bearing deposits with vertebrate faunas in the southwestern United States (Johnson and others, 1975; Lindsay and others, 1976; Opdyke and others, 1977; Reynolds and Larsen, 1972).

Fig. 8 is a correlation chart (modified from Hawley, 1975, table 2; 1978, chart 1) showing representative events and deposits in the Desert Project region and adjacent areas. The chart is a state-of-the-art effort that illustrates information gaps and inferences as well as hard data on Quaternary stratigraphy and geomorphic processes in the region. The U.S. Geological Survey has recently started a research program on direct dating of Quaternary sediments. Experimental projects in the western states have used both thermoluminescence and U-238 decay-series techniques. Middle and upper Pleistocene deposits of the Desert Project area have been sampled as part of this program, and their ages are currently being determined using the "uranium trend" method of Rosholt (1980). As absolute dating improves, there will be revisions in age ranges of sediments and surfaces as well as in genetic concepts of landscape evolution.

The first two columns in fig. 8 show: A) an age scale and B) Quaternary and late Tertiary epochs with tentative placement of subepoch boundaries. In its upper part, column C shows a sequence of inferred glacial-interglacial cycles, termed "glacial cycles" by Fairbridge (1972). Oxygen isotopic stages for the last 250,000 yrs are also shown (stages 1-8; Ruddiman and McIntyre, 1981, fig. 2). These stages, based on 0-18 and 0-16 ratios in marine benthic foraminifera (Shackleton and Opdyke, 1973), best record the growth and decay of continental ice. Even numbers (2, 4, 6, 8) indicate intervals of heavier isotopic values (larger ice volumes) that correlate with major glaciations. Each complete interglacial-glacial oscillation has a period of about 115,000-120,000 yrs, the approximate length of the last full cycle completed at the end of the Wisconsin Glaciation (Broecker and Van Donk, 1970; Cooke, 1973; Suggate, 1974). The glacial-cycle concept is discussed by Fairbridge and other contributors in Kukla and others (1972). Relatively short and intense interglacials (IG) and full glacials (PG), modeled after the Holocene and the preceding glacial maximum (late Wisconsin), marked the earliest and latest parts of a complete cycle. The Holocene constitutes the first part of the "present" glacial cycle. Placement of terms "Wisconsin" and "Kansan" in column C suggests that these stage units of the classic Midwest succession of glaciations and interglaciations are the only ones that have been dated with any precision in the Southwest. The "Kansan" here includes glacial-pluvial units 1.0-0.5 m.y. in age.

Column D shows tentative placement by Berggren and Van Couvering (1974) of provincial (land-mammal) age boundaries for the Blancan (Wood and others, 1941), Irvingtonian, and Rancholabrean (Savage, 1951) ages. Column E shows position of magnetic-polarity epochs (Dalrymple, 1972) and subdivisions (Depositions A to E) of the late Quaternary alluvial chronology developed by Haynes (1968a) for the western United States. The upper San Pedro Valley of southeast Arizona (column F) about 200 mi (320 km) west of Las Cruces, is a very important reference area for late Cenozoic stratigraphy. Contrasting magnetic-polarity zones in the Saint David Formation of Gray (1967), the basal unit of a Pliocene-

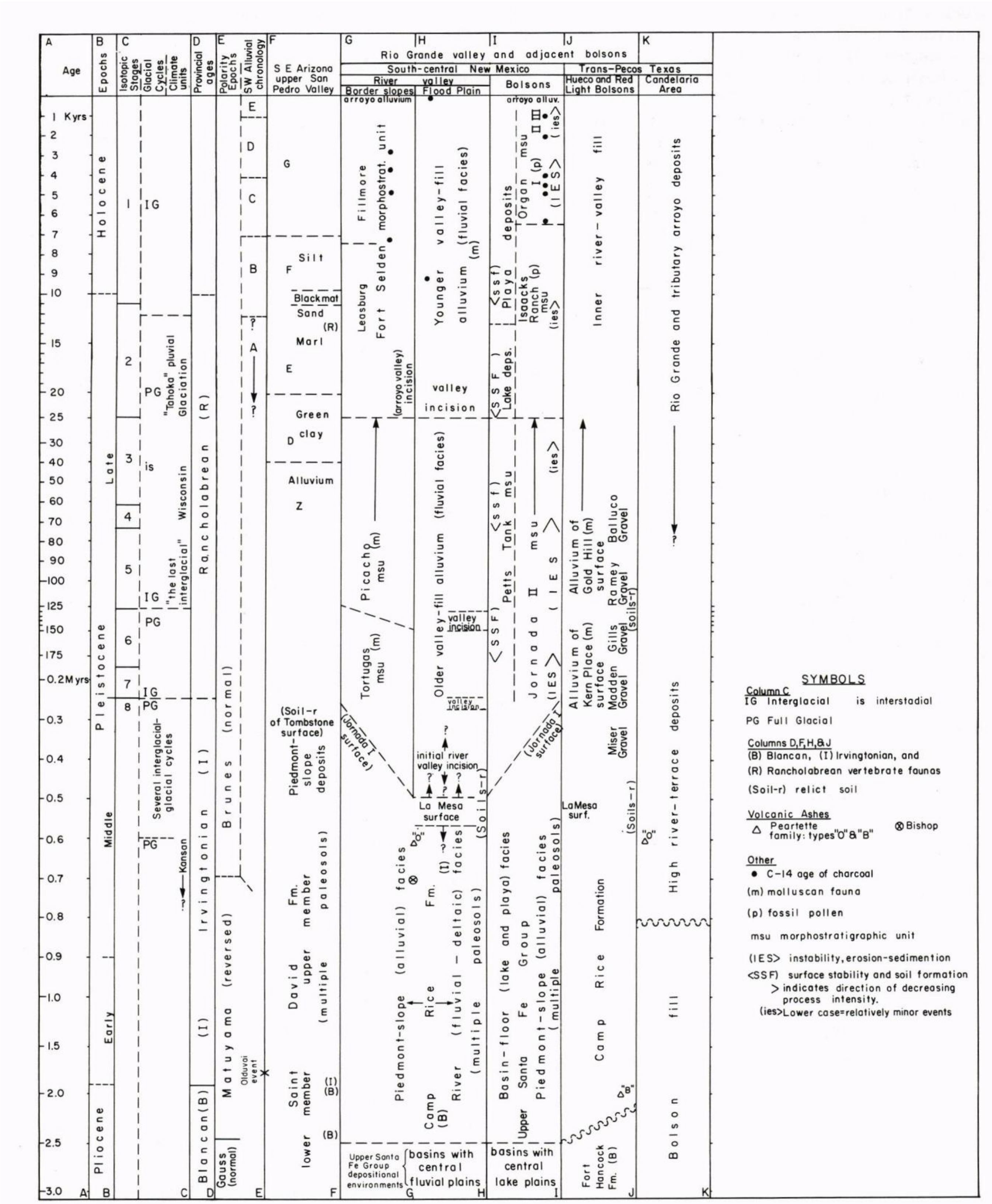


FIGURE 8—CHART SHOWING QUATERNARY DEPOSITS AND EVENTS IN THE DESERT PROJECT REGION (adapted from Hawley, 1975, table 2).

Pleistocene basin-fill sequence, have recently been described and dated by Johnson and others (1975). The Saint David Formation, a general correlative of the upper Santa Fe Group, contains two land-mammal assemblages, the Benson fauna (early Blancan) and the Curtis Ranch fauna (late Blancan-Irvingtonian). Overlying basin and valley fills have been described in detail by Gray (1967) and Haynes (1968b).

Columns G to K of fig. 8 relate to parts of south-central New Mexico and west Texas in or near the Desert Project. The most precise chronologic controls have been provided by 1) charcoal dated by C-14, 2) archaeologic materials associated with deposits and surfaces of Holocene age, and 3) local volcanic-ash lenses ranging from approximately 0.6 to 2 m.y. in age. Less precise dating has been based on K-Ar age determinations of basalt flows and C-14 dating of inorganic and organic carbon in soil-carbonate horizons. Paleoecologic interpretations of fossil mollusks and plant material associated with distinctive stratigraphic sequences and depositional environments (in both closed-basin and river-valley settings) have provided still another means of correlation.

2.71 Early to middle Quaternary history of project region

Basin fill of the Camp Rice Formation, representing the culmination of Santa Fe Group deposition (2.52; fig. 5), is shown on the lower parts of columns G to J. Two possible time spans for Camp Rice deposition were originally considered (Hawley, 1975, 1978). Strain (1966) described a Blancan fauna (with *Nannippus* and *Plesippus)* below lenses of a Pearlette ash near the base of the Camp Rice Formation in its type area. On the basis of this association he correlated the Camp Rice with deposits on the Great Plains (with similar faunas and volcanic ash) that at the time were considered to be of middle Pleistocene (Kansan) age (Hibbard and others, 1965). This correlation is now untenable because 1) the ash lenses are (2.0-m.y.) type-B rather than (0.6-m.y.) type-0 Pearlette (G. Izett, personal communication, 1978) and 2) the Blancan fauna contains forms that were extinct well before middle Pleistocene (Lindsay and others, 1977).

Initial river-valley entrenchment and termination of Camp Rice deposition in the Doña Ana County area occurred late in middle Pleistocene time. The triggering event is presumed to have been the integration of ancestral upper and lower Rio Grande systems (Hawley, 1975, 1981). The critical area for solving problems related to development of through-flowing drainage to the Gulf of Mexico is located in the Rio Grande canyon-and-valley reach between Hueco Bolson and the Big Bend (figs. 1, 5). Groat (1972, p. 31-32) described volcanic-ash lenses, probably derived from a single air fall, in high river-terrace deposits in the Presidio Bolson segment of that reach (fig. 8, column K). Composition of the terrace gravel shows that integration with an axial river draining the Hueco Bolson and upper Rio Grande region had occurred before ash deposition. Work to date (G. Izett, personal communication, 1978) indicates that the ash is type-0 Pearlette derived from the Yellowstone eruption about 0.6 m.y. ago (Izett and others, 1972). Type-0 ash in high-level river deposits (youngest Camp Rice) at El Paso and Selden Canyon also shows that the ancestral river was near its present position in middle Pleistocene time. However, valley entrenchment did not start until after 0.6 m.y. ago.

Hawley (1981) shows that the ancestral Rio Grande originally developed in Pliocene time, possibly much earlier than 2 m.y. ago. An early river channel in Fillmore Pass (fig. 5), between the Franklin and Organ Mountains, definitely connected the Mesilla and Hueco Bolsons as noted by Strain (1966, 1971) and mapped by Seager (1981). The early river system possibly continued southeast through Hueco Bolson and the downstream canyon-and-valley reach into Presidio Bolson (fig. 5). There it may have joined an ancestral Rio Conchos (heading in southwest Chihuahua) and flowed through the Big Bend country to the Gulf of Mexico. Subsequent uplift and west tilting of the Organ-Franklin chain of fault blocks diverted the river back into the Mesilla Bolson. This diversion resulted in temporary disruption of through drainage.

Termination of widespread basin filling (Camp Rice deposition) in late middle Pleistocene was caused by extension of the Rio Grande through the intermountain gap at El Paso, possibly by lake overflow, rapid integration with lower river-valley segments, and initial cutting of the present valley system upstream from El Paso soon after 0.6 m.y. ago.

2.72 Late Quaternary evolution of the Rio Grande valley

Middle through late Quaternary valley evolution resulted in the formation of the stepped sequence of graded surfaces located between the present valley floors and the Jornada I piedmont slopes. Correlation of geomorphic surfaces and associated fills (Tortugas, Picacho, and Fort Selden morpho-stratigraphic units) is possible over long distances upstream and downstream from the Las Cruces area (fig. 8; Ruhe, 1964; Hawley, 1965, 1978; Metcalf, 1967, 1969), thus indicating that factors other than local ones played a major role in the development of valley landscapes. The effects of episodic shifts in climate from semiarid to arid conditions, associated with pluvial and interpluvial intervals, were apparently the most important influences; however, structural deformation may have had significant local effect.

A working hypothesis of river-valley evolution has been developed that seems to fit the available information on the age of stratigraphic units, erosional and depositional features, fossil molluscan faunas, and paleoclimatic fluctuations recognized through to the upper Rio Grande watershed (Kottlowski , 1958; Metcalf, 1967; Hawley and Kottlowski , 1969; Hawley and others, 1976). This hypothetical scheme of river activity closely follows a sequence described by Schumm (1965, p. 790-792) and includes the following stages: 1) excavation of the axial valley and at least the lower segments of tributary valleys during waxing and full-glacial intervals, 2) deposition during waning glacial and early interglacial times, and 3) relative stability during the remainder of a given interglacial interval. Late Pleistocene pluvials and interpluvials seem to generally correlate with glacial and interglacial intervals recognized in glaciated parts of the Rio Grande drainage basin in southern Colorado and New Mexico.

The early cycles of valley entrenchment and aggradation are not precisely dated. They are known to be older than the last major (pre-Fort Selden) episode of Rio Grande entrenchment that occurred in late Wisconsinan time (apparently during the early part of the 25,000- to 10,000-yr-B.P. interval). The oldest valley fills include basalt flows near San Miguel dated by K-Ar at about 500,000 yrs B.P. (R. Marvin, personal communication, 1979). These fills are definitely younger than the 600,000-yr-old, type-0 Pearlette ash described by Seager and others (1975) in a Camp Rice section in Selden Canyon (table 10, columns G-H). Work to date indicates that the younger part of the Tortugas unit was deposited during the first part of the interglacial-glacial cycle preceding the Wisconsinan cycle (fig. 8, column C, 245,000-130,000-yr interval). However, the Tortugas may include still-older deposits.

Most of the Picacho unit probably was deposited during the last interglacial (IG) and the waning part of the preceding full glacial (PG). This depositional interval is tentatively considered to have started between 130,000 and 150,000 yrs ago (table 10, columns C and **H).** Well-developed soils with some morphological features formed under conditions significantly more moist than those of the present are preserved in surficial deposits of the Picacho unit (3.91; areas 2, 3, and 7). These pedogenic features clearly started forming during a relatively long interval of surface stability prior to late Wisconsinan valley entrenchment.

The Fort Selden and river-floodplain units are associated with the last major interval of valley incision and partial backfilling. On the basis of C-14 dating of charcoal in younger valley fill, deep entrenchment below a late Picacho base level and initial backfilling took place in late Wisconsinan time prior to 10,000 yrs B.P. (Hawley and Kottlowski, 1969). River entrenchment during this period was of regional extent, occurring from the Albuquerque Basin at least as far south as the southern Hueco Bolson (Davie and Spiegel, 1967; Hawley, 1965). Fillmore deposits make up the bulk of the younger valley-border alluvium and contain charcoal dated by C-14 ranging in age from approximately 7,300 to 2,600 yrs B.P. Archaeological studies of pueblo sites on parts of the Fillmore geomorphic surface indicate that most of the Fillmore subunit was deposited by 1,000 A.D. (Gile and others, 1969).

In summary, the younger river-valley fill in the project area and the buried erosion surface on which it rests record a sequence of climate-controlled events similar to cycles that must have occurred at least twice earlier in the late Pleistocene (Tortugas and Picacho). Historic river activity prior to closure of the Elephant Butte Dam and canalization of the main river channel (U.S. Reclamation Service, 1914) involved lateral shifting of the meander belt and reworking of upper valley-fill deposits in channel zones during major floods. Toes of Fillmore and arroyo fans were occasionally removed when impinged upon by the laterally shifting channel, thus initiating local arroyo incision.

2.73 Late Quaternary evolution of internally drained basins

The stacked sequence of multiple depositional units and buried soils in closed or formerly closed basins demonstrates that much of middle to late Quaternary time was characterized by an alternating succession of long intervals of general landscape stability and soil formation (SSF, fig. 8, column I), and shorter episodes of surface instability and widespread erosion-sedimentation (IES, column I). The main difference between bolson and river-valley areas is that basin-floor depressions were sites of lakes and aggrading alluvial plains during full-glacial times, while the inner Rio Grande valley was being deepened.

No materials (such as organic carbon) suitable for absolute dating of Jornada II and Isaacks' Ranch alluviums have been recovered. Vertebrate fossils are scarce and those found are not diagnostic of age. Fossil molluscan faunas are rarely found in pre-Holocene basin fills. Inorganic carbon in soil-carbonate horizons has been dated at a few sites (3.83). Dating of pedogenic carbonate provides at best only an approximate upper limit on the true ages of the soil-parent materials. This method of age determination was the only one available for dating units in the southern Jornada del Muerto during the period of active project investigations (1957-1972); but the ages obtained are consistent among themselves. In addition, the general ages indicated for the Isaacks' Ranch and uppermost Jornada II deposits fit relatively well with similar, more accurately dated alluvial sequences in the Rio Grande and elsewhere in the Southwest. The C-14 age of soil carbonates in these two morphostratigraphic units (summarized in table 8) indicate that deposition of much of the Jornada II and Isaacks' Ranch units had taken place, respectively, before 30,000 yrs and 8,000 yrs B.P. The Isaacks' Ranch geomorphic surface and associated alluvium, of course, must predate the basal Organ deposits dated at about 6,400 yrs B.P. As previously noted, the new uranium-trend dating method (Rosholt, 1980) may provide additional information on sediment and surface ages.

Several lines of geomorphic and pedologic evidence support the minimum age determinations of Jornada H and Isaacks' Ranch units based on inorganic carbon dates. Pedologic evidence of relative age differences is discussed in 3.91. The extensive distribution of Jornada II deposits in contrast to the more limited distribution of the Isaacks' Ranch and Organ alluviums supports the premise that the former was a product of erosional and depositional events taking place over a relatively long interval and under environmental conditions that at times differed considerably from those of the present. As previously mentioned, Isaacks' Ranch and Organ alluviums are very similar in facies characteristics and distribution patterns. Fossil pollen composition in these two units seems to be similar. The bulk of Organ alluvium was deposited during an interval of middle Holocene time locally recognized as being a period of landscape instability and relatively unfavorable conditions in terms of soil-moisture regimes and vegetative cover (Freeman, 1972). Isaacks' Ranch deposits are considered to be a product of a similar, though somewhat more moist environment. Studies of regional paleoclimate previously discussed (1.22) indicated that the late Wisconsinan-early Holocene shift from cooler to warmer and drier conditions occurred between 12,000 and 8,000 yrs B.P. (Lanner and Van Devender, 1981; Van Devender, 1977; Thompson and others, 1980). The bulk of the Isaacks' Ranch unit may have been deposited during this interval. A reasonable working hypothesis of deposition, surface stabilization, and subsequent soil formation includes the following stages: First, landscape instability, erosion, and concurrent deposition of the Isaacks' Ranch unit in closed-basin areas during one or more relatively dry (warm?) episodes at the end of the last glacial-pluvial cycle. Presumably these times were characterized by significant decrease in effectiveness of vegetative cover. Second, widespread landscape stabilization and pedogenesis during a brief interval of more moist environment and more continuous vegetative cover during a minor pluvial substage in latest Pleistocene or earliest Holocene time. Third, onset of erosion and basal Organ deposition about 7,000 yrs B.P. marking the start of the middle Holocene interval of landscape instability.

The widespread Jornada II unit must be considered in a much longer time frame than the short interval just discussed. A reasonable approach to interpreting the development of the ancient Jornada II landscape would be to consider it as a sheet-like complex of a number of Isaacks' Ranch- or Organ-type units deposited over a period ranging back from middle Wisconsinan to pre-Wisconsinan time. Successive depositional zones would shift (up, down, and laterally) across the piedmont slope as a complex response to climate-vegetation and local topographic controls, with the latter controls primarily resulting from preceding episodes of fan-piedmont

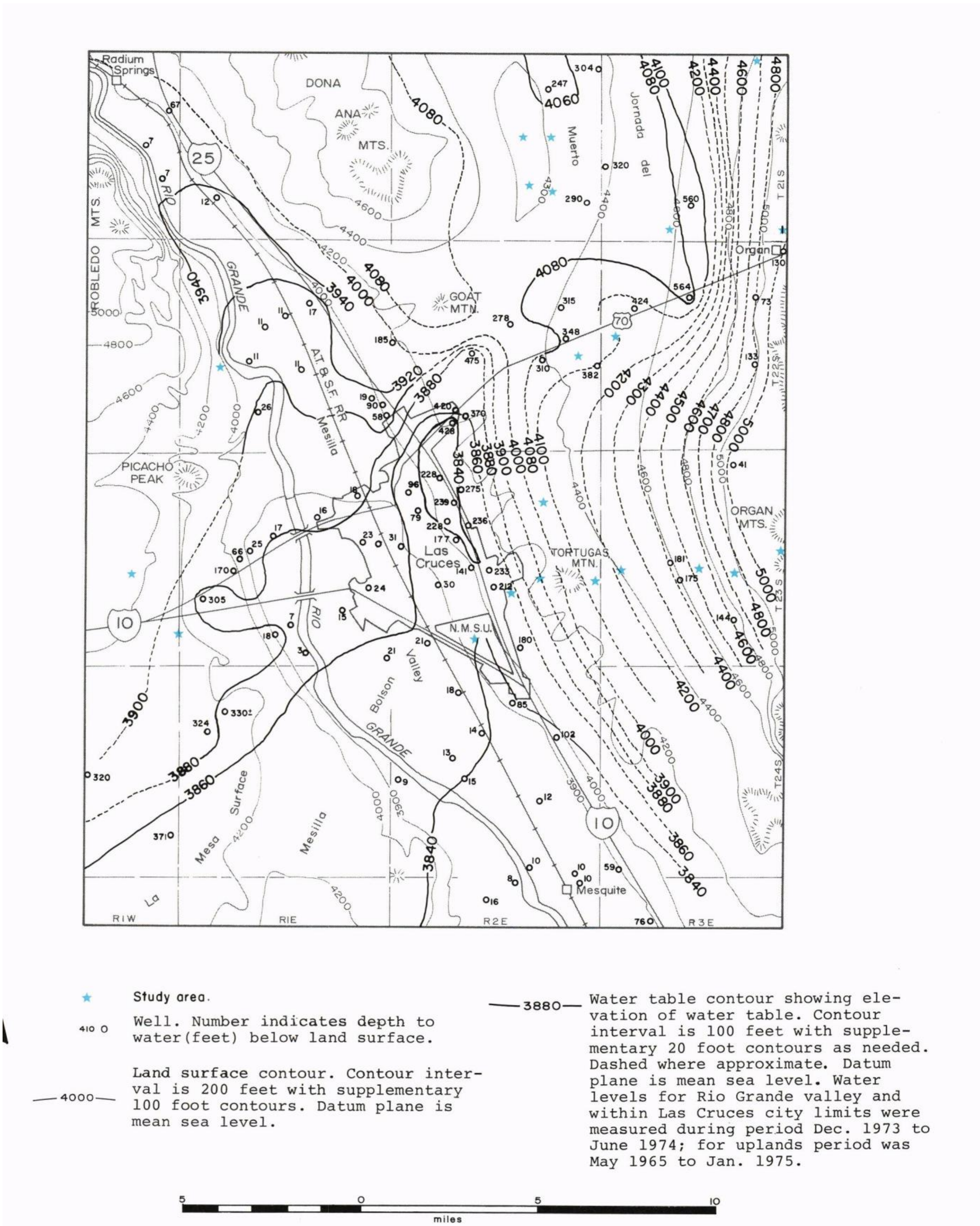


FIGURE **9—WATER-TABLE CONTOUR MAP FOR THE DESERT PROJECT** (from King and Hawley, 1975, fig. 2, with permission).

aggradation. The Isaacks' Ranch and Organ units illustrate this shifting depositional pattern in latest Quaternary time. Isaacks' Ranch deposits were initially laid down in broad drainageway swales on the Jornada II surface. Aggradation in these belts led to formation of minor topographic highs in former swale positions. Finally, during early stages of Organ deposition, gradational activity was diverted into new drainageway belts flanking Isaacks' Ranch depositional highs.

2.8 QUATERNARY GROUND-WATER CONDITIONS

The ground-water regime of the Desert Project area is, and has been throughout the Quaternary, basically controlled by the position of the Rio Grande channel system (fig. 9). Ground-water levels now range from 250 to 575 ft (75 to 175 m) below the intermountain basin floors and are generally more than 30 ft (9 m) below the general land surface in all areas except in the immediate vicinity of the Rio Grande valley floor. Studies of the present water-table configuration, physical properties of basin- and valley-fill deposits, and recharge conditions in local upland areas show that shallow ground-water occurrence (past, as well as present) should only be expected in river-floodplain areas (Conover, 1954; King and others, 1971; King and Hawley, 1975). At various times before initial valley entrenchment, large areas of La Mesa and Jornada I basin floors could have been affected by a high water table. However, the adjacent Jornada I and Doña Ma piedmont-slope landscapes (and upfaulted La Mesa remnants) would have remained well above the regional water table, except in areas of mergence with the basin floors and locally at the mountain fronts.

Since initiation of valley cutting, intervals of drainage of the ancient basin-fill deposits have occurred, generally coinciding with the several major episodes of valley entrenchment. Because of the relatively high hydraulic conductivity of basin and valley fills, no great lag between episodes of valley entrenchment and drainage of adjacent basin fills should be expected. Fig. 7, the cross section of the project area extending along US-70 from upper La Mesa (near study area 6) to San Agustin Pass (near study area 11), shows the present water-table profile, and past water-table positions can be inferred from reconstructed (Tortugas and Picacho) base levels of the ancestral river floodplain.

An important aspect of soil-geomorphic studies, in arid-semiarid regions and elsewhere, is the investigation of possible high water-table and capillary fringe effects on pedogenesis. Present influence of a shallow water table on pedogenesis in the project region is confined to parts of the present Rio Grande valley floor and to small areas of springs and seeps on uppermost piedmont slopes and in mountain canyons. Studies to date have not uncovered any evidence of significant influence by shallow water tables on the development of soils of middle to late Quaternary age at sites above river-floodplain level.

Chapter 3 Soils

A general discussion of soil taxonomy, soil-parent materials, soil development, and certain special studies is presented in this chapter. Details of soils and landscapes at specific sites are discussed in Part II.

Methods of laboratory analyses are identified by symbol (table 11) and have been presented elsewhere (Soil Conservation Service, 1972). Following are general statements on methods. Analyses are reported for the fine earth on a carbonate-containing basis unless otherwise indicated. For most samples the carbonate was not removed prior to the analysis except for the particle-size determination. A pH 5 NaOAc (sodium acetate) buffer was used to remove the carbonate. Some horizons contained coarse fragments cemented by authigenic carbonate, and these samples were first treated with the acidic NaOAc buffer to remove the carbonate (method 1B3). Analyses were then run on the carbonate-free material. Results are reported on a carbonate-containing basis assuming the carbonate was a diluent.

Volumes of total coarse fragments were commonly obtained by combining weight percentages for the smaller fractions and volume estimates for the larger fractions (method 3B2). Amounts of organic carbon, authigenic carbonate, and

TABLE 11—METHODS USED FOR LABORATORY ANALYSIS; symbols and methods from Soil Conservation Service (1972).

Determination	Method symbol	Comments
Bulk density	4A1	Method 4A1 (1/3 bar) unless otherwise noted. For most horizons, bulk density was assumed, not measured, from calculations involving weight to volume conversion.
Carbonate	6E	Several procedures as described under 6E. An "s" indicates that method 6E2 was employed. This is an effervescence test more sensitive than the quantitative procedures.
Cation-exchange capacity	5A1, 5A6	
Electrical conductivity	8Ala	
Gypsum	6F la	
Iron (extractable)	6C2	
Magnesium (extractable)	602	More than one procedure used for determination.
Mineralogy	7A2, 7A3, 7B1	
Organic carbon	6Ala	Amounts computed by method 6A.
Particle size		
>2mm	2A2	Volume calculated as described under 3B2.
Sand, silt, clay	3A1	Carbonate removed with pH 5 NaOAc; samples allowed to stand overnight in 0.1N NaOH; this treatment increased clay for surface horizon 10-15 percent relative.
Fine clay	3Alb	Pretreatment with 0.1N NaOH as above.
Potassium (extractable)	602a	Reported as milliequivalents or percent of exchange capacity parallel to method 5D2.
Sodium		
extractable	6P2a	
exchangeable	6P2a	Corrected for water soluble. Reported as percent of exchange capacity by method 5D2.

clay have been calculated for volumes of soil having a horizontal area of 1 sq m and variable thickness as described under method 6A. The carbonate calculation was based on assumption of 1 percent initially present.

3.1 SOIL TAXONOMY

A new soil classification system was published in 1975 (Soil Survey Staff, 1975), and the Desert Project illustrates the new system as it applies to many desert soils. Summary sections dealing with classification of soils in this area follow. Refer to Soil Survey Staff (1975) for complete definitions and details of the new system.

The classification system has six categories: order, suborder, great group, subgroup, family, and series. The first four and their diagnostic features for the project area are given in table 12.

TABLE 12—SOIL ORDERS, SUBORDERS, GREAT GROUPS, SUBGROUPS, AND DIAGNOSTIC FEATURES IN THE STUDY AREA. Diagnostic features listed are those important to the study area; see Soil Survey Staff (1975) for a complete list. *—A cambic horizon may be present but is not diagnostic. t — A calcic horizon may be present but is not diagnostic for the Haplargids; it is used as a series separation in some Haplargid s; s/c-sand/clay.

Order—diagnostic feature	Suborder—diagnostic feature	Great group—diagnostic feature	Subgroup—diagnostic feature
Aridisols—Ochric epipedon	Orthids—	Camborthids—Cambic horizon	Typic Camborthids
		Calciorthids*—Calcic horizon	Typic Calciorthids
			Ustollic Calciorthids—Organic C + s/c ratio
		Paleorthids*—Petrocalcic horizon	Typic Paleorthids
			Ustollic Paleorthids—Organic C + s/c ratio
	Argids—Argillic horizon	Haplargids†	Typic Haplargids
			Ustollic Haplargids—Organic C + s/c ratio
		Paleargids—Petrocalcic horizon	Typic Paleargids
			Petrocalcic Ustollic Paleargids—Organic C + s/c ratio
Entisols—lack diagnostic horizons	Psamments—Sandy particle-size class in all subhorizons between 25- and 100-cm depth, and have <35% (by volume) of rock fragments in all subhorizons to a depth of 1 m	Torripsamments—Torric moisture regime	Typic Torripsamments
	Orthents—Loamy or finer particle-size class in some horizon between 25- and 100-cm depth, or >35%, by volume, of rock fragments in some subhorizon	Torriorthents—Torric moisture regime	Typic Torriorthents
	Fluvents—Texture is 1fs or finer in some subhorizon between 25- and 100-cm depth, and organic carbon decreases irregularly with depth and/or is more than 0.2% at 125-cm depth	Torrifluvents—Torric moisture regime	Typic Torrifluvents
Mollisols—Mollic epipedon	Ustolls—Ustic moisture regime	Haplustolls	Pachic Haplustolls—Mollic epipedon >50 cm thick
			Torriorthentic Haplustolls—Lack cambic horizon
		Argiustolls—Argillic horizon	Aridic Argiustolls
		Calciustolls—Petrocalcic horizon	Petrocalcic Calciustolls
		Paleustolls—Petrocalcic horizon	Petrocalcic Paleustolls—Argillic horizon
Vertisols	Torrerts	Torrerts	Typic Torrerts

After the upper 18 cm have been mixed, have 30% or more clay in all horizons to a depth of 50 cm or more; at some period in most years have cracks that are open to the surface, and are at least 1 cm wide at a depth of 50 cm; at some depth between 25 cm and 1 m there are slickensides close enough to intersect.

- from fig. caption ttrom fig. caption

3.11 Soil-moisture regime

The *soil-moisture regime* refers to the presence or absence of either ground water or water held at a tension of less than 15 bars in the soil or in specific horizons by periods of the year. Water held at a tension of 15 bars or more is not available to keep most mesophytic plants alive. A horizon is considered to be dry when the moisture tension is 15 bars or more. If water is held at a tension of less than 15 bars but more than zero, the horizon is considered to be moist.

The soil-moisture regime is defined in terms of a *soil-moisture control section.* This control section lies between depths of approximately 10 and 30 cm if the particle-size class is fine-loamy, coarse-silty, fine-silty, or clayey; between 20 and 60 cm if the particle-size class is coarse-loamy; and between 30 and 90 cm if the particle-size class is sandy.

A study of soil moisture in the Jornada Experimental Range (Herbel and Gile, 1973) indicates that most soils in the arid part of the Desert Project have aridic (torric) moisture regimes. The terms "aridic" and "torric" refer to the same moisture regime but are used in different categories (order and great group respectively) of the taxonomy. In the aridic (torric) moisture regime the moisture-control section in most years is 1) dry in all parts more than half the time (cumulative) that the soil temperature at a depth of 50 cm is above 5° C and 2) never moist in some or all parts for as long as 90 consecutive days when the soil temperature at a depth of 50 cm is above 8 ° C.

Some Aridisols are defined as being drier. For example, Petrocalcic Paleargids "are dry in all parts of the moisture control section more than three-fourths of the time (cumulative) that the soil temperature at 50 cm depth is 5 ° C or more." Some Petrocalcic Paleargids in the area do not meet this requirement (Herbel and Gile, 1973, see area 6). Change in definition of the moisture regimes may be necessary. As stated by Soil Survey Staff (1975),

> If future studies show that the classifications of the soils are not in agreement with . . . definitions (of the soil moisture regimes) we are more likely to change the definitions than the classifications.

Refer to Smith (1973) for a further discussion of soil-moisture regimes as they pertain to soil classification.

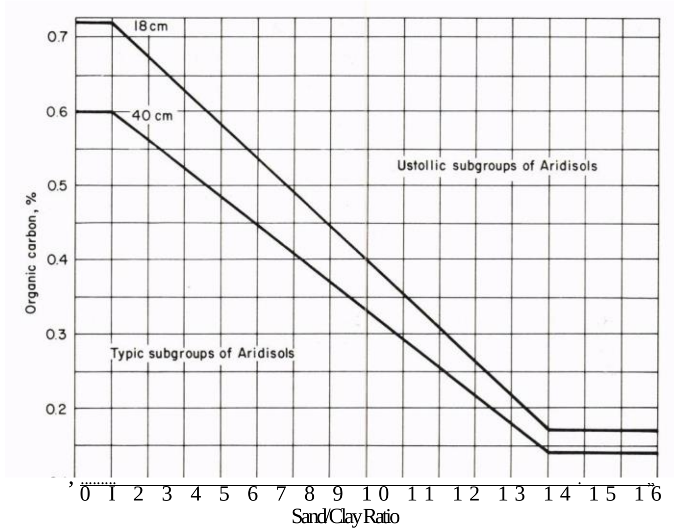


FIGURE 10—THE DISTINCTION BETWEEN TYPIC AND USTOLLIC SUBGROUPS OF ARIDISOLS by using sand/clay ratios and percentages of organic carbon. Organic carbon percentages are used for the upper 18 or 40 cm of soil (see 3.12).

3.12 Organic carbon and sand/clay ratios

Aridisols are dominant in the arid zone between the mountains, and Mollisols occur in places along the mountain fronts. Intergrades between these two orders are the Ustollic subgroups. Their identification is based on the amount of organic carbon relative to sand/clay ratios as illustrated in fig. 10 and the following example (Soil Survey Staff, 1975):

> Typic Haplargids are the Haplargids that . . . e have a weighted average percentage of organic carbon in the upper 40 cm that is <0.6 percent if the weighted average ratio of sand to clay in the soil above that depth is 1.0 or less, or is less than one-seventh percent if the ratio is 13 or more, or have intermediate percentage of organic carbon if the ratio of sand to clay is between 1 and 13; or have a weighted average percentage of organic carbon in the soil to a depth of 18 cm that is not as much as one-fifth more than the values just stated if there is a lithic or paralithic contact at a depth <40 cm but >18 cm . . . h are dry in all parts of the moisture control section more than three-fourths of the time (cumulative) that the soil temperature is 5° C or higher at a depth of 50 cm.

Ustollic Haplargids are like the Typic except for **e** with or without **h.** They have a mean annual soil temperature of 8° C or higher and an aridic moisture regime that borders on an ustic regime. Ustollic Paleorthids and Petrocalcic Ustollic Paleargids also occur in the project area; they are most extensive in and near the semiarid zone. Definitions of these soils are similar to the above except that they have a petrocalcic horizon deeper than 18 cm and shallower than 40 cm (Soil Survey Staff, 1975).

In the project area, the percentage of organic carbon is closely related to clay content (3.5), and the occurrence of Ustollic subgroups may readily be predicted in soils with little gravel. Soils in particle-size families coarser than fine-loamy are all Typic; only a few soils in fine-loamy families are Ustollic, and these are all in the heavy end of the family. Low-gravel soils in Ustollic subgroups are common in landscape positions (basin floor and drainageways) favorable to run-in. High volumes of coarse fragments increase organic carbon percentages and the tendency towards Ustollic subgroups. The pattern is particularly complex where both coarse-fragment volume and depth to a petrocalcic horizon are locally variable (see discussion of Ustollic Aridisols at area 2).

3.13 Horizon nomenclature

Nomenclature for soil horizons is of two general kinds. In one, master horizons and subhorizons are indicated by symbols (such as Al and B2) that are used to describe soils in the field. The other kind consists of diagnostic horizons (such as mollic epipedon and argillic horizon) that are definitive for various taxa in soil classification. Diagnostic horizons were defined for purposes of classification because there is a lack of agreement on many of the horizon symbols.

DIAGNOSTIC HORIZONS—SIX diagnostic horizons are important in the classification of soils in this area. Two of these—the mollic epipedon and the ochric epipedon—are surface horizons. The other four (the cambic, argillic, calcic, and petrocalcic horizons) are subsurface horizons.

The *mollic epipedon* occurs only in the semiarid part of the area and has at least 0.6 percent organic carbon. Color values are darker than 3.5 when moist and 5.5 when dry, and chromas are less than 3.5 when moist. Thickness requirements vary depending on other horizons present; but, in the soils considered here, the mollic epipedon must be at least 25 cm thick. *Ochric epipedons are* too light in color, too thin, and/or have too little organic carbon for mollic epipedons.

The *cambic horizon* is an altered horizon with the texture of very fine sand or finer and with its base at least 25 cm below the surface. Most or all of the rock structure (such as sedimentary strata) has been obliterated. In this area, some of the parent materials have carbonates, and calcareous dust has fallen on all soils. Thus, the cambic horizon must have evidence of redistribution of carbonates, and it must have less carbonate than the underlying ca horizon. In Camborthids of this area, the most common type of cambic horizon is reddish brown and has evidence of illuvial clay but not enough clay increase for an argillic horizon.

The *argillic horizon* contains illuvial silicate clay. The argillic horizon is at least 7.5 cm thick if it is loamy or clayey and at least 15 cm thick if it is sandy. If the eluvial horizon has not been truncated, the increase in clay to the argillic horizon is as follows:

Clay **content of eluvial horizon**	**Minimum clay increase required for an argillic horizon**
percent	*percent or ratio*
less than 15	3
15-40	ratio of 1.2 or more
more than 40	8

Various kinds of evidence for clay illuviation are required in different situations. In this arid region, the pertinent evidence is at least 1 percent of oriented clay as viewed in thin section. Most argillic horizons in this area easily meet the requirement because the Bt horizons are characterized by a fabric in which the sand grains are prominently coated with oriented clay (Bt material, 3.7). The Bt material ranges to 100 percent by volume in horizons. If the horizon contains approximately 10 percent or more of this Bt material, the horizon is considered an argillic horizon.

The *calcic horizon* is a horizon of secondary carbonate enrichment, at least 15 cm thick and having a calcium carbonate equivalent content of 15 percent or more unless the particle size class is sandy, sandy-skeletal, coarse-loamy, or loamy-skeletal with less than 18 percent clay. In these cases the 15 percent requirement for $CaCO_3$ equivalent is waived and the calcic horizon must have at least 5 percent (by volume) more soft, powdery secondary $CaCO_3$ than an underlying horizon; it must also be at least 15 cm thick and have an upper boundary within 1 m of the surface of the soil.

The *petrocalcic horizon* is cemented by carbonates. Dry fragments do not slake in water. It is cemented or indurated and cannot be penetrated by spade or auger when dry. It is massive or platy, very hard or extremely hard when dry, and very firm or extremely firm when moist. Hydraulic conductivity is moderately slow to very slow. Accessory silica may be present but is not enough for a duripan. Laminar horizons are commonly present in the uppermost part of the horizon but are not required.

Application of the diagnostic horizons—Some diagnostic horizons are diagnostic at more than one categorical level. The argillic horizon, for example, is diagnostic at the level of both order (Aridisols vs Entisols) and suborder (Argids vs Orthids). Some horizons are diagnostic only if other diagnostic horizons are absent. For example, an Aridisol with both cambic and petrocalcic horizons is a Paleorthid instead of a Camborthid. This is because the petrocalcic horizon, which is diagnostic for the Paleorthids, is considered to be the more important of the two horizons.

The calcic horizon is diagnostic for the Calciorthids and the petrocalcic horizon is diagnostic for the Paleorthids in Aridisols that lack argillic horizons.

In Aridisols the petrocalcic horizon is diagnostic only if the upper boundary occurs within a depth of 1 m. The argillic horizon is diagnostic for the Haplargids whether or not a calcic horizon is present. Aridisols with argillic horizons and petrocalcic horizons are Paleargids.

The calcic and petrocalcic horizons may be related to the stages of carbonate accumulation (3.61). Stage III horizons contain enough carbonate for calcic horizons, and in some cases stage H horizons qualify as calcic horizons. Horizons that are in late stage I of carbonate accumulation (horizons with common carbonate filaments, for example) usually qualify as calcic horizons if the parent materials contain abundant calcium carbonate (area 12). Minimum expression of the petrocalcic horizon corresponds to late stage III of carbonate accumulation, in which the horizon of accumulation is plugged with accumulated carbonate (area 3). Nearly all petrocalcic horizons are in stage IV of carbonate accumulation. Soils with petrocalcic horizons are designated as pale great groups or as petrocalcic subgroups depending on the great group involved.

Soils are Camborthids if 1) they have a cambic horizon and lack a calcic, petrocalcic, or argillic horizon or 2) they have a calcic horizon but are noncalcareous in some horizon above the calcic horizon after the soil has been mixed to a depth of 18 cm. (The latter condition does not occur in this area; for, by the time a calcic horizon has formed, if a horizon above it is noncalcareous, then a distinct argillic horizon is present.)

Other soils without diagnostic horizons have altered horizons that are too thin or too coarse textured to qualify as cambic horizons. Although some of these horizons are quite distinct (such as at area 19) the soils are Entisols because they do not have diagnostic horizons required for the Aridisols. Thus Entisols constitute a significant portion of the developmental scale in soils of the region and are classified as Psamments, Orthents, or Fluvents depending on amount of sand, gravel, or organic carbon (table 12). Entisols occur in steeper, younger, less stable areas along the valley border, and in high-carbonate parent materials of late Holocene age.

Mollisols have mollic epipedons and occur in the stablest areas along the mountain fronts. Mollisols of this area are Haplustolls if they lack argillic horizons and petrocalcic horizons. Argiustolls have argillic horizons. Paleustolls of this area have argillic horizons and petrocalcic horizons. Calciustolls lack argillic horizons and have calcic or petrocalcic horizons.

HORIZON SYMBOLS—Definitions and designations for soil horizons follow Soil Survey Staff (1962) except as noted below. Master genetic horizons are designated A, B, and K. The C horizon designates horizons that are largely or wholly not genetic soil horizons, except for hard bedrock, which is designated R.

A horizons—The A horizons of desert and mountain soils differ markedly in the study area. The A horizons of mountain soils are dark, contain distinct amounts of organic carbon, and qualify as Al horizons as defined in Soil Survey Staff (1962). Some of these horizons are thick enough and have enough organic carbon to qualify as mollic epipedons.

In contrast, desert soils at low elevations between the mountain ranges have A horizons that are not as dark and that do not qualify as Al horizons. Some of these A horizons are A2 horizons. The others, which are designated A without suffix, have the surficial position characteristic of A horizons and lack evidence (such as still-preserved sedimentary strata) for C horizon materials. These A horizons generally are thin (approximately 5 cm in many soils) and differ from underlying B or K horizons in texture, structure, color, and/or consistence.

B horizons—The notation B is used to designate textural B-horizons and color B horizons. It is also used for two kinds of horizons that do not qualify as B as defined in Soil Survey Staff (1962). In both instances the horizons show marked alteration of the parent materials, and the designation of C horizon does not, therefore, seem appropriate.

The designation B is used to indicate horizons that have distinct structural development (commonly termed structural B horizons) but that lack evidence of the formation of silicate clay or liberation of oxides. Such horizons are most common in soils developed in highly calcareous parent materials.

The designation B is used to indicate horizons in the B position (between the thin A horizon and the K horizon or the Cca horizon). Fine strata are absent, and the horizons have been mixed by roots and soil fauna. In older soils, particularly, there has been a high degree of alteration since deposition of the parent materials and the start of soil formation; and evidence exists for abundant carbonate redistribution in the form of underlying K horizons.

K horizons—This horizon has a prominent accumulation of pedogenic carbonate (Gile and others, 1965). The K horizon is defined in terms of volumes of K-fabric, in which fine-grained authigenic carbonate occurs as an essentially continuous medium. The carbonate coats and commonly separates skeletal pebbles, sand, and silt grains. The K horizon contains 90 percent or more o f K-fabric. Small amounts of silica, gypsum, and more soluble salts may also occur. The horizons are usually prominent and light colored, and many are white throughout. Consistence ranges from soft to extremely hard, but most K horizons are cemented to a noticeable degree and many are indurated.

The K1 horizon is a transitional horizon between an A or B horizon and an underlying K2 or K2m horizon. The K1 horizon contains 50 percent or more K-fabric and may be transitional because of less hardness, less continuous induration, or smaller volume of K-fabric.

The K2 horizon is the most prominent, hardest, and whitest part of the K horizon. The K2 horizon contains 90 percent or more of K-fabric and may be blocky, platy, nodular, or massive. Indurated horizons, designated K2m, commonly consist of a plugged horizon overlain by one or more laminar horizons.

The K3 horizon is a transitional horizon between the K2 or K2m horizon and an underlying C horizon, buried soil, or bedrock. The K3 horizon contains 50 percent or more of K-fabric. It has less carbonate or is not as hard or as light colored as the overlying K2 horizon. The K3 horizon is not continuously indurated but can contain indurated nodules or agglomerations of skeletal grains. Carbonate content and volume of K-fabric of the K3 horizon commonly decrease with increasing depth.

The K and B and K and C horizons have from 50 to 90 percent of K-fabric; the remainder is B or C horizon material. These designations are used in soils lacking horizons with more than 90 percent K-fabric.

Other soil horizons with carbonate accumulations are noted with the ca symbol in combination with the appropriate master horizon designation.

C horizons—The definition of the C horizon in Soil Survey Staff (1962) includes both pedologically unmodified materials and strong genetic horizons in the same master horizon. As used here, the C notation designates horizons that consist largely or wholly of material that has undergone little or no pedogenic alteration.

R horizons—An R horizon is a horizon of extremely hard rock that has little or no evidence or pedogenesis and that cannot be removed with a shovel or pick; machinery is required.

3.14 Family differentiae

Properties diagnostic for the soil family in the project area are particle size, mineralogy, calcareous class, depth, and soil temperature. Classes of particle size are given in table 13. There are two mineralogy classes, mixed and carbonatic. In the carbonatic class, materials in the control section have more than 40 percent by weight of carbonates (expressed as $CaCO_3$) plus gypsum, and the carbonates are greater than 65 percent of the sum of carbonates and gypsum. The determinant size fraction is the whole-soil particles less than 2 mm in diameter or the whole soil less than 20 mm, whichever has the higher percentage of carbonates plus gypsum. Soils with mixed mineralogy have less than 40 percent of any one mineral other than quartz or feldspars. In soils with mixed mineralogy the determinant size fraction is 0.02 to 2 mm except for clayey and clayey-skeletal soils in which the determinant size fraction is less than 0.002 mm. Soils that have a petrocalcic horizon at a depth less than 50 cm are in the shallow family. In soils of the calcareous class, the fine-earth fraction effervesces in all parts with cold dilute HC1.

Measurements of soil temperature (Gile and Grossman, 1979) have shown that all soils are within the thermic temperature class—that is, they have mean annual soil temperatures between 15° C to 22° C (59° F to 72° F).

3.15 The family control section

Names of particle-size classes are not applied to indurated horizons or layers but to specified horizons or to materials between given depth limits defined in terms of either the distance below the surface of the mineral soil or the upper boundary of a specified horizon. The vertical section so defined is called the *control section*. Definitions of the control section for determination of the particle-size classes are arranged below as a key. (Only the parts that apply to soils of the project area are listed; see Soil Survey Staff, 1975, for a complete list.)

A The control section extends from the surface to a lithic or paralithic contact or to a petrocalcic horizon if any of these are within a depth of 36 cm.

B In other soils that do not have an argillic horizon or a natric horizon:

> I) The control section extends from the base of the Ap horizon or from a depth of 25 cm, whichever is greater, to a lithic or paralithic contact, or petrocalcic horizon if any of these are within a depth of 1 m.
>
> 2) Otherwise, the control section extends from a depth of 25 cm to a depth of I m.

C In great groups of Aridisols and Mollisols that have an argillic horizon that has a) a lower boundary deeper than 25 cm (see **E)** and b) an upper boundary shallower than 1 m:

> 1) If there is no petrocalcic horizon between the top of the argillic horizon and a depth of 1 m, the control section is the whole argillic horizon if it is less than 50 cm thick or the upper 50 cm of the argillic horizon if **it** is greater than 50 cm thick.

TABLE 13—THE PARTICLE-SIZE CLASSES AND THEIR DEFINITIONS.

Class	Definition
Fragmental	Stones, cobbles, gravel, and very coarse sand particles; too little fine earth to fill interstices >1 mm in diameter.
Sandy-skeletal	Rock fragments 2 mm in diameter or larger make up 35 percent or more by volume; enough fine earth to fill interstices >1 mm; the fraction <2 mm is sandy as defined for the sandy particle-size class.
Loamy-skeletal	Rock fragments make up 35 percent or more by volume; enough fine earth to fill interstices >1 mm; the fraction <2 mm is loamy as defined for the loamy particle-size class.
Clayey-skeletal	Rock fragments make up 35 percent or more by volume; enough fine earth to fill interstices >1 mm; the fraction finer than 2 mm is clayey as defined for the clayey particle-size class.
Sandy	The texture of the fine earth is sand or loamy sand but not loamy very fine sand or very fine sand; rock fragments make up <35 percent by volume.
Loamy[1]	The texture of the fine earth is loamy very fine sand, very fine sand, or finer, but the amount of clay is <35 percent; rock fragments are <35 percent by volume.
Coarse-loamy	By weight, 15 percent or more of the particles are fine sand (diameter 0.25 to 0.1 mm) or coarser, including fragments up to 7.5 cm in diameter; <18 percent clay in the fine-earth fraction.
Fine-loamy	By weight, 15 percent or more of the particles are fine sand (diameter 0.25 to 0.1 mm) or coarser, including fragments up to 7.5 cm in diameter; 18 through 34 percent clay in the fine-earth fraction (<30 percent in Vertisols).
Coarse-silty	By weight, <15 percent of the particles are fine sand (diameter 0.25 to 0.1 mm) or coarser, including fragments up to 7.5 cm in diameter; <18 percent clay in the fine-earth fraction.
Fine-silty	By weight, <15 percent of the particles are fine sand (diameter 0.25 to 0.1 mm) or coarser, including fragments up to 7.5 cm in diameter; 18 through 34 percent clay in the fine-earth fraction (<30 percent in Vertisols).
Clayey[1]	The fine earth contains 35 percent or more clay by weight, and rock fragments are <35 percent by volume.
Fine	A clayey particle-size class for soils having 35 through 59 percent clay in the fine-earth fraction (30 through 59 percent for Vertisols).
Very fine	A clayey particle-size class for soils having 60 percent or more clay in the fine-earth fraction.

[1] Carbonates of clay size are not considered to be clay but are treated as silt in all particle-size classes. (If the ratio of 15-bar water to clay is 0.6 or more in half or more of the control section, for this purpose the percentage of clay is considered to be 2.5 times the percentage of 15-bar water.) For example, 18 through 34 percent of noncarbonate clay is required for the fine-loamy class. This should be kept in mind where the control section contains abundant pedogenic carbonate and is dominated by textures averaging sandy clay loam or clay loam. If the parent material was sand, these soils (Calciorthids) are commonly coarse-loamy (see area 18).

2) If there is a petrocalcic horizon below an argillic horizon, the control section extends from the top of the argillic horizon, excluding any part incorporated in an Ap horizon, to the top of the petrocalcic horizon, or the upper 50 cm of the argillic horizon, whichever of these is less.

D In great groups of Aridisols and Mollisols that have an argillic horizon with its upper boundary at a depth greater than 1 m, the control section extends from a depth of 25 cm to a depth of 1 m.

E In other soils where the lower boundary of the argillic horizon is shallower than 25 cm (that is, having a ca horizon with soft powdery lime, having a calcic or other named diagnostic horizon whose upper boundary is within 25 cm of the surface, or having rock structure dominant within that depth), the control section extends from the top of the argillic horizon or the base of an Ap horizon, whichever is shallower, to a lithic or paralithic contact, a petrocalcic horizon, or to a depth of 1 m, whichever is shallowest.

3.16 Buried soils

Buried soils are common in the project area, and observations elsewhere indicate that they also are extensive in other desert regions (2.14). Buried soils are designated with the symbol "b" (Soil Survey Staff, 1975). The B2t horizon of a buried Argid, for example, would be designated B2tb. By convention and in this study, the symbol "b" is not used unless the overlying materials are at least 30 cm thick.

The buried soils vary considerably in thickness and in the depth at which they occur. Buried soils considered in classification of soils at the land surface have been defined as follows (Soil Survey Staff, 1975):

> **A** soil is considered to be a buried soil if there is a surface mantle of new material that is 50 cm or more thick, or if there is a surface mantle between 30 and 50 cm thick and the thickness of the mantle is at least half that of the named diagnostic horizons that are preserved in the buried soil. A mantle that is <30 cm thick is not considered in the taxonomy but, if important to the use of the soil, is considered in establishing a phase. The soil that we classify in places where a mantle is present, therefore, has its upper boundary at the surface or <50 cm below the surface, depending on the thickness of its horizons.
>
> A surface mantle of new material as defined here is largely unaltered. It is usually finely stratified and overlies a horizon sequence that can be clearly identified as the solum of a buried soil in at least part of the pedon. . . .

Thus, if the mantle of new material is more than 50 cm thick or is 30 to 50 cm thick and is half or more the thickness of the buried diagnostic horizon, the upper boundary of the soil that we classify is at the land surface. In both cases the soils would be classified as Entisols because a surface mantle of new material, as defined, is excluded from the concept of diagnostic horizons.

Psamments must have sandy particle size in all subhorizons to a depth of 1 m. Soils with 50-100 cm of new sandy materials over buried horizons with finer texture are Torrifluvents because the buried upper horizons cause irregular decrease in organic carbon. This feature is illustrated by two soils in eolian sediments (area 5). Pintura soils, Torripsamments, occur where the sandy sediments are at least 1 m thick. Pintura, thin variant, occurs where the sandy sediments are 50-100 cm thick over buried horizons that are finer than sandy.

3.17 Series differentiae and index to soils

Soil series, variants, phases and taxadjuncts used in this book are given in table 14. Refer to Gile and Grossman (1979) for a list of all soils observed in the project area. Several families have more than one series; table 15 gives differentiae for these series. Table 16 is an index to laboratory data, soil photographs, and study areas, by soil classification.

TABLE 14—CLASSIFICATION OF SOIL SERIES, VARIANTS, PHASES, AND TAXADJUNCTS. Classification is according to Soil Survey Staff (1975). All series are established except Soledad. In positions subject to concentrated runoff from areas upslope, overflow phases of the following are shown on figs. 69 and 75: Bucklebar, clayey subsoil variant; Dalby taxadjunct; Headquarters, clayey subsoil variant; and Stellar. SNDseries not designated; the number following SND is the laboratory sample number. All soils are thermic, and all soils have mixed mineralogy unless otherwise stated. Only the soils presented in this book are listed here. See Gile and Grossman (1979) for a list of all soils known to exist at the time of its writing. Bucklebar, clayey subsoil variant occurs only in Isaacks Lake playa; scarcity of vegetation in the playa and data for Dalby taxadjunct 60-16 suggest Typic (table 68).

Series, variant, or phase	Classification
Adelino	Typic Camborthids, fine-loamy
Aladdin	Torriorthentic Haplustolls, coarse-loamy
Algerita	Typic Calciorthids, coarse-loamy
Algerita, partially indurated variant	Typic Calciorthids, coarse-loamy
Anthony	Typic Torrifluvents, coarse-loamy (calcareous)
Anthony, loamy-skeletal variant	Typic Torrifluvents, loamy-skeletal (calcareous)
Arizo	Typic Torriorthents, sandy-skeletal
Berino	Typic Haplargids, fine-loamy
Berino, Ustollic variant	Ustollic Haplargids, fine-loamy
Bluepoint	Typic Torripsamments
Boracho	Petrocalcic Calciustolls, loamy-skeletal, shallow
Boracho, carbonatic variant	Petrocalcic Calciustolls, loamy-skeletal, carbonatic, shallow
Bucklebar	Typic Haplargids, fine-loamy
Bucklebar, clayey subsoil variant	Typic Haplargids, fine
Bucklebar, overflow phase	Typic Haplargid, fine-loamy
Cacique	Petrocalcic Paleargids, fine-loamy
Caliza	Typic Calciorthids, sandy-skeletal
Caliza, sandy variant	Typic Calciorthids, sandy
Canutio, loamy subsoil variant	Typic Torriorthents, coarse-loamy (calcareous)
Caralampi	Ustollic Haplargids, loamy-skeletal
Casito	Petrocalcic Ustollic Paleargids, loamy-skeletal, shallow
Conger	Ustollic Paleorthids, loamy, shallow
Coxwell, shallow variant	Ustollic Haplargids, loamy-skeletal
Cruces	Petrocalcic Paleargids, loamy, shallow
Cruces, loamy-skeletal variant	Petrocalcic Paleargids, loamy-skeletal, shallow
Dalby, taxadjunct	Typic Torrerts, very-fine
Dalian	Typic Torriorthents, loamy-skeletal, carbonatic
Delnorte	Typic Paleorthids, loamy-skeletal, shallow
Dona Ana	Typic Haplargids, fine-loamy
Earp, light subsoil variant	Ardic Argiustolls, loamy-skeletal
Glendale	Typic Torrifluvents, fine-silty, (calcareous)
Hap	Typic Haplargids, fine-loamy
Hawkeye	Torriorthentic Haplustolls, sandy
Headquarters	Ustollic Haplargids, fine-loamy
Headquarters, clayey subsoil variant	Ustollic Haplargids, fine
Hueco	Petrocalcic Paleargids, coarse-loamy
Jal	Typic Calciorthids, coarse-loamy, carbonatic
Kokan	Typic Torriorthents, sandy-skeletal
Monterosa	Ustollic Paleorthids, loamy-skeletal, shallow
Monterosa, carbonatic variant	Ustollic Paleorthids, loamy-skeletal, carbonatic, shallow
Nickel	Typic Calciorthids, loamy-skeletal
Nolam	Ustollic Haplargids, loamy-skeletal
Onite	Typic Haplargids, coarse-loamy
Onite, deep petrocalcic phase	Typic Haplargids, coarse-loamy
Onite, gravelly variant	Typic Haplargids, coarse-loamy
Onite, sandy subsoil variant	Typic Haplargids, sandy
Onite, thin solum variant	Typic Haplargids, coarse-loamy
Pajarito	Typic Camborthids, coarse-loamy
Pintura	Typic Torripsamments
Pintura, thin variant	Typic Torrifluvents, coarse-loamy
Reagan	Ustollic Calciorthids, fine-silty
Reagan, light subsoil variant	Ustollic Calciorthids, fine-loamy
Santo Tomas	Pachic Haplustolls, loamy-skeletal
Santo Tomas, Torriorthentic variant	Torriorthentic Haplustolls, sandy-skeletal
Simona	Typic Paleorthids, loamy, shallow
SND 59-12	Typic Haplargids, coarse-loamy
SND 59-9	Typic Haplargids, fine-loamy
SND 59-3	Typic Torriorthents, sandy
Soledad	Typic Haplargids, loamy-skeletal
Sonoita	Typic Haplargids, coarse-loamy
Stellar	Ustollic Haplargids, fine
Tencee	Typic Paleorthids, loamy-skeletal, carbonatic, shallow
Terino	Petrocalcic Ustollic Paleargids, loamy-skeletal, shallow
Terino, thick solum variant	Petrocalcic Ustollic Paleargids, clayey-skeletal
Terino, moderately deep variant	Petrocalcic Ustollic Paleargids, loamy-skeletal
Tres Hermanos	Typic Haplargids, fine-loamy
Upton	Typic Paleorthids, loamy, carbonatic, shallow
Vado	Typic Camborthids, loamy-skeletal
Vado, sandy-skeletal variant	Typic Camborthids, sandy-skeletal
Vinton	Typic Torrifluvents, sandy
Vinton, gravelly variant	Typic Torrifluvents, sandy
Weiser	Typic Calciorthids, loamy-skeletal, carbonatic
Whitlock	Typic Calciorthids, coarse-loamy
Yturbide	Typic Torriorthents, sandy

TABLE 15—SERIES DIFFERENTIAE FOR SOILS IN THE PROJECT AREA.

Series	Series differentiae
Typic Torrifluvents, coarse-loamy	
Anthony	Occurs on slopes of 0 to 5 percent
Pintura, thin variant	Occurs on dunes with slopes more than 5 percent
Typic Torripsamments	
Bluepoint	Has 10 percent or more of silt plus clay in the control section; at least one subhorizon in the control section is calcareous
Pintura	No restriction on silt plus clay; noncalcareous throughout or at most is calcareous only in a few spots
Typic Torriorthents, sandy-skeletal	
Arizo	Occurs on slopes less than about 10 percent
Kokan	Occurs on slopes ranging from about 10 to 60 percent
Typic Haplargids, coarse-loamy	
Onite	Combined thickness of A and B horizons totals 25 to 75 cm
Sonoita	Combined thickness of A and B horizons totals more than 75 cm
Typic Haplargids, fine-loamy	
Bucklebar	Lacks calcic horizon within 1 m depth
Berino	Has calcic horizon within 1 m; does not have macroscopic carbonate in all subhorizons of the Bt horizon
Dona Ana	Has calcic horizon within 1 m; has macroscopic carbonate in all subhorizons of the Bt horizon
Hap	Has calcic horizon within 1 m; averages 15 to 35 percent by volume of coarse fragments in the control section
Tres Hermanos	Has calcic horizon within 1 m; has some macroscopic carbonate in all subhorizons of the Bt horizon; averages 15 to 35 percent coarse fragments in the control section
Petrocalcic Ustollic Paleargids, loamy-skeletal	
Terino	Does not have macroscopic carbonate in all subhorizons of the Bt horizon
Casito	Has some macroscopic carbonate in all subhorizons of the Bt horizon
Ustollic Haplargids, loamy-skeletal	
Caralampi	Lacks a calcic horizon within 1 m
Nolam	Has a calcic horizon within 1 m
Typic Camborthids, coarse-loamy	
Pajarito	Averages less than 15 percent by volume of coarse fragments in the control section
Agustin	Averages from 15 to 35 percent by volume of coarse fragments in the control section
Typic Calciorthids, coarse-loamy	
Algerita	Control section averages 10 to 20 percent carbonate clay and is dominantly sandy clay loam or clay loam*
Whitlock	Control section averages less than 10 percent carbonate clay and is dominantly coarser than sandy clay loam

* Algerita soils have thicker calcic horizons than do Whitlock soils. Most Algerita soils are much older than Whitlock soils, occurring on La Mesa surface and on Jornada I and II surfaces (the latter in high-carbonate materials). Whitlock soils occur mostly on the valley-border Picacho surface.

TABLE 16-PAGE LOCATION OF LABORATORY DATA, SOIL PHOTOGRAPHS, AND TEXT DISCUSSION BY SOIL CLASSIFICATION. See table 14 for alphabetical listing of soil series, variants, phases, and taxadjuncts.

Subgroup; family; series, variant, or phase	Page: Laboratory data	Page: Photograph	Page: Text
ARIDISOLS			
Typic Haplargids			
loamy-skeletal			
Soledad	66, 73, 76, 202	202, 203	66, 72, 76, 200
sandy			
Onite, sandy subsoil variant	70, 79, 179	180	70, 78, 177
coarse-loamy			
Onite	70, 77, 79, 176	175	72, 77, 78, 173, 174
Onite, deep petrocalcic phase	77, 79, 114	115	77, 78, 113, 114
Onite, gravelly variant	79		78
Onite, thin-solum variant	77, 179		78, 177
Sonoita	77, 79, 114, 156		77, 78, 113, 155
SND 59-12	169		
fine-loamy			
Berino	70, 73, 77, 79, 138, 143, 176, 179	137, 142, 178	70–72, 77, 78, 134, 138, 139, 173–177
Bucklebar	70, 73, 77, 79, 114, 121, 138, 143, 144, 149, 179	140, 142, 145	70, 71, 77, 78, 117, 124, 139, 143, 144, 172, 177
Dona Ana	70, 77, 79, 138		70, 71, 77–79, 134, 138
Hap			
SND 59-9	169		169
Tres Hermanos			
fine			
Bucklebar, clayey subsoil variant			
Ustollic Haplargids			
loamy-skeletal			
Coxwell, shallow variant	77, 79, 155	153	77, 78, 151, 155
Caralampi	70, 73, 209		70, 72, 200, 203, 206
Nolam		107	107, 203
fine-loamy			
Berino, Ustollic variant	143	142	139
Headquarters			
fine			
Headquarters, clayey subsoil variant	77, 79		77, 78, 181
Stellar	70, 77, 79, 184, 189	188	70, 77, 78, 186–188
Petrocalcic Paleargids			
loamy-skeletal, shallow			
Cruces, loamy-skeletal variant	69, 70, 76, 77, 104	69, 107	67–70, 76, 77, 107
loamy, shallow			
Cruces	69, 73, 77, 79, 121, 122	121	67–70, 72, 76–79, 118, 122, 123
coarse-loamy			
Hueco	123		123, 124
Petrocalcic Ustollic Paleargids			
loamy-skeletal			
Terino, moderately deep variant			
loamy-skeletal, shallow			
Casito	70, 104, 108		70, 102, 104, 108
Terino	69, 73, 77, 79, 104		67–69, 72, 77, 78, 203
clayey-skeletal			
Terino, thick solum variant	70, 77, 79, 209		70, 78, 206
Typic Calciorthids			
sandy-skeletal			
Caliza			
loamy-skeletal			
Nickel	70		70, 96
Weiser (carbonatic)			
coarse-loamy			
Algerita	70, 77, 191	191	70, 78, 189, 190
Algerita, partially indurated variant	70, 77, 191		70, 78, 189, 190
Jal taxadjunct (carbonatic)	79		78, 79
Whitlock	102	103	102
sandy			
Caliza, sandy variant			
Ustollic Calciorthids			
fine-loamy			
Reagan, light subsoil variant	77, 184		77, 183, 185
fine-silty			
Reagan	77, 79, 161, 184	162, 187	77, 78, 160–162, 183, 185

Subgroup; family; series, variant, or phase	Page: Laboratory data	Photograph	Text
ARIDISOLS			
Typic Camborthids			
sandy-skeletal			
Vado, sandy-skeletal variant	107		106
coarse-loamy			
Pajarito	73, 147	148	72, 146, 149
fine-loamy			
Adelino			
Typic Paleorthids			
loamy-skeletal, shallow			
Delnorte	104		106, 107
Tencee (carbonatic)	69, 128		67–69, 130
loamy			
Simona	70		70, 71, 110
Upton (carbonatic)	69, 77		67–69, 76, 77, 130
Ustollic Paleorthids			
loamy-skeletal, shallow			
Monterosa	11, 111, 212	211	110, 209, 212
Monterosa, carbonatic variant (carbonatic)			
loamy, shallow			
Conger			
ENTISOLS			
Typic Torrifluvents			
sandy-skeletal			
Vinton, sandy-skeletal variant			
loamy-skeletal			
Anthony, loamy-skeletal variant			
sandy			
Vinton	70, 76, 78		70, 76–78
Vinton, gravelly variant		97	96, 97
coarse-loamy			
Anthony	76, 161	159	76, 77, 158, 160
Pintura, thin variant			
fine-silty			
Glendale	77, 79		77, 78
Typic Torriorthents			
sandy-skeletal			
Arizo			
Kokan			
loamy-skeletal			
Dalian (carbonatic)	128	129	128
coarse-loamy			
Canutio, loamy subsoil variant	98, 99		98, 99
sandy			
Yturbide			
SND 59-3	78		78
Typic Torripsamments			
Bluepoint	70, 78, 196	196	70, 78, 194, 197
Pintura	116	116, 117	115, 117
MOLLISOLS			
Aridic Argiustolls			
loamy-skeletal			
Earp, light subsoil variant			
Petrocalcic Calciustolls			
loamy-skeletal, shallow			
Boracho	212		212
Boracho, carbonatic variant (carbonatic)			
Pachic Haplustolls			
loamy-skeletal			
Santo Tomas	209	208	206
Torriorthentic Haplustolls			
sandy-skeletal			
Santo Tomas, Torriorthentic variant			
sandy			
Hawkeye	78, 156	154	78, 155
coarse-loamy			
Aladdin	78		78, 155, 156
VERTISOLS			
Typic Torrerts			
very-fine			
Dalby taxadjunct	77, 79, 174	174	77, 78, 172

Three soils do not fall within the range of characteristics of established series but are placed in the Dalby, Jal, and Yturbide series as follows. The Dalby series is a member of the fine, montmorillonitic, thermic family of Typic Torrerts. In the study area, a typical pedon (number 60-16) of the playa soils concerned has mixed mineralogy, and clay content of the 25-100 cm control section averages about 65 percent. The soil is considered to be a taxadjunct to the Dalby series and is classified as a Typic Torrert, very fine, mixed, thermic.

The Jal series is a member of the fine-loamy, carbonatic, thermic family of Typic Calciorthids. A typical pedon (65-6) of the soils concerned is well within the coarse-loamy family by laboratory analyses. This is the case for many Calciorthids with strong carbonate accumulation and developed in materials containing abundant sand, because the carbonate accumulation has diluted the parent materials; when carbonate clay is treated as silt, silicate clay for the 25-200 cm control section averages less than 18 percent. The soil concerned is designated Jal taxadjunct and classified as a Typic Calciorthid, coarse-loamy, carbonatic, thermic.

The Yturbide series is a member of the mixed, thermic family of Typic Torripsamments. Psamments must have less than 35 percent (by volume) of rock fragments in all subhorizons to a depth of 1 m. Average content of rock fragments of Yturbide soils ranges from 15 to 35 percent by volume, but the Yturbide series was proposed before formulation of the criterion involving the amount of rock fragments for Orthent-Psamment distinction. Yturbide soils generally contain too much gravel for the Psamments; because Yturbide soils average 15-35 percent gravel, some subhorizon would likely contain more than 35 percent rock fragments by volume, and these soils would qualify as Orthents. Such sandy materials were excluded from Psamments because they are much less subject to blowing and drifting than nongravelly sands and provide a better support for wheeled vehicles (Soil Survey Staff, 1975). For these reasons, Yturbide soils are best classified as Orthents rather than as Psamments. The soil concerned is therefore designated Yturbide and is classified as a Typic Torriorthent, sandy, mixed, thermic.

The youthful materials of arroyo channels were not studied in enough detail to establish a dominant category at the series level. These materials are designated Entisols or Torriorthents, depending upon the level of knowledge for the area concerned.

3.2 PARENT MATERIALS

Most soils have formed in alluvium of the intermontane basins (2.5). Bedrock is a parent material only in the mountains and in scattered outliers near the mountains. Distribution of the bedrock in the mountains is important because it is the ultimate source of the piedmont-slope deposits below. The distribution of general types of bedrock is shown in sheet 1. Eolian sediments occur primarily as coppice dunes (area 5).

Extensive areas of soils that range widely in age have formed in a single kind of parent material. For example, sediments of large piedmont-slope areas were derived mainly from a single type of rock such as rhyolite or monzonite. Also, many soils have formed in noncalcareous sandy sediments of the ancestral Rio Grande. These sediments occur along the Rio Grande valley and in the closed basin north of US-70.

The weathering relations between the soils and their parent materials are complicated because the parent materials of many soils contained sediments eroded from older soils upslope. These earlier cycles of soil development would have taken place at higher elevations than a given soil and in some instances under higher precipitation. Transportation and possible prior weathering may have reduced easily weathered components such as books of biotite.

Generally, particle size decreases from the mountain fronts to the gentler slopes of the alluvial-fan piedmont, although there may be large lateral variations at any position on the slope. The variations are due to differences in position with respect to the streams that deposited the alluvium; fragments in the main channel zones are coarser than those in areas away from these zones. At a given distance from the mountain front, Pleistocene alluvium commonly has a greater proportion of rock fragments than does Holocene alluvium.

3.21 Rhyolite bedrock and alluvium

The Organ Mountains south of Fillmore Canyon are almost entirely composed of rhyolite (2.41). The CaO content (0.16 percent) of most of this rhyolite is much lower than that of most rhyolites and the FeO content is higher (Gile and Grossman, 1979). The rhyolite bedrock is extremely hard and dense. Accumulations of clay and carbonate occur locally along fracture planes in the bedrock.

Rhyolite is an extensive rock in the southern Organ Mountains; consequently, rhyolitic alluvium is extensive downslope. Rhyolite resists comminution, and alluvium derived from it tends to be gravelly or very gravelly. Most soils tend to be skeletal at slopes of approximately 3 percent and greater. At 2-percent slope, in many places there are abrupt changes from high-gravel to low-gravel materials. The fine earth of high-gravel rhyolite alluvium typically has little medium sand and substantially more very coarse, coarse-fine, and very fine sand.

3.22 Monzonite bedrock and alluvium

The northern part of the Organ Mountains consists primarily of monzonite (2.41). In many places soils have formed in the monzonite because of numerous joints. Water readily infiltrates along the joints, and horizons of clay and carbonate accumulation have formed. Distinct soils have formed in monzonite in the vicinity of San Agustin Pass and on a broad pediment west of the pass (area 11). An extensive area of piedmont-slope sediments derived from monzonite occurs west of the northern part of the Organ Mountains. The monzonite comminutes rather easily in weathering and transport. Consequently the soils are low in gravel except for steeper slopes.

Fine earth of high-gravel monzonitic sediment is similar to fine earth of high-gravel rhyolitic sediment in size of sand. Monzonitic alluvium free of gravel has a high proportion of fine sand; thus, it differs from its gravelly monzonitic counterpart and from rhyolitic alluvium but is similar to alluvium deposited by the ancestral Rio Grande.

3.23 Sedimentary rocks and alluvium

Sedimentary rocks are dominant in the San Andres and Robledo Mountains (2.41, 2.43). Small areas also occur in the Doña Ana Mountains and in places along the front of the Organ Mountains. Limestone and other calcareous rocks are the dominant component, with variable amounts of igneous rocks, chert, and quartzite. The Holocene alluvium tends to be free of gravel on slopes of approximately 2 percent or less.

Pleistocene alluvium usually has some gravel even on slopes of 1 percent.

Holocene alluvium on the middle and lower piedmont slopes is high in silt and clay and commonly has little sand. Along the mountain front, lateral variation in the particle-size distribution of the Holocene alluvium is large. Commonly the fine earth of gravelly sediments is lower in coarse and very coarse sand than are gravelly monzonitic or rhyolitic alluviums.

3.24 River alluvium of mixed lithology

Middle Pleistocene river alluvium (the fluvial facies of the Camp Rice Formation) underlies extensive areas of the basin floors (2.52). It is exposed to substantial depths in the upper slopes of the valley border south of the Robledo and Doña Ana Mountains. In those areas they crop out just below the outer valley-rim scarp as a gravelly, erosion-resistant unit overlying sandy sediments with little or no gravel. In most other places the sediments at the surface contain little or no gravel. River alluvium of late Pleistocene age is exposed in places along the valley border between the Doña Ana and Robledo Mountains. The alluvium of both late and middle Pleistocene age is informally designated ancient-river alluvium. The fine earth of the low-gravel alluvium tends to be high in fine sand and very low in silt.

3.25 Significance of carbonate and rock fragments

Carbonate content and rock fragment percentage affect the accumulation of both silicate clay and authigenic carbonate in soils. This accumulation in turn affects soil classification. General relations of these two factors to soils of various ages and terrains are summarized in table 17, which also indicates the approximate times for development of various diagnostic horizons under stated conditions.

3.3 ATMOSPHERIC ADDITIONS

Prominent horizons of carbonate accumulation occur in soils formed in parent materials very low in calcium. The atmosphere is a possible source of the calcium. Dust traps were placed at seven locations during the dry, dusty season (February to June). The traps consisted of marble-filled trays at heights of 30 or 90 cm. Table 18 summarizes the characterization data. Consult Gile and Grossman (1979) for details of the study.

Clay content of the dust ranges from 20 to 40 percent. Some of the clay probably was transported as aggregates or coatings on larger grains. The dust catch becomes coarser as the amount increases, with sand substituting for clay and silt. Only a small portion of the dust exceeds 0.25 mm despite appreciable material greater than 0.25 mm in some of the nearby soils. Particles larger than approximately 0.2 mm are not moved in suspension but rather by saltation. Saltation has apparently been a minor contributing process to the traps at 90-cm height.

Organic carbon ranges from 2.5 to 6.6 percent for the traps at 90 cm (table 18) and is negatively correlated with the amount of dust. The organic carbon percentages are severalfold higher than for surface horizons of the soils in the vicinity of the traps.

Carbonate in the dust ranges from 1.3 to 5.7 percent for the traps at 90 cm. Omitting trap 4 (high carbonate related to strongly calcareous surface horizons) and trap 6 (large dust catch because of the local conditions), the range is only 0.2 to 0.4 g/sq m/yr. Water-soluble calcium expressed as $CaCO_3$-equivalent ranges from 0.1 to 0.2 g/sq m/yr and shows no relationship to the amount of carbonate. The amounts exceed the solubility of calcite; salts more soluble than calcite must be present. The measured carbonate plus the water-soluble calcium expressed as $CaCO_3$-equivalent (together termed labile calcium) range from 0.35 to 1.3 g/sq m/yr for all traps and 0.35-0.55 g/sq m/yr if traps 4 and 6 are excluded.

Deposition of labile calcium by dust is relatively uniform over most of the project. Winds during the dusty season come from the west, roughly at right angles to the Rio Grande valley. This wind transports dust containing labile calcium (mostly carbonate) eastward into the Organ Mountains, where the parent rocks are noncalcareous and mostly very low in calcium. Movement of labile calcium in dust over a long period of time apparently was an important agency for the dissemination of carbonate over the landscape. This dissemination is indicated by the increasing amount of carbonate with increasing age of soils in noncalcareous parent materials (3.6).

Labile calcium in the dry dust is not the only source of calcium, which also occurs in the precipitation. Monitoring from July 1955 to July 1956 of the ionic composition of precipitation (dust from between precipitation events excluded) for the continental United States indicated an average of about 3 mg/L of Ca^{++} in the precipitation of the project area (Junge and Werby, 1958). A similar study by Lodge and others (1968) from 1960 to 1968 supports the estimate of 3 mg/L. From these figures, the Ca^{++} in the mean annual precipitation for the arid part of the study area, taken as 200 mm, would be sufficient to form about 1.5 g/sq m/yr of carbonate or roughly two to three times the carbonate from labile calcium in the dry dust.

Ionic calcium in the precipitation (Junge and Werby, 1958) plus labile calcium in the dry dust would be sufficient to form about 2 kg/sq m of carbonate per thousand years, assuming that all the calcium enters the soil and is there deposited as carbonate. Such computations assume that all the labile calcium in the dry dust is leached into the soil and all the precipitation enters the soil. These assumptions are highly artificial.

The computation assumes that the zone of carbonate accumulation acts as a sink for the calcium from the atmosphere. The precipitation contains sodium, currently about 1 mg/L (Junge and Werby, 1958), and the principal anion is sulfate. A number of soils contain little exchangeable sodium and water-soluble ions within the zone of carbonate accumulation. For these soils, occasional deep wetting would seem a necessary corollary of the hypothesis that the calcium came largely from the precipitation. Occasional deep wetting does occur at the present time in some soils (Gile and Grossman, 1979), and deep wetting should have been much more frequent in pluvials. Certain soils do show a distinct increase in exchangeable sodium with depth (area 5). The relationships at area 5 suggest conditions in which sodium of atmospheric origin might be retained within soils of the study area.

3.4 SOIL MOISTURE

The Jornada Experimental Range is located partly in and immediately north of the project area (fig. 1). Herbel and Gile (1973) present soil moisture, soil morphology, and vegetative growth data for some of the soils in the arid part of the experimental range. Some of these data are included in the discussion of study areas 1, 6, and **17,** which contain soils similar to those in which the moisture measurements were made.

TABLE 17—RELATION OF SOIL DEVELOPMENT AND CLASSIFICATION TO CARBONATE AND ROCK FRAGMENTS IN THE PARENT MATERIALS (ARID ZONE). Soils are on stable sites that show little or no evidence of landscape dissection unless indicated "Low-carbonate" designates materials with less than approximately 2 percent CaCO, equivalent ; "high-carbonate" designates materials with more than about 15 percent CaCO, equivalent. "Low-gravel" designates materials with less than approximately 20 percent rock fragments by volume; "high-gravel" designates material with more than annroximatelv 50 percent rock fragments by volume.

	Low-carbonate parent materials				High-carbonate parent materials	
Soil age	Great group and *diagnostic horizon*		Obliteration of the argillic horizon*		Great group and *diagnostic horizon*	
	Low-gravel materials	High-gravel materials	Low-gravel materials	High-gravel materials	Low-gravel materials	High-gravel materials
Late Holocene	Torripsamments Torrifluvents Torriorthents Camborthids; *Cambic horizon*	Torriorthents Camborthids; *Cambic horizon* Haplargids; *Argillic horizon*			Torrifluvents Torriorthents	Torrifluvents Torriorthents
Middle Holocene	Haplargids; *Argillic horizon*				Calciorthids; *Calcic horizon*	Calciorthids; *Calcic horizon*
Early(?) Holocene						
10,000 years B.P.						
Latest Pleistocene	Haplargids; *Calcic horizon*	Haplargids; *Calcic horizon*				
Late Pleistocene		Paleargids; *Petrocalcic horizon*	Calciorthids; *Calcic horizon*	Paleorthids; *Petrocalcic horizon*		Paleorthids; *Petrocalcic horizon*
Late middle Pleistocene						
Middle Pleistocene	Paleargids; *Petrocalcic horizon*		Paleorthids; *Petrocalcic horizon*			

* Where the argillic horizon has been obliterated by landscape dissection, carbonate engulfment, and/or faunal activity (see study areas 2, 3, and 4).

TABLE 18—SUMMARY OF CHARACTERIZATION DATA FOR DUST COLLECTED AT SEVEN LOCATIONS IN THE PROJECT AREA. See Gile and Grossman (1979) for source data. The percentage values given are the average of the yearly values and are not weighted means adjusted for differences in amounts of dust from year to year. Unless otherwise indicated, the averages pertain to the years listed in the second column. The quantity values (g/sq m/yr) were obtained by averaging the yearly quantities; they are not the product of the average weights and percentages. The amounts for the 30-cm-square pan were multiplied by 10.8 to obtain the values for 1 sq m. Traps at 90-cm height unless otherwise indicated.

Trap number and site description	Years	Weight	Particle-size distribution* mm					Organic carbon		$CaCO_3$ equivalent			
			2–0.25	0.25–0.1	0.1–0.05	0.05–0.002	<0.002			Measured		Water-soluble calcium†	Sum
		$g/m^2/yr$	%	%	%	%	%	%	$g/m^2/yr$	%	$g/m^2/yr$	$g/m^2/yr$	$g/m^2/yr$
Trap 1--Within Organ Mts.; elevation 6,200 ft, 1,891 m; vegetation grass and cedar trees; 100% gravel pavement between vegetation; surface horizon noncalcareous, very gravelly sandy loam.	1962-67	12.4	1	12	10	41	36	5.3	0.57	2.6	0.30		
Trap 2--Fan piedmont below Organ Mts.; elevation 5,000 ft, 1,525 m; vegetation grass and shrubs; 30% gravel pavement; surface horizon noncalcareous, very gravelly sandy loam.	1962-72	9.3	1	10	7	45	37	6.6	0.54	2.6	0.25	0.096	0.35
Trap 3--Basin floor west of Rio Grande valley; elevation 4,450 ft, 1,357 m; vegetation mostly grass; no gravel pavement; weak crust; surface horizon noncalcareous sandy loam.	1962-72	17.9	1	17	9	34	39	4.8	0.78	1.3	0.21	0.17	0.38
Trap 3a--30 cm height.	1965-72	35.0	6	32	12	26	24	3.1	0.87	0.8	0.23	0.15	0.38
Trap 4--Fan-piedmont west of San Andres Mts.; elevation 4,475 ft, 1,446 m; vegetation creosotebush and mesquite; 90% gravel pavement; surface horizon calcareous very gravelly loam that effervesces strongly.	1962-72	15.7	2	14	14	43	27	5.0	0.71	5.7	1.1	0.16	1.3
Trap 5--Fan-piedmont below Dona Ana Mts.; elevation 4,350 ft, 1,327 m; vegetation shrubs; 30% gravel pavement; surface horizon noncalcareous gravelly sandy loam.	1962-72	26.3	2	20	22	34	22	3.5	0.73	1.5	0.33	0.17	0.50
Trap 5a--30 cm height.	1965-72	125.8	6	35	29	17	13	1.4	1.3	0.4	0.43	0.12	0.55
Trap 6--Lower part fan-piedmont below San Andres Mts., elevation 4,370 ft, 1,333 m; vegetation shrubs, with many barren sandy areas; no pavement; loose-appearing; surface horizon noncalcareous sand.	1962-72	58.6	4	27	21	26	22	2.5	1.2	1.8	1.1	0.22	1.3
Type 7--Fan piedmont below Doña Ana Mts.; elevation 4,525 ft, 1,380 m; vegetation shrubs; 5 to 30% gravel pavement; surface horizon calcareous sandy loam.	1962-72	19.2	3	14	17	42	24	5.0	0.76	2.4	0.39	0.12	0.51

* 3a, 5a, 1965-67; others, 1963-67.

† 1969-72 for traps 3, 3a, 5, 5a; others 1970-72. Measured calcium in the water extract was reduced by 3 me to correct for the contribution by carbonate to the water-soluble calcium. This correction is based on an assumed carbonate solubility of about 1 me/L, approximately the solubility of calcite in water in equilibrium with atmospheric CO_2.

The soil moisture was measured with gypsum electrical resistance blocks in livestock enclosures. Measurements were made two or three times a week in the summer and monthly the rest of the year. The significance of run-in was evaluated at several sites by making moisture measurements within and immediately outside of a metal cylinder, 3 m in diameter, set 15 cm into the soil.

Landscape position, microrelief, and soil morphology are important factors affecting soil moisture. Landscape position is significant because it affects runoff and run-in. Runoff from higher areas markedly increases depth of wetting in soils of topographic lows such as the soils discussed at study area 17. Conversely, such runoff decreases moisture in the soils upslope.

Microrelief can greatly influence moisture infiltration. Depth of moisture infiltration is considerably increased by small depressions and holes in the soil surface and by cracks in soil horizons that are connected to the holes and depressions at the surface. Soils without these surface features wet frontally, and the depth of wetting is much less. As a consequence the depth of wetting can differ greatly in a distance of only a few meters.

Soil texture is important because surficial horizons of sandy texture should have the most rapid infiltration rates. Conversely, low infiltration rates would be expected in soil horizons with high clay content, where wetting is through frontal advance (such as the soil discussed at study area 17) and not down large voids. Platy structure of the A horizon is also important, particularly in finer-textured soils because such horizons tend to seal when wetted.

Where runoff and run-in are low, soils and landscapes with the following characteristics have the most favorable moisture conditions for plant growth: 1) level or nearly level areas of a stable landscape that shows little or no evidence of erosion; 2) a surficial horizon, about 5 to 10 cm thick, with texture of sand or loamy sand to maximize infiltration of moisture; and 3) a slightly finer-textured horizon (such as sandy loam) just beneath the surficial horizon, to capture the moisture that has infiltrated and to prevent movement to greater depths where plants cannot use it. Also, petrocalcic horizons act as a barrier to downward moisture movement and increase the time that upper horizons are moist. See area 6 for further discussion of such soils and landscapes.

Two moisture-control sections are involved for the studied soils (Soil Survey Staff, 1975). The one for coarse-loamy soils extends from 20 to 60 cm; the one for fine-loamy, fine-silty, and clayey soils extends from 10 to 30 cm. The number of moist days differs in different parts of these control sections. The control section was divided into 10-cm sections and the 10-cm zone with the highest number of moist days was determined by graphical interpolation between the measured values.

3.5 ORGANIC CARBON ACCUMULATION

The total amount of organic carbon and its distribution with depth are affected by vegetation, elevation and associated climate, content of rock fragments, silt and clay content, landscape position (which determines runoff and run-in), and local differences in soil erosion.

Table 19 illustrates the influence of rock fragment volume on the amount of organic carbon. The pedon with the greater rock fragment volume has the higher percentage of organic carbon in the fine earth. But because of the diluent effect of the rock fragments, the amounts of organic carbon on a volume basis are nearly the same.

High temperatures at and just below the soil surface are thought to be an important factor leading to reduced carbon (area 1), particularly in soils with gravelly desert pavements (table 19). In these soils roots tend to be sparse in the upper few centimeters.

Organic carbon generally increases as clay content rises. Fig. 11 shows the regression between amount of organic carbon and percentage of clay for 28 pedons of Typic or Ustollic Haplargids that occur in the arid part of the study area. The regressions are significant at the 1-percent level. The finer soils commonly occur in landscape positions subject to run-in and the resultant more vigorous vegetation.

3.6 CARBONATE ACCUMULATION

The horizon of carbonate accumulation is one of the most common horizons in the project area. The accumulations range from slight to prominent in various soils and cause pronounced morphological changes in the carbonate horizon as it develops (Gile and others, 1966). Most carbonate horizons in the project area are of pedogenic origin, as indicated by these characteristics: 1) the horizons approximately parallel the soil surface; 2) in the arid part of the project their upper boundaries are usually within a few centimeters to about one-half meter of the soil surface and are or have been within reach of wetting; 3) their morphology is distinctive, predictable, and differs markedly from that of adjacent horizons; 4) the horizons form in morphogenetic sequences that are related to time, as discussed later; and 5) depth to the horizon of carbonate accumulation increases toward the mountains in soils of stable sites. This increase in depth reflects increase in precipitation and indicates an el uvial-illuvial relationship.

TABLE 19—ORGANIC **CARBON FOR THE 5- TO 25-CM ZONE OF TWO ADJACENT PEDONS DIFFERING IN VOLUME OF ROCK FRAGMENTS.**

Pedon	Classification	Volume coarse fragments %	Organic carbon Fine earth %	Organic carbon Total volume kg/m²
Soledad 66-16*	Typic Haplargid loamy-skeletal	60	0.38	0.44
Adjacent (Pajarito)	Typic Camborthid, coarse-loamy	10	0.16	0.38

*On a fine-earth basis this pedon has the following percentages of organic carbon in the 0- to 5-cm, 5- to 15-cm, and 15- to 25-cm horizons: 0.20 percent, 0.32 percent, and 0.46 percent. The low percentages for the first two horizons are thought to be partially due to high temperature. In particular, the sur ficial horizon is capped by a very gravelly and cobbly desert pavement that should cause very high temperatures during summer days.

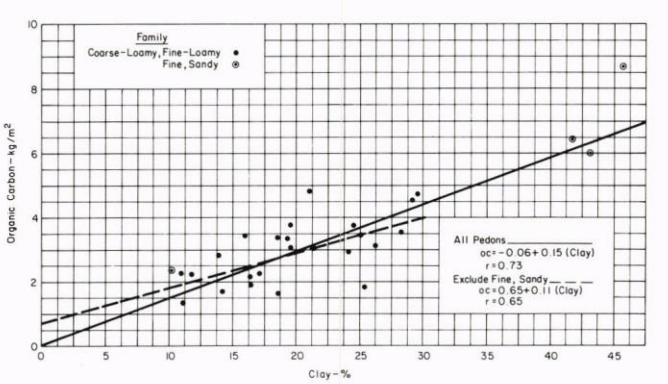


FIGURE 11—AMOUNT **OF ORGANIC CARBON VERSUS CLAY PERCENTAGE FOR TYPIC AND USTOLLIC HAPLARGIDS** from the arid part of the project area. The amount of organic carbon is the kilograms in a unit of volume one square meter in horizontal cross section and extending through the horizon with a lower limit closest to 1 m. The clay percentage is the noncarbonate clay expressed on a carbonate-containing basis weighted for the upper 50 cm or to a K horizon, whichever is shallower. C horizons at the surface were excluded. All pedons contain less than 10 percent by volume coarse fragments within the upper 50 cm. The range of elevation is 4,200 to 4,675 ft (1,280-1,425 m).

Geologic evidence indicates that most of the carbonate accumulations could not have been emplaced from water tables or lakes. Arguments presented by Bretz and Horberg (1949b) and Brown (1956) also apply in this area (2.8).

Calcium of the pedogenic carbonate was derived from the parent materials and/or from atmospheric additions (both from dry dustfall and from dust in precipitation). These atmospheric additions must have been essentially the only source of calcium in parent materials with very little or no calcium. Calcium from the atmosphere enters the soil when it is wetted. Calcium bicarbonate in solution moves downward each time the soils are wetted, and calcium carbonate is deposited on drying. Carbonate tends to accumulate in the lower part of the zone that is wetted frequently under the climate existing at a given time in soil history. The carbonate occurs in places most accessible to percolating water: the surfaces of grains and peds, the interiors of still-pervious carbonate accumulations, and along channels formed by roots and soil fauna.

Some carbonate in the area is of geologic origin. An example occurs in ancestral deposits of the Rio Grande (the fluvial facies of the Camp Rice Formation). Carbonate in these beds is thought to have been deposited by waters of the ancestral Rio Grande. In strongly dissected areas this carbonate is at or very near the surface and may be intimately mixed with carbonate of pedogenic origin.

In places, carbonate of uncertain origin is found well below the normal depth of carbonate accumulation for the soils. This carbonate cannot be positively related to a soil and may have been deposited by laterally moving ground water or may have moved completely through soil horizons some distance above. Such accumulations occur deep in alluvial fans in some areas and may have been emplaced during pluvials in very gravelly materials of the mountain fronts (area 21).

3.61 Stages of carbonate accumulation

The development of carbonate horizons of pedogenic origin is closely related to soil age. Two sequences of carbonate mor-

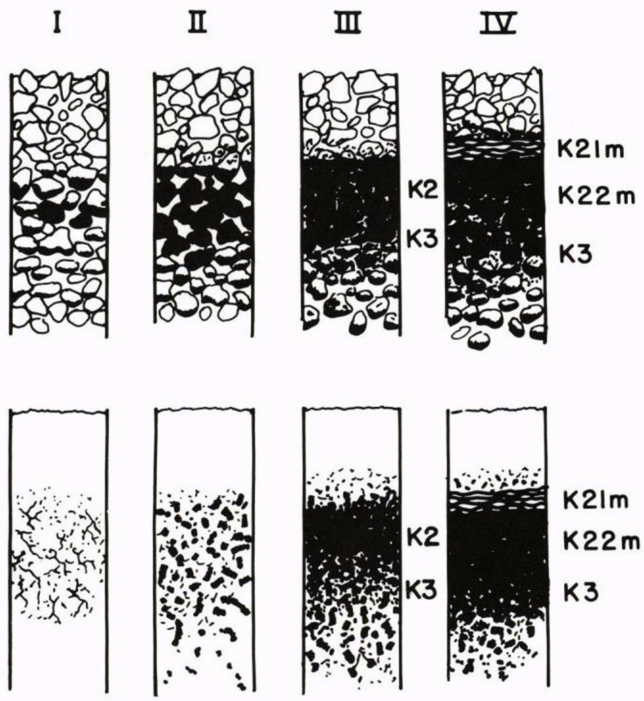


FIGURE 12—SCHEMATIC DIAGRAM OF THE DIAGNOSTIC MORPHOLOGY OF THE STAGES OF CARBONATE-HORIZON FORMATION in gravelly and nongravelly materials. Carbonate accumulations are indicated by black forms and shadings for clarity (from Gile and others, 1966, fig. 5, with permission).

phology associated with increasing soil age and amount of authigenic carbonate have been ordered in stages (fig. 12). One of the sequences is in low-gravel (less than approximately 20 percent gravel) materials and the other is in high-gravel (more than approximately 50 percent gravel) materials. Materials with intermediate contents of gravel have intermediate morphologies. Table 20 summarizes the morphology of the stages; table 21 shows their occurrence in soils of both the arid and semiarid zones.

The more complex horizons contain carbonate forms that are relict from earlier stages. Carbonate horizons that contain the greatest variety of relict features occur on land surfaces shown to be older by geomorphic evidence. This relationship lends phylogenetic significance to the stages of carbonate accumulation. The stage notations in table 20 designate development of the horizon of carbonate accumulation as a whole in a given soil. However, the notations may also be used to indicate specific subhorizons within the overall horizon of carbonate accumulation.

3.62 The plugged and laminar horizons

With continued carbonate accumulation, most or all pores and other openings in the soils become filled by carbonate; primary grains have been forced apart; bulk density has increased; and infiltration rate has markedly decreased. This process results in the *plugged horizon,* which develops in the last part of stage III (fig. 12).

After development of the plugged horizon, the *laminar horizon* forms on top of it. Differences between the laminar and plugged horizons are so great that the fabrics differ in kind. The laminar horizon has much more carbonate than the plugged horizon and essentially no allogenic skeletal grains. Rather than the carbonate being a filling between skeletal grains, it occupies almost the entire horizon and the skeletal grains are incidental. The laminar horizon is a new soil horizon in the sense that it consists almost entirely of authigenic material and hence thickens the soil by its own thickness. The overlying horizons must have been displaced upward from their original position.

If the plugged horizon formed in thick, freely drained sediments that had undergone little erosion or deposition, then the depths between which it had formed would correspond to the depths of frequent wettings by unsaturated flow. As the final carbonate impregnation of the plugged horizon occurred and its macropores were filled, the zone of maximum carbonate accumulation would be forced upward. With impregnation completed, the plugged horizon interposes a zone only slowly pervious to moisture flow above the depth of the most frequent wetting and well above the depth to which wetting from a heavy storm would reach. Development of the *laminar horizon* (figs. 12, 13; table 22) is initiated at this

TABLE 20—STAGES OF CARBONATE ACCUMULATION IN THE TWO MORPHOGENETIC SEQUENCES.

Stage and general character	Diagnostic carbonate morphology	
	Gravelly sequence	Nongravelly sequence
I		
Weakest expression of macroscopic carbonate	Thin, discontinuous pebble coatings	Few filaments or faint coatings
II		
Carbonate segregations separated by low-carbonate material	Continuous pebble coatings, some interpebble fillings	Few to common nodules
III		
Carbonate essentially continuous; plugged horizon forms in last part	Many interpebble fillings	Many nodules and internodular fillings
IV		
Laminar horizon develops	Laminar horizon overlying plugged horizon	Laminar horizon overlying plugged horizon

TABLE 21-STAGES OF THE MORPHOGENETIC SEQUENCES IN THE ARID AND SEMIARID PARTS OF THE PROJECT AREA.

Stage: Nongravelly soils	Stage: Gravelly soils	Youngest geomorphic surface on which stage of horizon occurs	and age - yrs B.P. or epoch
		Arid (valley border)	
I	I	Fillmore	100 to 7,000 yrs
II	II, III	Leasburg	early Holocene-latest Pleistocene 8,000 to 15,000 yrs
III	III, IV	Picacho	late Pleistocene 25,000 to 75,000 yrs
III	IV	Jornada I	late to middle Pleistocene 250,000 to 400,000 yrs
IV		La Mesa	middle Pleistocene >400,000 yrs
		Arid (fan-piedmont)	
I	I	Organ	100 to 7,000 yrs
II	II	Isaacks' Ranch	early Holocene-latest Pleistocene 8,000 to 15,000 yrs
III	III, IV	Jornada II	late Pleistocene 25,000 to 75,000 yrs
III	IV	Jornada I	late middle Pleistocene 250,000 to 400,000 yrs
		Semiarid (canyons in the Organ Mts.)	
	0 or I	Organ	100 to 7,000 yrs
	I	Jornada II	late Pleistocene 25,000 to 75,000 yrs
	I	Jornada I	late to middle Pleistocene 250,000 to 400,000 yrs
	III, IV	Doña Ana	middle Pleistocene >400,000 yrs

point. Infiltrating water concentrates at the top of the carbonate-plugged horizon to the extent that a thin zone of free water results. This water collects in hollows along the top of the plugged horizon and moves downward along faces of vertical prisms if they are present. Deposition of carbonate as these water films evaporate explains the thinness of the laminae and the filling of low spots in the upper surface of the plugged horizon (fig. 13). It also explains carbonate coatings on prism faces and the occurrence of the laminar horizon only on a material of low permeability (other dense materials can substitute for the plugged horizon).

The numerous laminae suggest that accretion of carbonate in the laminar horizon is an episodic process that reflects many wettings and subsequent dryings. Carbonate deposition from ponded free water along a plane implies that the upper laminae should be younger. This implication is supported by radiocarbon carbonate dates (table 22 and fig. 13) that show that carbonate of the plugged horizon is the oldest, that carbonate of the lower, hard laminae is somewhat more recent, and that carbonate of the upper, soft laminae is the youngest. Absolute ages are questionable, but relative ages demonstrate that upper laminae are younger than lower laminae. Because of the lack of precision in absolute ages, dates are reported in kyr (thousand-year) units.

Moisture is reaching the laminar horizon of certain soils in the area (see moisture data and discussion, area 6), and it is probably developing slowly in these soils at the present time. Many laminar horizons must have formed primarily during wetter times in the Pleistocene. Radiocarbon ages support this (area 6) and indicate that some laminar horizons formed rapidly.

Two inversions of whole-soil dates are apparent in table 22. These are the 5.7 and 4.6 kyr dates of the B22tca and uppermost K21m horizons and the 18.3 and 15.3 kyr dates of the lowermost K21m horizon and the K22m horizon. These inversions may be caused by widely variable ages of different carbonate forms within certain horizons. For example, the whole-soil age of B22tca horizon is 5.7 kyrs whereas age of the carbonate pebble coatings in the same horizon is 10.2 kyrs (table 22). Computed age of the fine-earth carbonate in the B22tca horizon is 1.3 kyrs (table 22). Thus, part of the carbonate in the B22tca horizon is much younger than carbonate in the uppermost K21m horizon. A similar explanation may apply to the other inversion because pebble coatings of the

TABLE 22—CARBONATE C-14 AGES FOR DIFFERENT FORMS OF CARBONATE IN CRUCES VARIANT 59-16; detailed C-14 data are in Gile and Grossman (1979).

Horizon and depth	Material	C-14 age kyrs
B22tca	Whole sample	5.7
15-28 cm	Pebble coatings*	10.2
	Fine earth†	1.3
K21m	Soft upper laminae	4.6
28-30 cm	Hard lower laminae	13.9
	Non-laminar	18.3
K22m	Whole sample	15.3
30-64 cm	Pebble coatings	27.9

* Pebbles ground and sample includes carbonate within pebbles as well as coatings.
† Computed from carbonate contents and C-14 activities of whole sample and pebble coatings.

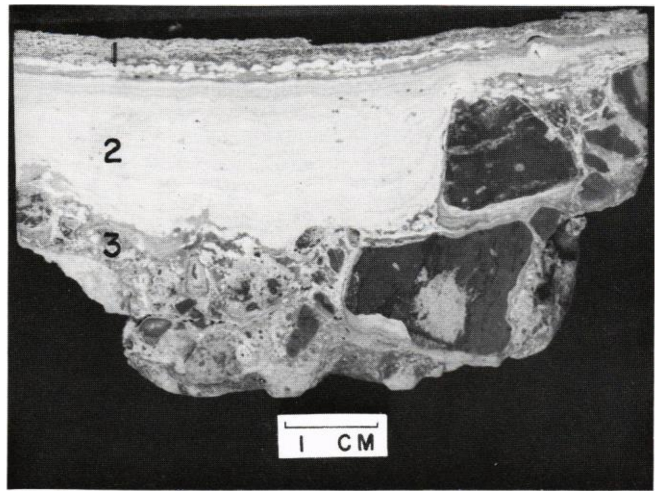


FIGURE 13-POLISHED SECTION OF K21m HORIZON OF CRUCES VARIANT 59-16, a vertically oriented section showing the laminar horizon and upper 2 cm of the carbonate-plugged horizon. The laminae fill and smooth over the depressions between protrudent pebbles of the preexisting plugged horizon. Rhyolite pebbles in the plugged horizon are widely separated by authigenic carbonate. Carbonate zones dated by radiocarbon methods (see table 22) are 1) soft upper laminae, 2) hard lower laminae, and 3) carbonate of adhering upper portion of plugged horizon (from Gile and others, 1966, fig. 4, with permission).

K22m horizon are much older than the whole-soil date (27.9 versus 15.3 kyrs). Greater ages for pebble coatings than for carbonate between the coatings would be expected from the phylogenetic arrangement in table 20, because carbonate first accumulates on the surfaces of pebbles.

The laminar horizon has the extreme properties of the stage IV horizon and of carbonate horizons as a whole (table 23). It is the hardest and most dense; it also has the most carbonate and the lowest infiltration rate (area 6). The laminar horizon breaks down completely on acid treatment, and the silicate clay in the residue disperses completely. As evidence, the ratio of exchange capacity to clay is similar to that for non-cemented horizons. Therefore carbonate seems to be the only cementing agent (see Gile and Grossman, 1979, for more complete discussion).

Usually the residue after carbonate removal is higher in silicate clay and organic carbon than for adjacent horizons (table 23). Clay and organic matter suspended in downward-moving water are probably deposited on top of, and then incorporated in, the upward-developing laminar horizon. Organic matter may be contributed by roots that concentrate immediately above the laminar horizon.

Stage IV horizons may disintegrate through a combination of soil truncation, carbonate engulfment, and mixing by soil biota. Truncation usually begins the process of disintegration.

Truncated soils usually occur on crests of ridges that have no, or very little, area of transversely level surfaces. Truncation brings the laminar horizon closer to the surface, concentrating

TABLE 23—SELECTED DATA FOR LAMINAR AND PLUGGED HORIZONS; CEC—cation-exchange capacity.

Series, pedon classification parent material source	Material	Carbonate[1] %	Organic[1] carbon %	Clay[1] %	CEC[2] clay ratio
Cruces variant 59-16	Laminar horizon				
Petrocalcic Paleargid	Soft, upper part	74	1.9	53	0.67
Rhyolite	Hard, lower part	83	0.91	31	0.70
	Plugged horizon[3]	46	0.46	24	
Cruces 61-7	Laminar horizon				
Petrocalcic Paleargid	Whole	89	0.82	36	0.64
Camp Rice	Browner upper portion	91	1.3	45	0.72
	Plugged horizon[3]	75	0.29	26	
Tencee 62-1	Laminar horizon	75	1.4	28	0.84
Typic Paleorthid					
Calcareous sedimentary rock					
Upton 66-5	Laminar horizon				
Typic Paleorthid	Hard, lower part	88	0.60		
Calcareous sedimentary rock					
Terino 70-8	Plugged horizon				
Petrocalcic Ustollic	Whole	63	0.43	25	
Paleargid	Pebble coatings[4]	86	3.8		
Rhyolite					

[1]All on less than 2 mm basis. Organic carbon, clay and CEC on carbonate-free basis.
[2]By NH_4OAc procedure.
[3]That portion of the plugged horizon adhering to the laminar horizon, 2–5 cm thick.
[4]Flaky, hard carbonate coatings that adhere to pebbles. Much of these coatings have 2.5Y hue. The appreciable organic carbon percentage may be a factor that causes a yellower hue than occurs in other soils of the area.

TABLE 24—CARBONATE PERCENTAGE (LESS-THAN-2-MM BASIS) FOR K2 AND NONLAMINAR K2m HORIZONS OF PEDONS DEVELOPED IN LOW-CARBONATE PARENT MATERIALS; if more than one K2 or K2m horizon, single horizon selected having lowest carbonate percentage.

Horizon	No. of Pedons	Carbonate Range %	Carbonate Median %
K2m, nonlaminar			
Very gravelly	3	46-62	55
Nongravelly	4	35-53	51-53
K2 (nongravelly)	16	14-40	22-23

the activity of plant roots and soil fauna in a smaller space. Thus, roots could enter cracks and force platy segments of the laminar horizon apart. Also, moisture from precipitation reaches the laminar horizon more frequently when it is shallow. Additional water would leach carbonate adjacent to cracks and holes, enlarging them and weakening the material. In other places, evaporation of water may lead to carbonate crystallization, forcing sections of the horizon apart so that it is no longer continuously cemented.

3.63 Quantity of carbonate and rate of accumulation

Table 24 shows the relationship between carbonate percentage and expression of K2 horizons in stage III of carbonate accumulation. Data in table 24 suggest that a minimum of 1520 percent carbonate on a less-than-2-mm basis is required before a horizon enters stage III—that is, qualifies as a K2 horizon. Carbonate percentages in excess of 40 percent are required for the plugged or near-plugged horizon (or nonlaminar K2m) that represents the maximum development of stage III. Similar percentages on a fine-earth basis are required whether the materials are very gravelly or nongravelly.

TABLE 25—CALCULATED AMOUNT OF AUTHIGENIC CARBONATE ACCUMULATED TO THE DEPTH INDICATED FOR PEDONS DEVELOPED IN PARENT MATERIALS LOW IN CARBONATE CONTENT; method of calculation parallels that described under 6A in Soil Conservation Service, 1972.

Pedon	Depth cm	$CaCO_3$ kg/sq m	Pedon	Depth cm	$CaCO_3$ kg/sq m
59-4	0-74	-0.8	61-3	0-221	1,080
59-5	0-84	20	61-4	0-119	254
59-6	0-71	68	61-5	0-112	11.3
59-7	0-147	75	61-7	0-353	1,840
59-8	0-178	300	61-8	0-340	1,200
59-10	0-114	12	61-9	0-104	46
59-11	1-122	254	62-3	0-112	13
59-13	0-132	158	65-7	0-307	1,370
59-15	0-145	24	66-1	0-107	104
59-16	0-127	260	66-2	0-165	302
60-1	0-104	140	66-12	0-305	1,380
60-2	0-137	220	66-16	0-132	4.9
60-5	0-168	453	67-3	0-127	8.1
60-6	0-310	751	67-4	0-178	-1.3
60-7	0-183	215	67-5	0-160	22
60-7	0-300	834	68-3	0-117	-0.1
60-10	0-127	325	68-4	0-130	19
60-11	0-86	96	68-6	0-249	795
60-13	0-114	85	68-9	0-185	213
60-21	0-305	1,050	69-8	0-125	55
60-22	0-178	223	70-5	0-87	-0.8
61-1	8-196	1,090	70-6	0-120	25
61-2	8-185	569	70-7	0-129	254
			70-8	0-179	262

Distinct differences in horizons of carbonate accumulation are apparent between soils of various ages, with larger amounts occurring in the older soils. The quantitative relations between soils of various ages are not at once apparent, however, because of variations in soil texture, content of coarse fragments, and horizon thickness. The carbonate accumulations for various pedons formed in low-carbonate materials have therefore been converted to kg/sq m (table 25). The depths selected are determined by the lower limit of carbonate accumulation associated with pedogenesis of the soil at the land surface and of buried soils in some instances. The initial carbonate content for the fine earth before pedogenesis started is assumed to have been 1 percent. Laboratory analyses of the lower parts of C horizons suggest that for some pedons the initial carbonate content was below 1 percent and in a few instances would probably exceed 1 percent. Analyses of two samples of fresh monzonite arroyo alluvium from different locations yielded a trace (less than 0.4 percent) and 1 percent carbonate. The relations suggest that 1 percent should be a reasonable value for the soils in table 25. The calculation has increasing relative error as the amount of carbonate decreases. The initial carbonate content assumed has greater significance if the carbonate contents are low. A few soils with upper horizons very low or free of carbonate and a weak bulge have negative values. These negative values are a consequence of the assumptions of the initial carbonate content and should not be construed as indicating that the pedon has actually undergone a net loss in carbonate.

Table 26 presents the kilograms of carbonate accumulated by stage of the carbonate horizon for nongravelly and gravelly pedons. Horizon thickness is not a criterion of stage but is involved in the total amount of carbonate and is an important reason for the wide range in the potential amount of carbonate for a given stage. Other reasons for the wide range are variations in texture and volume of rock fragments. As table 26 shows, amounts of carbonate in a given stage are lower for the gravelly soils.

In table 27, the amounts of carbonate have been grouped by soil age and estimates made of the rate of carbonate accumulation. The pedons selected were those considered to be typical ones for stable sites on the various geomorphic surfaces and those thought to have retained most or all of their

TABLE 26—AMOUNT OF CARBONATE IN STAGES I-IV OF CARBONATE ACCUMULATION FOR PEDONS DEVELOPED IN LOW-CARBONATE PARENT MATERIALS, TO VARIABLE DEPTH DETERMINED BY LOWER LIMIT OF CARBONATE ACCUMULATION ASSOCIATED WITH PEDOGENESIS OF SOIL AT LAND SURFACE. One percent initial carbonate is assumed. The calculated algebraic sum is negative for several soils that contain very little carbonate.

Stage and coarse fragments	No. of pedons	Amount of carbonate Range	Amount of carbonate Median
		kg/sq m	
I			
Nongravelly	10	-0.8-55	11-12
Gravelly	2	0.9-4.9	
II			
Nongravelly	4	25-75	46-68
Gravelly	2	22-24	
III			
Nongravelly	16	85-1400	250-300
Gravelly	4	96-250	140-160
IV			
Nongravelly	2	1400-1800	
Gravelly	4	260-330	260-300

TABLE 27—AMOUNT AND RATE OF CARBONATE ACCUMULATION FOR PEDONS GROUPED BY SOIL AGE IN THE ARID PART OF THE PROJECT AREA.

Epoch	Estimated range in age	Geomorphic surface	Pedons	Range in carbonate as $CaCO_3$ Total	Range in carbonate as $CaCO_3$ Accumulation rate
	kyrs			kg/sq m	kg/sq m/kyr
Holocene	1-4	Fillmore	66-16	5	1-5
	4-7		59-10	12	2-3
	2-4	Organ	67-3, 61-5 59-5, 68-4	8-20	2-10
Latest Pleistocene	8-15	Leasburg	61-9	46	3-6
Latest Pleistocene	8-15	Isaacks' Ranch	67-5, 70-6, 59-6, 59-7	22-75	1-9
	25-75	Picacho	60-2	220	3-9
Late Pleistocene	15-75	Jornada II	68-9, 60-22, 61-4, 70-7, 59-8, 60-7	213-300	3-12
Late middle Pleistocene	250-300	Jornada I	60-6, 60-7	751-834	2-3
Late middle Pleistocene	300-400	Jornada I	68-6, 60-21, 61-3, 61-1	795-1,090	2-3
Middle Pleistocene	400-500	Lower La Mesa	61-8, 65-7	1,200-1,370	2-3
Middle Pleistocene to early Pleistocene	>500*	Upper La Mesa	66-12, 61-7	1,380-1,840	2-3

* 500-700 kyrs assumed for calculation.

pedogenic carbonate. For example, the very gravelly pedons of Jornada I (pedons 60-10, 66-1, and 70-8) were excluded because of the anomalously low values when compared to low-gravel soils of the same age (pedons 60-6 and 60-7 with buried soils included). In pluvials and before plugging, a considerable amount of carbonate could presumably move lower than the sampled horizons in these very gravelly soils. That this movement occurs is indicated by the low carbonate values and deeper horizons of carbonate accumulation for soils of Holocene and Pleistocene age along the mountain fronts.

The ranges in rates of accumulation for the various age classes fall mostly between 1 and 10 kg/sq m/kyrs. Considering the uncertainties, no significance should be attached to differences among the soil-age classes. The maximum amount of carbonate added from current atmospheric sources of calcium (3.3) has been computed as about 2 kg/sq m/kyrs, within the range of the computed rates of carbonate accumulation.

3.7 SILICATE-CLAY ACCUMULATION

Reddish-brown and red horizons of silicate-clay accumulation are extensive in the project area. Evidence presented later indicates that they contain illuvial clay and are Bt horizons. In the arid part of the project their upper boundaries are commonly 5-10 cm below the surface, and the Bt horizons generally range from approximately 15 cm to 1 m in thickness. Sand grains and pebbles in these horizons are at least partially coated with oriented clay; and, if the criterion for clay increase is met (3.13), they qualify as argillic horizons. When the clay increase is not met, the Bt horizon is a cambic horizon if it is fine enough, extends below 25 cm, and does not contain the carbonate maximum.

Some of the clay in the parent materials originated by weathering of igneous rocks in the mountains; monzonite in the northern part of the Organ Mountains is particularly susceptible to weathering. Other clay has been released through the weathering of sedimentary rocks in the San Andres and Robledo Mountains. Parent materials of the fan piedmont commonly contain some clay eroded from soils upslope. The dry dust that currently falls on soils contains clay (3.3).

Presence or absence of an argillic horizon distinguishes soils at the categorical level of order or suborder (Argids versus Orthids or Entisols). Because this difference is important in distinguishing between many contiguous polypedons of arid regions, the factors that cause it are critical to soil identification and mapping.

Many argillic horizons have prominent morphologies and are not difficult to identify. Thin-section studies have shown that most argillic horizons in this area easily meet the requirement of at least 1 percent of oriented clay (3.13). In the field, therefore, one may safely identify the reddish-brown or red, relatively clayey horizons of silicate clay accumulation as argillic horizons.

However, the argillic horizon is not always as prominent, and it is less readily identified in its transitional stages to other horizons in the B position. In some soils argillic horizons have not developed because of high carbonate content of the parent materials; other soils are too young for such horizons to develop. The occurrence of the argillic horizon in some areas is complex because of major environmental changes since an argillic horizon formed. Some argillic horizons have been partly or wholly truncated; others have been partly or completely engulfed by prominent carbonate accumulations; and still others have been partly or wholly obliterated by soil fauna. These factors are discussed in sections that follow, and illustrative study areas for each are indicated.

3.71 Evidence for illuviation

The clay accumulation in arid soils was formerly thought to be due to in-place weathering (Nikiforoff, 1937; Brown and Drosdoff, 1940; Agricultural Experiment Stations, Soil Conservation Service, 1964). Later work has indicated an illuvial origin for much of the clay despite the absence of clay skins on peds and in pores (Gile and Grossman, 1968; Smith and Buol, 1968; Nettleton and others, 1969; Nettleton and others, 1975). A number of factors indicate clay illuviation and suggest that the absence of clay skins is caused by unfavorable conditions for their formation or preservation rather than by lack of illuvial clay:

1) Soils of stable sites have a thin, grayish A2-like horizon with less clay than the underlying reddish-brown or red B horizon. The grayish color is most apparent when dry.

2) Prominent coatings of oriented clay on sand grains and pebbles are a distinctive micromorphological feature of all Bt horizons in the study area. These coatings do not of themselves demonstrate clay movement subsequent to initiation of soil development because some of the clay on the grains could be inherited from parent materials. In this respect the oriented coatings differ from clay skins on ped surfaces, which postdate the ped surface and hence must have formed after soil development started. The oriented coatings do provide evidence for illuviation where their maximum expression coincides with the clay maximum. They are in fact the only marker of clay illuviation to be expected in massive Bt horizons. This material, which is characterized by coatings of oriented clay on sand and silt grains and on pebbles if they are present, is termed Bt material.

3) Prominent clay skins do occur in many pipes of Bt material (3.75, study area 9) that penetrate horizons of carbonate accumulation. Their presence deep in the soil where water content is nearly constant and roots and fauna seldom penetrate suggests that the absence of clay skins in Bt horizons at shallower depths may be due to physical disruption associated with biotic activity and shrinking and swelling as the soil dries and then is wetted.

4) Clay skins also occur in certain soils of the semiarid portion of the study area. This fact suggests that clay skins would form in soils of the arid part of the study area if the soils were wetter.

5) Reddish coatings of silicate clay have been observed on and in cracks in the tops of petrocalcic horizons that underlie argillic horizons at shallow depths (for example, less than about 30-40 cm in observed areas of upper La Mesa). This clay must have illuviated from the overlying B horizon. Similar but less prominent coatings occur in upper parts of many calcic horizons that underlie argillic horizons.

6) Distinct linear bodies of oriented clay occur within many peds. Some of these linear bodies are interpreted as former clay skins, now inside the peds because of the development of new faces as the soil wetted and dried. Buol and Yesilsoy (1964) and Nettleton and others (1969) have made the same interpretation.

7) Wetting and drying of a mixture of sand grains and silt-size aggregates of clay did not produce coatings of oriented clay on the sand grains (Gile and Grossman, 1979). Formation of such coatings evidently required prior disaggregation of the clay, which would have been its state during illuviation. This finding agrees with work of Thorp and others (1957, 1959). In leaching experiments dealing with aspects of clay movement they state: ". . . clay is brought into suspension and moves through the soil as individual clay particles."

8) Only slight weathering of primary minerals has been found in the oldest argillic horizons; little clay apparently has been produced by weathering in place.

9) Some clay was apparently derived from atmospheric additions, particularly in pervious sediments (areas 3 and 20). Such clay would be illuvial because it must have moved from the surface downward.

10) The clay increase from A to B consists largely of fine clay. Changes in the fine to total clay meet the requirements of the argillic horizon (Soil Survey Staff, 1975).

11) The positional relation of the horizon of silicate clay accumulation to the horizon of carbonate accumulation suggests illuviation. In Holocene soils, the horizon of silicate clay accumulation is just above or extends slightly into the carbonate horizon. This arrangement would be expected on a theoretical basis if the accumulations were illuvial. Clay moves downward in suspension (Thorp and others, 1957, 1959) and would be deposited at the base of the zone that is wetted by water movement rapid enough to maintain the clay in suspension. Calcium bicarbonate, being in solution rather than suspension, would be expected to move deeper than the clay and then to precipitate below it as the soil solution dries.

12) In sandy and sandy-loam parent materials, clay increases with increasing soil age back to the late Pleistocene. Because little evidence of weathering has been observed, an illuvial origin for some of the clay is strongly implied. However, the increase in clay with age does not accord well in soils older than the late Pleistocene (see Gile and Grossman, 1979, for further discussion).

3.72 Bt horizons in low-gravel soils

Development of Bt horizons and their relation to age are separately illustrated by low-gravel and high-gravel soils (table 28) because rock fragments strongly influence morphology of the Bt horizon and the character of its development. The Bt horizons of illustrative low-gravel soils (table 28) have less than approximately 15 percent by volume of rock fragments. See areas 6, 8, and 10 for discussion of Cruces, Berino, and Pajarito pedons (table 28). See Gile and Grossman (1979) for discussion of the Bucklebar and Onite pedons in table 28.

3.73 Bt horizons in high-gravel soils

Morphology of the argillic horizon in very gravelly materials differs markedly from that in nongravelly materials. Fine earth occurs as pebble coatings and interpebble fillings rather than as peds bounded by planar surfaces. The clayey pebble coatings can be seen with the naked eye. In thin section the coatings appear as strongly oriented clay that rests abruptly on the pebbles. The surfaces of pebbles are favorable sites for the preservation of oriented clay. They are stable compared to ped surfaces, which move with change in moisture. Volume changes of skeletal material when wetted are small because of the low proportion of fine earth per unit volume and the tendency of fine earth in each interstice to act as an independent unit.

Numerous pebbles confine the soil solution to relatively small volumes, and this confinement should speed the illuviation of silicate clay. Hence the time available for very gravelly cambic horizons in the developmental scale should be short (study area 3a).

The more rapid and distinct development of argillic horizons in very gravelly than in nongravelly materials is illustrated by soils of the Organ surface (Gile and Grossman,

TABLE 28—CHRONOLOGY AND SELECTED DATA FOR LOW-GRAVEL AND HIGH-GRAVEL SOILS ILLUSTRATING DEVELOPMENT OF THE ARGILLIC HORIZON; silicate clay from carbonate-free, less-than-2-mm materials; tr(s), trace $CaCO_3$ detected by qualitative procedure more sensitive than quantitative procedure used; -(s), none detected by sensitive qualitative tests (6E2; Soil Conservation Service, 1972).

	Low-gravel All soils have formed in monzonitic alluvium except Cruces 61-7, which formed in ancient river alluvium.					*High-gravel* All soils have formed in rhyolitic alluvium.				
Soil age	**Horizon**	**Depth cm**	**Clay %**	**Carbonate %**	**Dry color**	**Horizon**	**Depth cm**	**Clay %**	**Carbonate %**	**Dry color**
Late Holocene						Soledad 66-16, Typic Haplargid, on terrace sloping 2 percent				
						A2	0–5	9	-(s)	6YR 5.5/4
						B21t	5–15	12	tr(s)	5YR 4.5/4
						B22tca	15–25	12	1	5YR 4.5/4
						C1ca	25–58	9	2	
						C2ca	58–94	8	3	
						C3ca	94–132	7	1	
						B2	5–25	10	tr(s)	
						Clay, kg/cu m:52				
						Volume >2 mm, 0–100 cm:60%				
Middle Holocene	Pajarito 67-3, Typic Camborthid, ridge on fan piedmont sloping 2 percent									
	A	0–3	7	tr(s)	7.5YR 5/4					
	A	3–10	9	tr(s)	7.5YR 5/4					
	B21t	10–20	9	tr(s)	6YR 5/4					
	B22t	20–28	9	tr(s)	6YR 5/4					
	C1ca	28–58	8	2						
	C2ca	58–91	9	3						
	C3	91–127	4	1						
	Clay, kg/cu m:100									
	Volume >2 mm, 0–100 cm:10%									
Early(?) Holocene	Onite 62-3, Typic Haplargid, ridge on fan piedmont sloping 1 percent					Soledad 67-4, Typic Haplargid, on fan sloping 4 percent				
	A2	0–5	7	tr(s)	7.5YR 5/3	A2	0–5	8	tr(s)	7.5YR 5/4
	B1t	5–8	12	tr(s)	6YR 5/4	B1t	5–18	11	tr(s)	6YR 5/4
	B21t	8–20	14	tr(s)	5YR 5/4	B2t	18–30	15	tr(s)	5YR 5/4
	B22t	20–30	14	1	5YR 5/4	B3t	30–51	13	tr(s)	7.5YR 5/4
	IIC1ca	30–43	13	5		C1ca	51–71	9	2	
	IIIC2ca	43–61	11	3		C2ca	71–94	8	1	
	IVC3ca	61–76	8	3		C3	94–147	4	1	
	Clay, kg/cu m:110 to 76 cm					Clay, kg/cu m:55				
	Volume >2 mm, 0–100 cm:15% to 76 cm					Volume >2 mm, 0–100 cm:60%				
10,000 years B.P.										
Latest Pleistocene	Bucklebar 59-7, Typic Haplargid, in broad drainageway sloping 1 percent					Soledad 67-5, Typic Haplargid, on fan sloping 3 percent				
	A	0–15	14	1	10YR 5/3	A1	0–5	9	tr(s)	7.5YR 5/4
	B21t	15–38	22	tr	5YR 4/3	B1t	5–15	17	tr(s)	5YR 5/4
	B22tca	38–58	23	3	5YR 5/4	B2t	15–36	18	tr(s)	5YR 5/5
	C1ca	58–97	19	8		B3t	36–51	18	tr(s)	6YR 5/4
	C2ca	97–127	27	6		C1ca	51–64	16	4	
	Bbca	127–147	23	8		K&C2ca	64–89	11	11	
	Clay, kg/cu m:270					C3ca	89–104	7	7	
	Volume >2 mm, 0–100 cm:5%					C4ca	104–124	7	4	
						C5ca	124–160	7	2	
						Clay, kg/cu m:75				
						Volume >2 mm, 0–100 cm:65%				
Late Pleistocene	Berino 60-7, Typic Haplargid, on fan piedmont sloping 1 percent					Caralampi 59-15, Ustollic Haplargid, on fan sloping 4 percent				
	A	5–13	14	tr	5YR 5.5/4	A2	0–6	12	-(s)	7.5YR 5/4
	B21t	13–33	28	tr	2.5YR 4/4	B21t	6–23	26	-(s)	2.5YR 4/4
	B22tca	33–43	33	2	5YR 4/5	B22t	23–43	28	tr(s)	2.5YR 4/6
	K11	43–66	24	9		B3ca	43–71	14	4	
	K12	66–91	20	10		K&C	71–109	13	10	
	K2	91–140	18	15		Cca	109–145	8	6	
	C1ca	140–157	13	8		Clay, kg/cu m:87				
	IIC2ca	157–165	12	7		Volume >2 mm, 0–100 cm:70%				
	Clay, kg/cu m:310									
	Volume >2 mm, 0–100 cm:3%									
Late middle Pleistocene						Terino 70-8, Petrocalcic Ustollic Paleargid, on fan piedmont sloping 3 percent				
						A2	0–5	14	tr(s)	7.5YR 6/3
						B21t	5–18	30	tr(s)	4YR 4.5/5
						B22t	18–28	32	tr	2.5YR 4/6
						B23tca	28–46	34	6	5YR 5/4
						K2m	46–64	25	63	
						K31	64–82	14	41	
						K32	82–121	16	29	
						K33	121–159	12	25	
						C	159–179	9	4	
						Clay, kg/cu m:86				
						Volume >2 mm, 0–100 cm:55%				
Middle Pleistocene	Cruces 61-7, Petrocalcic Paleargid, on basin floor, nearly level									
	A	0–5	10		5YR 5/4					
	B1t	5–18	9		5YR 3.5/4					
	B1t	18–25	13		5YR 3.5/4					
	B21t	25–36	15	1	4YR 4/4					
	B22tca	36–48	17	16	7.5YR 5/2					
	K21m	48–74	23	75						
	K22m	74–102	18	65						
	K23m	102–150	19	51						
	K31	150–185		52						
	K32	185–236		41						
	C1ca	236–272	5	13						
	C2	272–353	5	2						
	Clay, kg/cu m:150									
	Volume, >2 mm, 0–100 cm: <1%									

1979). Argillic horizons have formed in places, even in soils of late Holocene age, where the materials are very gravelly (table 28).

Soledad 66-16 and four other skeletal Argids form a developmental sequence in soils that increase in age (table 28). The low clay content of the C horizons of these soils suggest that most of the clay in the maximum was derived from atmospheric additions. Size of the clay maxima shows a closer relation to age in these materials than in nongravelly materials because very gravelly materials are more pervious and the gravel pavement at the soil surface traps dust that contains clay. See study area 20 for discussion of the Soledad and Caralampi soils and Gile and Grossman (1979) for discussion of the others.

3.74 Color

Hues of the Bt horizon become redder and chromas higher with increasing age. Holocene soils have Bt horizons with hues no redder than 5YR and chromas no higher than 4 (table 28). The B horizons of Holocene soils are distinctly reddened only if parent materials contained biotite and/or hornblende (compare Bluepoint 59-10 at area 19 with Soledad 67-4 at area 20). Redder colors of Bt horizons such as in Soledad 67-4 may have been caused by slight weathering of these minerals in the A and B horizons. Smith and Buol (1968) and Nettleton and others (1975) also found evidence of weathering in A and B horizons of desert soils.

In soils of Pleistocene age, many Bt horizons have 2.5YR hue and chroma of 6. Colors redder than 2.5YR do not occur in the arid part of the study area.

Holocene soils developed in high-carbonate parent materials show no reddening. In soils of Pleistocene age, some reddening is found if the parent materials contain only moderate amounts of carbonate, but no hues are redder than 5YR. Horizons with 5YR hue develop only after carbonate has been leached from the horizon. At any one place slight variations in initial carbonate content may determine if all of the allogenic carbonate was removed. Consequently, the gradation from 5YR to 7.5YR hues is often in intricate pattern. No reddening is found in soils with very high content of carbonate rock fragments, even in soils of Pleistocene age.

Increasing evidence points to hematite as the reddening agent (Walker, 1967; Torrent and others, 1980). The mechanism proposed is that in dry, warm environments with soils having low organic matter, ferrihydrite, the necessary precursor, converts to hematite. In moist and cool environments, particularly if organic matter is appreciable, goethite is favored, which in turn leads to more yellow colors.

3.75 Pipes

Commonly the Bt horizon of a given soil does not vary greatly in thickness. In places, however, one finds funnel-shaped downward extensions of the Bt horizon that are termed pipes (areas 2, 6, 9, 15). They range in width from a few centimeters to 10 m or more, being widest and most complex in the oldest soils. Pipes have not been observed in Holocene soils. The greater effective moisture of the Pleistocene pluvials was apparently required for the formation of pipes, and they are a characteristic feature of soils of widely variable ages in the Pleistocene. Hence pipes did not form all at once but appear to be a normal developmental feature of these soils through the Pleistocene, developing primarily or wholly during pluvials. The large pipes of oldest soils have apparently been in these soils for a very long time, although they became more complex as they continued to develop (area 6). Pipes are more common in low-gravel soils, probably because high-gravel materials tend to plug with carbonate more rapidly and may inhibit the development of large roots and burrows discussed later.

Pipes seem to form by local concentration of water caused by substantial differences in permeability. Some are initiated in the pervious fillings of animal burrows and of cavities created when large roots decay. The funnel shape may be due in part to the shape of former roots. It may also arise because the frequency of depth of wetting is progressively less with depth in the pipes. Laminar and plugged horizons, because of their low infiltration rates, would deflect water into pipes and increase the depth of water penetration.

Most pipes in soils of late Pleistocene age occupy less than 2 sq m and therefore are considered part of a pedon (see area 9). However, some pipes in soils of middle Pleistocene age are larger and are considered to be different soils from soils between the pipes (area 6).

3.76 Obliteration of the argillic horizon

Obliteration of clay skins by wetting and drying and obliteration of the lower part of the argillic horizon by carbonate engulfment were discussed earlier. This section considers the obliteration of the whole argillic horizon and the effect of the obliteration on soil morphology and classification. The main obliterative processes are landscape dissection and associated soil truncation, carbonate engulfment, and mixing by soil fauna.

The upper part of the argillic horizon typically contains little or no carbonate. But in some soils in the arid part of the study area, all subhorizons of the Bt horizon contain appreciable carbonate due to landscape dissection and related soil truncation. Carbonate horizons are brought closer to the soil surface by truncation, and greater runoff (due to increased slopes) leads to decreased depths of wetting with resultant carbonate accumulation at shallower depths. The carbonate disrupts clay skins and clay coatings on skeletal grains and pebbles. The disruption is accentuated because places in which carbonate first accumulates are also places in which clay coatings develop. Crystallization of the carbonate is thought to push the silicate clay away from the surfaces of the skeletal material. As evidence, sand from K horizons after particle-size analysis is nearly free of silicate clay, whereas patches of silicate clay are present on the sands from other kinds of horizons. See areas 2, 3, and 4 for evidence of obliteration of the argillic horizon by soil truncation.

Argillic horizons have also been obliterated by soil fauna. Kangaroo rats and badgers destroy argillic horizons by the construction of tunnels and mounds. Termites obliterate argillic horizons by mixing. Burrowing is most intense in low-gravel materials with textures of sandy loam or calcareous, light, sandy clay loam because these materials are easiest to dig. See area 18 for an example of an argillic horizon obliterated by soil fauna.

The Argids and the adjacent soils (in which the argillic horizon has been obliterated) are mostly of Pleistocene age. In the field, the morphological change is usually from an argillic horizon that can be readily identified (because of its distinct silicate clay maximum and reddish-brown and red colors) to a B horizon lacking these features. The argillic horizon gradually becomes less red and lighter colored with increasing carbonate accumulation. Carbonate also affects the estimation of silicate clay, which is needed to assess the requirement for clay increase. Some horizons feel fine-textured enough, but analyses show that the increase in fineness is due to fine-grained carbonate instead of to silicate clay.

In soils of Pleistocene age in the study area, several factors are useful in the distinction between Argids and their associates in which the argillic horizon has been obliterated. These factors are effervescence with acid, color, and macroscopic carbonate. If part of the horizon of clay accumulation is still noncalcareous, then enough oriented clay remains for the horizon to qualify as an argillic horizon. If the argillic horizon is calcareous it can still have enough oriented clay. The point at which the horizon in B position contains too little oriented clay is marked by a shift in color. If part of the horizon of silicate clay accumulation is reddish brown (approximately 5YR 5/4, dry) or redder, then enough oriented clay usually remains for the horizon to qualify as an argillic horizon in soils of the study area. As carbonate continues to accumulate and hues become yellower than 5YR, most soils contain so much carbonate that essentially all of the oriented clay has been obliterated, marking the shift to the Orthids. At this point macroscopic carbonate is visible as grain coatings; and in very gravelly materials, pebble coatings are prominent. Also, the carbonate content in these horizons is high enough that estimates of silicate clay are less reliable.

There are all degrees of obliteration of the reddish-brown and red argillic horizon material. If the horizon in B position (the horizon below the A horizon and above the carbonate maximum) has at least 10 percent by volume of argillic horizon material, the soil has been classified as an Argid in the study area. If the horizon has less than 10 percent, it is classified as a Calciorthid or a Paleorthid. The 10 percent figure has been used because long exposures of soils illustrating the Argid-Orthid transition indicate that much smaller percentages may occur in the transition zone. Such minor amounts might easily be missed with an auger or small pit.

Observations elsewhere in the Southwest and in desert regions of northern Mexico indicate that similar relations for obliteration of the argillic horizon are extensive in arid regions similar to the study area. However, the argillic horizon is generally not as red in the colder deserts, and the color changes caused by landscape dissection and soil truncation would probably differ accordingly.

3.77 Effect of allogenic carbonate

Goss and others (1973) have reviewed the literature on the influence of carbonate on clay movement. In the project area, soils developed in parent materials that contain high proportions of calcareous rock fragments, even soils that are on stable sites and that developed in part during the last full glacial, lack argillic horizons. See area 7 for further discussion.

3.8 LABORATORY DATA INTERPRETATION

3.81 Sand and silt mineralogy

Quartz, feldspar, and microcrystalline grains predominate the fine or very fine sand (0.25-0.05 mm). The microcrystalline grains consist largely of small crystals of feldspar. Quartz ranges from 35 to 55 percent. Most discrete grains of quartz and feldspar are fairly angular. The discrete feldspar grains are mostly orthoclase and albite with up to 25 percent in the oligoclase-anorthosite composition range. Biotite is appreciable in the sands for some samples; all samples of the coarse silt (0.05-0.02 mm) examined contain considerable mica.

Individual grains commonly show alteration around the edges and along planes of weakness. But apart from these surfaces or planes the grains are weakly altered if at all. Much of the alteration appears to be the result of geological process rather than of pedogenic weathering. Changes with depth indicative of reduced pedogenic weathering are slight. Soils of middle Pleistocene age that formed in rhyolite alluvium have somewhat lower portions of microcrystalline grains in upper horizons. Soils of Pleistocene age that developed in monzonitic alluvium along the mountain front have somewhat less biotite in upper horizons.

3.82 Clay mineralogy, *by W. C. Lynn*

The clays from the dust samples contain small amounts of kaolinite, mica, and poorly ordered montmorillonite.

The residue from Paleozoic calcareous sedimentary rocks after carbonate removal consists of mica, with some kaolinite and a little chlorite; no montmorillonite or vermiculite were identified. Clays in soils developed in sediments derived from these rocks contain small amounts of kaolinite and mica and small to moderate amounts of poorly ordered montmorillonite. Clay mineralogy changes with depth are small.

In the semiarid zone, soils of Pleistocene age developed on high-biotite monzonite contain well-ordered kaolinite, mica, montmorillonite and, in some instances, regularly interstratified mica-montmorillonite. The biotite alters to montmorillonite even if the rocks are consolidated. Holocene soils developed in alluvium derived from this high-biotite monzonite contain small amounts of kaolinite and mica and small to moderate amounts of poorly ordered montmorillonite throughout the pedon.

The clays of soils of Pleistocene age derived from the lowbiotite monzonite contain small amounts of kaolinite and mica throughout the pedon; montmorillonite is poorly ordered in upper horizons and more abundant and better ordered in and below the K horizon.

Turning to rhyolite alluvium, Holocene soils contain small amounts of poorly ordered montmorillonite. Soils of Pleistocene age have a similar distribution of kaolinite and mica; but, as with the soils of this age in monzonite alluvium, the montmorillonite increases in abundance and degree of ordering within and below the K horizon.

Greater amounts of montmorillonite in the K horizon and improved ordering with depth may be a regional pattern. Buol and Yesilsoy (1964) found an increase in montmorillonite in the K horizon. For the particular pedon studied, however, the change may not have a pedogenic origin because there is evidence for a lithological change at the top of the K horizon. Frye and others (1974) report that crystallinity improves with depth through the upper part of caliche sections located in east-central New Mexico.

An explanation for the better-ordered montmorillonite within and below the K horizon is that it was largely emplaced in Pleistocene pluvials and during subsequent drier periods has not been subjected to appreciable pedogenesis. In shallower horizons, this weathering after the last Pleistocene pluvial has acted to reduce the crystalline quality of the montmorillonite.

3.83 Carbon-isotope studies of pedogenic carbonate

A number of C-14 ages of soil carbonate were determined. In a few instances organic carbon associated with the car-

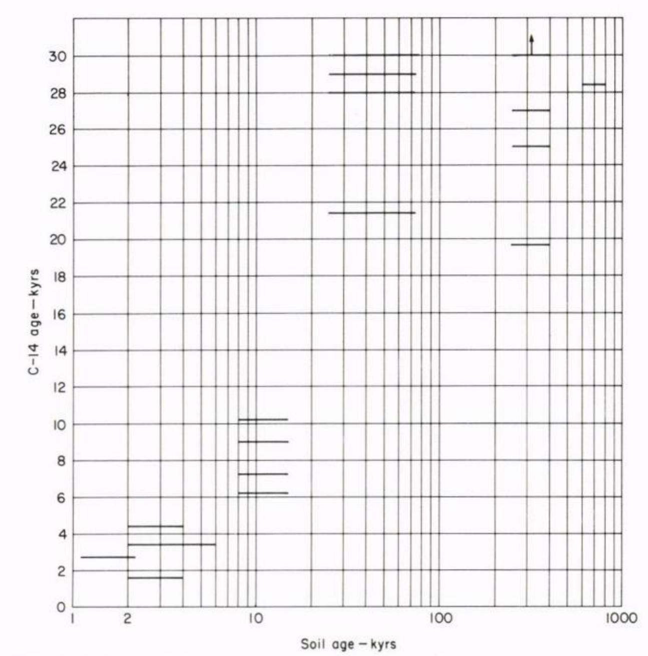


FIGURE 14—C-14 AGES OF CARBONATE VERSUS SOIL AGE independently evaluated. Maximum carbonate ages were used; laminar horizons were excluded.

bonate was also dated. C-13 determinations were made on some of the samples (Gile and Grossman, 1979). No correction was made in the C-14 ages for the proportion of C-13. Nearly all of the analyses were run by Isotopes, Inc.

Fig. 14 compares age based on carbonate radiocarbon (C-14) to soil age based on independent estimates. Carbonate C-14 ages appear useful to corroborate the relative ages of soils from late Pleistocene through Holocene but are of little value in distinguishing between late Pleistocene and older soil horizons. As evidence, all C-14 ages of horizons of latest Pleistocene (8,000-15,000 yrs) exceed those of the horizons of Holocene age. Likewise, carbonate C-14 ages for horizons of late Pleistocene and older (over 25 kyrs) exceed those for the younger horizons. On the other hand, the carbonate C-14 ages for the horizons in the 25-75 kyrs range in age are similar to those for horizons that exceed 200 kyrs.

TABLE 29—I
AGE (after K

True age (kyr
0.6
1
5
10
25
40

Many investigators (for example, Williams and Polach, 1971) have reported increasing C-14 ages with depth in the soil. As shown in section 3.6, components of individual horizons may differ greatly in C-14 ages.

EFFECT OF EXCHANGE WITH MODERN CARBON—The chemical reaction, $CaCO_3 + CO_2 + H_20 = 2HCO_3$, describes the solution-precipitation of calcite. During each cycle of solution-precipitation, half of the carbon in the precipitated $CaCO_3$ originates from CO_2. If the CO_2 is modern, during each cycle the radiocarbon activity increases by half the decrement from that for modern carbon. Isotopic exchange of carbon in solution with solid carbonate is not considered an important factor; change in activity is mainly the result of solution and precipitation. A small proportion of recently precipitated carbonate has a large influence on the C-14 age (table 29; Kim and others, 1969).

The carbonate in most of the horizons exceeding 200 kyrs in age must have undergone exchange with environmental C-14 after emplacement because all but one has an activity high enough to obtain a date. Frye and others (1974) present C-14 ages for carbonate from middle Pleistocene and older carbonate accumulations in east-central New Mexico that are within the datable range. Apparently most carbonate accumulations associated with the land surfaces in the region have an activity within the datable range.

INITIAL AGE OF AUTHIGENIC CARBONATE—Age of carbonate when deposited is important to the use of carbonate ages for chronology. The carbonate C-14 ages in table 30 indicate that the initial age of authigenic carbonate is less than 3 kyrs.

TABLE 30—C-14 AGES OF YOUTHFUL CARBONATE.

Pedon	Sample	C-14 age kyrs	Age of soil from other evidence kyrs	Other evidence
Anthony 65-2, Typic Torrifluvent	Soft coatings on limestone pebbles in 2C2ca horizon	2.7	1.1-2.2	Charcoal dates
Vinton 67-1, Typic Torrifluvent	Whole pebble coatings from C1ca horizon	4.4	2-4.0	Minimum age - soil and geomorphic tracing from charcoal dates; maximum age - charcoal date in Vinton 67-1
	0.02-0.002 mm from pebble coatings of C1ca horizon	1.6		
Cruces variant 59-16, Petrocalcic Paleargid	Computed for fine earth of B22tca horizon	1.3	25-75	Late Pleistocene age
Soledad 67-4, Typic Haplargid	Pebble coatings of C1ca horizon	3.4	2-6	Soil and geomorphic tracings from charcoal dates

TABLE 31—C-14 AGES OF CARBONATE IN THE LAMINAR HORIZON OF THREE SOILS WITH PETROCALCIC HORIZONS.

Soil, age, parent material	C-14 age Carbonate	Organic carbon
	kyrs	kyrs
Cruces variant 59-16, late-Pleistocene rhyolitic alluvium	14	10
Upton 66-5, late-Pleistocene calcareous sedimentary rocks	15	11
Cruces 61-7, mid-Pleistocene river alluvium		
upper half	29	21
lower half	30	21

Assuming initially dead carbonate, the carbonate would have gone through two or more cycles of solution and precipitation.

The dates in table 30 also show that in pedons 65-2 (area 12) and 67-1 (the only two with absolute control by dated charcoal), both C-14 dates from inorganic carbon are older than they could be by dated charcoal.

DIFFERENCES BETWEEN INORGANIC AND ORGANIC CARBON AGES—Table 31 presents paired organic and inorganic C-14 dates from hard laminar horizons. The C-14 ages from organic and inorganic carbon differ, and the difference becomes greater with increasing age (table 31). In the first two soils (both of late Pleistocene age) the C-14 ages from inorganic carbon are 3 and 4 kyrs, respectively, older than C-14 ages from organic carbon in the same horizon. One soil developed in noncalcareous rhyolitic alluvium and the other in alluvium from calcareous sedimentary rocks of Paleozoic age. Similarity in ages of the organic carbon suggests that the laminar horizons were formed at approximately the same time. The presence of limestone apparently did not affect the age of the authigenic laminar carbonate. Dates for the organic matter postdate the last full glacial, but are within a period of effective precipitation probably greater than at present (Mehringer, 1967; Haynes, 1975).

In the soil of middle Pleistocene age, the difference between organic and inorganic C-14 ages is even greater (table 31). The differences exceed any reported by Williams and Polach (1969, 1971). Initial age of authigenic carbonate may be partly responsible. The differences for the middle Pleistocene soil, however, exceed 5.7 kyrs, which is the theoretical age of dead carbonate after going through one solution-precipitation cycle. The difference, moreover, is much greater than the initial age of 3 kyrs for carbonate suggested by data in table 30. Occurrence of preexisting carbonate in the laminar zone is not a tenable explanation. A minimum of 30 percent allogenic dead carbonate would be needed to increase the initial age from 5.7 kyrs (the maximum for authigenic carbonate) to 9 kyrs. Such a proportion of allogenic carbonate is inconsistent with the morphology of the laminar subhorizon (Gile and Grossman, 1979).

An alternative explanation for the difference is that the organic carbon has had its C-14 age reduced more than the carbonate since emplacement. Polished sections of laminar horizons reveal occasional cracks that have been sealed by carbonate. Roots may have entered these cracks and contributed modern organic carbon. The explanation assumes that the carbonate, which later seals the cracks, has had less effect on the C-14 ages than the organic carbon added.

The similarity of ages of the upper and lower parts of the laminar horizon (table 31) suggests that it formed rapidly. The date of 21 kyrs for the organic carbon falls within the last full glacial (fig. 8).

3.84 Particle size

CARBONATE—The size distribution of inherited carbonate depends mainly on the mode of deposition of the sediment. If the carbonate is authigenic the size distribution becomes coarser as cementation progresses, until in an advanced stage the horizon is continuously cemented.

Taking both the Argids developed in noncalcareous materials and the Calciorthids or Torrifluvents developed from calcareous materials, a third or more of the carbonate in uncemented horizons with over 10 percent total carbonate is clay size. In soils with carbonate to the surface but lacking appreciable carbonate cementation, the proportion of the total carbonate of clay size increases from the A horizon into the B horizon or K horizon beneath.

FINE CLAY—Fine clay (less than 0.0002 mm) was determined on the carbonate-free soil material for some 30 pedons. The ratios of fine to total clay are given in table 32.

The A horizons of the Argids have coarser clay than the associated Bt horizons. In most instances, the clay of the associated K horizons is finer than that of the Bt horizons. Coarser clay in the A horizon is not limited to the Argids; all but one of the eight pedons in other orders have coarser clay in the A horizon. The Calciorthids and Torrifluvent in table 30 have developed in calcareous sediments derived from sedimentary rocks. Their noncarbonate clay tends to be coarser than that of the Argid pedons, which developed mostly in alluvium from igneous rocks.

Intense heat and extreme desiccation in surface horizons may be responsible for the relative coarseness of the clay.

TABLE 32—RATIO OF FINE TO TOTAL CLAY (0.0002/0.002 MM) OF CARBONATE-FREE, LESS-THAN-2-MM MATERIAL FOR ZONES OF PEDONS ARRANGED BY GREAT GROUP OR SUBORDER. Horizons with less than 10 percent clay and buried horizons excluded. A includes A, A2, and A3 horizons but not surficial C horizons. Bt includes B1 and B2 horizons but not B3 horizons; K includes K1 and K2 horizons or to top of buried horizon, whichever is shallower, but not K3. Zone from bottom of lowermost A horizon to 100 cm designated "sub A to 100 cm."

Taxa	Pedon	Horizon or zone A	Bt	K	C	Sub A to 100 cm
Argids	59-7	0.38	0.48		0.36	
	60-6	0.33	0.50	0.74		
	60-7	0.25	0.48	0.62		
	60-13	0.57	0.74	0.51		
	60-21	0.13	0.37	0.51		
	60-22	0.30	0.40			
	61-3	0.12	0.39	0.54		
	62-3		0.60		0.41	
	65-5	0.22	0.40	0.54		
	65-7	0.36	0.46	0.69		
	66-9	0.37	0.43			
	66-10	0.46	0.54			
	68-4	0.35	0.50		0.42	
	68-9	0.21	0.38	0.45		
	69-8	0.20	0.41		0.32	
	70-5	0.27	0.42		0.50	
	70-6	0.44	0.54			
	70-7	0.21	0.44	0.45		
	70-8	0.35	0.59	0.56		
	72-1	0.52	0.56	0.72		
	72-2	0.35	0.61	0.72		
	72-3	0.30	0.63			
	median	0.33	0.48	0.55		
Calciorthids	60-14	0.13				0.24
	60-17	0.13				0.27
	65-1	0.26				0.30
	66-6	0.16				0.14
	66-7	0.24				0.27
	68-7	0.10				0.32
Fluvents	60-15	0.32				0.45
Torrerts	60-16	0.14				0.36

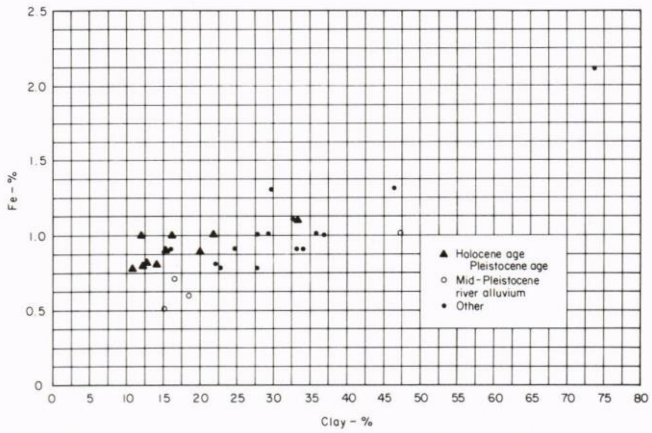


FIGURE 15—EXTRACTABLE IRON VERSUS SILICATE CLAY, both on a carbonate-free basis, for the B2t horizon of maximum clay of Argids.

Lower maximum temperatures and less intense desiccation may also explain the increase in fineness of the clay from Bt horizons to underlying K horizons. Finer clay in K horizons is consistent with their having an appreciable component of illuvial clay, as would be expected if they developed by carbonate engulfment of the lower part of once-deeper argillic horizons.

3.85 Extractable iron

Fig. 15 shows the relationship between extractable-iron and silicate-clay percentage for the subhorizon of the argillic horizon of Argids having maximum clay. The values tend to rise with increasing clay, but the scatter is large. Some of the scatter is related to parent material. This relationship is shown by the lower iron relative to clay percentage for pedons developed in middle Pleistocene river alluvium. The Holocene pedons do not have lower extractable iron relative to the clay than do the Pleistocene pedons. In some Argids the maximum in extractable iron coincides with the clay maximum; both the A horizons above and the C horizons below contain less extractable iron commensurate with their lower clay percentages. In other Argids, the extractable iron with depth shows little relationship to clay.

Table 33 compares extractable iron for weakly developed Holocene soils. The pedons that formed in reworked river alluvium have lower extractable iron than those formed in monzonite alluvium. The soils formed in the monzonitic alluvium contain more ferromagnesian minerals; these minerals apparently are the reason for the higher extractable iron. Hawkeye 59-2 is at area 11 and Bluepoint 59-10 is at area 19.

3.86 Exchange chemistry

Table 34 summarizes extractable cation and electrical conductivity data for the Bt horizon of Argids and for a depth range from the base of the surface horizon to near 50 cm for pedons in other suborders. With one exception the pedons are located on the basin floor or the lower piedmont slope. In this position soils with appreciable extractable sodium or soluble salts (as evidenced by electrical conductivity) within moderate depths are more common than over the project as a whole.

The ratio of the cation exchange capacity of NH_4OAc to silicate clay ranges from 0.4 to 0.8. Within this range, Argids in fine families have low values, and so does the Torrert pedon. These pedons have mixed clay mineralogy in the taxonomic sense. Their ratios of exchange capacity to clay are consistent with placement in mixed families.

Extractable magnesium ranges from approximately 10 to 35 percent of the exchange capacity. It tends to be higher for pedons with appreciable extractable sodium. Extractable sodium ranges from a trace to 12 percent of the exchange capacity, with most of the pedons having **1** percent or less. Low extractable sodium for the Stellar pedons (fine, Ustollic Haplargids) and for the Torrert is noteworthy, suggesting that the local moisture regime may be very important in determining the extractable sodium relationship (areas 14 to 17).

A factor contributing to low extractable sodium in the upper parts of soils is the abundance of carbonate in the environment. It occurs at the land surface (over which runoff water travels) and usually is present in the soil horizons themselves. This carbonate should maintain a calcium-ion concentration in the soil solution that would promote replacement of sodium by calcium during movement of water downward in the soil.

Extractable potassium decreases with depth, and for that reason the average value for the upper 50 cm is a better value for comparison purposes. Extractable potassium as a percent of the exchange capacity ranges widely. For pedons of Onite the range is from 3 to 9 percent and for the soils overall the range is from a trace to 13 percent. The lowest value is for the Torrert, and the highest value is for the fine-silty Ustollic Calciorthid. Three pedons have an average of 2 me (milli-equivalents) or more of extractable potassium in the upper 50 cm. They belong to a fine family of Ustollic Haplargids or to a fine-silty family of Ustollic Calciorthids.

Both the decrease in potassium with depth and the pattern of abundance among soils suggest that the intensity of vegetational return is important in determining the level of potassium. The soils with high potassium support appreciable perennial grass vegetation; hence, the organic carbon is relatively high. The Torrert, which has very low extractable potassium, supports only scattered blueweed, a perennial; usually it is largely barren.

Argids tend to have more illite and less montmorillonite in upper horizons. This pattern has been noted in soils of other arid areas and ascribed to recharge by potassium originating from vegetation (Nettleton and others, 1973).

3.87 Bulk density

Table 35 contains bulk-density data to illustrate the major trends with depth. Bulk densities within a pedon commonly increase with depth into the K2 horizon and are a maximum there; laminar K2m horizons, in particular, have high bulk densities. Plugging of K2 horizons by carbonate leads to high bulk densities (3.6). The K1 and K3 horizons usually have lower bulk densities than associated K2 horizons, related to less pore filling by carbonate in some soils. K1 horizons are zones of active faunal and root activity, and as a consequence the bulk density is lower.

TABLE 33—EXTRACTABLE IRON AND CLAY FOR HOLOCENE PEDONS LACKING SUBSOIL DIAGNOSTIC HORIZONS. The percentages are weighted averages from the base of the surface horizon to 50 cm.

Parent material and pedon	Iron %	Clay %
Monzonitic alluvium		
Aladdin 59-1	0.7	11
Hawkeye 59-2	0.9	6
SND 59-3	0.8	6
Vinton 59-4	0.9	7
Reworked river alluvium		
Bluepoint 59-10	0.4	5
Bluepoint 59-17	0.4	5

TABLE 34—SUMMARY OF ION-EXCHANGE AND RELATED DATA FOR PEDONS FROM THE PROJECT AREA. Data are weighted averages for the indicated depths unless otherwise indicated. Depths for weighted averages, except for the 0-50-cm (organic carbon) column. For Argids include Bit and B2t horizons; for others, subsurface horizon and horizons below to depth nearest to 50 cm. Some of the variability for a series, particularly in sodium, is relatable to differences in thickness of the zone averaged; CEC—cation-exchange capacity.

Classification and series	Pedon	Depth	Clay (%)	Organic carbon (%)	Organic carbon 0–50 cm (%)	CEC by NH_4OAc / Clay	Extractable bases as % of CEC[2]: Mg (%)	Na (%)	K (%)	K 0–50 cm (%)	Ext. K 0–50 cm (me/100 g)	Depth to upper boundary of horizon: Ext. Na >1 me (cm)	Conductivity >2 mmhos/cm (cm)
Typic Haplargids													
Coarse-loamy													
Onite, gravelly variant	61-5	8-23	15.2	0.22	0.20	0.73	13	tr	10	8	0.8	86	61
Onite, deep petrocalcic phase	61-8	13-71	12.1	0.16	0.19	0.75	33	12	3	3	0.3	23	56
Onite, sandy subsoil var.	68-3	8-23	11.5	0.21	0.17[3]	0.78	14	1	4	6	0.4	117	
Onite, thin-solum variant	68-5	5-23	11.2	0.19	0.22	0.89	16	2	6	6	0.6	48	64
Onite	70-5	6-32	18.7	0.22	0.19	0.61	15	1	6	6	0.7	157	169
Onite	70-6	6-41	15.2	0.16	0.15	0.70	20	tr	6	6	0.6	165	165
Onite, deep petrocalcic phase	72-1	5-26	11.5	0.13	0.12	0.69	25	3	13	9	0.8	40	61
Onite, deep petrocalcic phase	72-2	4-65	14.6	0.23	0.24	0.74	19	8	4	5	0.5	46	65
Sonoita	72-3	4-104	11.3	0.14	0.20	0.78	17	4	4	5	0.5	104	57
Fine-loamy													
Bucklebar	68-2	5-33	19.5	0.32	0.30	0.77	15	1	5	5	0.7	218	
Bucklebar	68-4	15-46	21.4	0.29	0.35	0.67	15	1	8	9	1.2	206	
Berino	68-9	3-43	24.8	0.32	0.30	0.65	22	1	7	7	1.1	185	
Berino	70-7	7-49	30.4	0.34	0.45	0.60	9	1	6	6	1.1	71	153
Dona Ana	61-4	5-33	26.7	0.53	0.50	0.71	14	tr	6	7	1.2	142	142
Dona Ana	68-6	8-58	17.1	0.33	0.33	0.75	13	3	8	6	0.7	58	
Ustollic Haplargids													
Loamy-skeletal													
Coxwell, shallow var.	70-1	5-21	20.6	0.55		0.67	16	1	4			21	
Fine													
Headquarters, clayey, sub. var.	69-8	10-79	47.7	0.60	0.85	0.59	18	4	6	7	2.0	49	79
Stellar, overflow phase	60-21	13-79	45.0	0.38	0.60	0.47	27	tr	11	11	2.6	305	
Stellar	61-3	8-58	43.4	0.48		0.53	24	tr	12			94	
Petrocalcic Ustollic Paleargids													
Loamy-skeletal													
Terino	70-8	5-46	31.3	0.71	0.61	0.66	15	1	5	5	1.1	159	
Clayey-skeletal													
Terino, thick-solum variant	60-5	8-58	57.6			0.43	36	7	5	6	1.1	20	58
Typic Calciorthids													
Coarse-loamy													
Algerita	60-2	5-58	21.7	0.21	0.21	0.63	30	12	4	4	0.6	36	
Algerita, part. ind. variant	61-1	13-46	9.6	0.32	0.31	0.82	16	3	4	5	0.4	81	81
Algerita	61-2	28-56	12.7	0.29		0.73	24	1	4			76	76
Ustollic Calciorthid													
Fine-silty													
Reagan	60-17	8-43	32.4	0.71	0.75	0.55	16	1	14	13	2.3	142	76
Typic Torrifluvent													
Fine-silty													
Glendale	60-15	5-38	21.9	0.73	0.70	0.61	15	1	8	8	1.0	86	64
Typic Torrert													
Very fine													
Dalby	60-16	5-48	61.6	0.34	0.35	0.51	14	tr	tr	tr	tr	114	114

[1]Noncarbonate clay on carbonate-containing basis.
[2]Used maximum values for extractable cations of 0.04 me for trace amounts.
[3]Extended value for bottom horizon analyzed to 50 cm.

Although within a pedon bulk density generally increases with carbonate content, the correlation for samples drawn from a number of pedons is poor (Gile and Grossman, 1979). The linear correlation coefficient is only 0.15 for the relationship between bulk density and carbonate content for twelve K2 horizons developed in noncalcareous parent material. Differences in silicate clay content may be one reason for the low correlation.

Bulk densities commonly are higher in the upper B and the lower A horizons than in the lower B horizon (table 33). The horizon immediately above a shallow root-limiting K horizon usually has a lower bulk density than adjacent horizons. The decrease in bulk density with depth is attributed to 1) scarcity of roots and low faunal activity in upper horizons due to extremely high summer temperatures and intense desiccation and 2) the concentration of roots in the lower part of B horizons and just above the root-limiting K horizons.

The Torrifluvents and most of the Calciorthids have developed in fine-silty or fine-loamy sediments derived from

TABLE 35—BULK-DENSITY DATA FOR THREE PEDONS; clod bulk densities for fine earth; Cruces 61-7 air-dry; others 1/3 bar.

Pedon and parent material	Depth (cm)	Horizon	Bulk density (g/cc)	Carbonate as $CaCO_3$ (%)
Cruces 61-7	5-18	B1t	1.86	-
Petrocalcic Paleargid	18-25	B1t	1.78	-
loamy, mixed, shallow;	25-36	B21t	1.70	1
ancient river alluvium	36-48	B22tca	1.53	16
	48-74	K21m		
	Laminar		2.22	93
	Nonlaminar		1.93	65
	74-102	K22m	1.68	65
Doña Ana phase 65-7	4-10	B1t	1.60	1
Typic Haplargid	10-18	B21tca	1.44	2
fine-loamy, mixed;	18-33	B22tca	1.39	6
ancient river alluvium	33-46	B23tca	1.31	10
	61-79	K12	1.70	31
	79-109	K13	1.70	25
Jal 65-6	4-10	B1ca	1.46	8
Typic Calciorthid	10-23	B2ca	1.22	22
coarse-loamy, carbonatic;	23-33	K1	1.39	51
alluvium from calcareous	33-58	K21	1.49	52
sedimentary rocks				

calcareous sedimentary rocks. Soils formed in these parent materials tend to have lower bulk densities than do soils in alluvium from monzonite or ancient river alluvium. The latter parent materials contain more sand coarser than 0.1 mm, less silt, and generally less clay than the alluvium from calcareous sedimentary rocks.

3.9 SOIL OCCURRENCE AND GENERAL SOIL-GEOMORPHIC RELATIONS

Factors affecting soil occurrence are discussed in detail in Gile and Grossman (1979) and are summarized below. Major soils of mapping units having a high proportion of single series occur on landscapes that are undissected or only slightly dissected and that lack substantial deposition by wind; particle size does not differ greatly; and discontinuous argillic, calcic, or petrocalcic horizons are not present. These soils occur mostly in the basin floors and on the middle and lower piedmont slopes.

The most complex patterns of soil distribution and the largest number of soils in a given area are found in dissected landscapes, where the soils have been truncated in varying degrees. The soil patterns are complex because diagnostic horizons have been truncated in some places but not in others. Dissection also has caused abrupt changes in particle-size families. Landscape dissection along the mountain fronts is a major factor determining the location of the Mollisol-Aridisol boundary because it can result in chromas or values too high for a mollic epipedon.

At stable sites, soil age is the most important factor affecting soil morphology and occurrence. For example, in the stepped sequence of geomorphic surfaces along the valley border, the soils of stable sites are progressively older, thicker, and more prominent with increasing elevation of the steps. The horizon of carbonate accumulation is the soil horizon that is responsible for most of the morphological change and that is best related to soil age (table 21). Carbonate horizons are deeper in the soil than are other horizons, and those that date from late Pleistocene or earlier are commonly compact and some are indurated. Thus they are less apt to be disturbed by soil biota than are overlying horizons and are more resistant to erosion. Also, horizons of silicate clay accumulation may be obliterated after they have formed (3.76). The illuviation of silicate clay has not been demonstrated (and argillic horizons have not been found) in parent materials containing abundant fragments of high-carbonate rocks, even in soils of late Pleistocene age (area 7). In contrast, carbonate can accumulate in any desert soil if moisture can enter and there is a source of carbonate, in either dust or the parent material.

Increasing soil development is also shown by increasing thickness of the carbonate horizon with age. Several factors are involved. Carbonate moves deeper in soils during full-glacial times (area 3). Large amounts of the accumulated constituents themselves thicken a soil by virtue of their own volume. Many K horizons contain substantial amounts of silicate clay as well as carbonate, partly because their upper sub-horizons were once argillic horizons that have been engulfed by carbonate. In contrast, thickness of the B horizon is not well related to soil age because of engulfment of lower parts of former B horizons by carbonate (areas 2 and 3) and truncation of upper parts of B horizons in some areas.

3.91 Pedogenic significance of geomorphic surfaces

Degree of soil development is well related to age of geomorphic surface (3.6). This is particularly evident when degree of carbonate-horizon development in the arid zone is considered (see areas 1-7). A number of great groups can occur on the same geomorphic surface (table 36) because of variations in parent materials, landscape stability, and climate. Following are summary sections concerning pedogenic significance of the various surfaces. The discussion is presented according to the three general physiographic areas in the project area—the valley border, the piedmont slopes, and the basin floor north of US-70. Specific examples and quantitative information are presented at the various study areas.

THE VALLEY BORDER—Geomorphic surfaces of the valley border are significant because of the stepped sequence of surfaces and highly variable degree of soil truncation (2.22, 2.62). By means of the stepped sequence and associated chronologic markers, the soils may be chronologically related to each other to study the effects of age on soil morphology. Similarly, the effects of shifts in parent materials on soil development can be studied while the soil-forming factors of age and climate are kept constant. Morphology of soils that have been truncated in varying degree can also be assessed and compared to the soils of stable sites. The valley-border surfaces also illustrate effects of polygenesis in soils that started their development at various times since middle Pleistocene.

The Historical materials of arroyo channels (2.62) suggest the general character of soil-parent materials. The sediments are stratified and fresh-appearing. Authigenic carbonate is restricted to a very few discontinuous, extremely thin flakes on pebbles. A few pebbles with thick, hard carbonate coatings occur in places; these could only have been derived from some carbonate horizon upstream. Such heavily coated pebbles are distributed randomly throughout the sediment rather than in a horizon.

Coppice dunes (area 5) have not been formally recognized as a geomorphic surface. The dunes are Historical and show little evidence of soil development except for occasional disruption of strata by soil biota.

Soils of the Fillmore surface (2.62; areas 1, 3, 7, 19) must have formed under a climate very similar to the present one, and their morphology cannot 1be attributed to a Pleistocene pluvial. Soils of the Fillmore illustrate the beginnings of soil horizons. All soils have a stage I horizon of carbonate accumulation. In soils that have formed in low-carbonate materials and that occur on the oldest and stablest part of the Fillmore, soil morphology indicates that silicate clay is accumulating at the present time by illuviation (3.7). Because of the limited time available for pedogenesis, however, the clay increase is usually too slight for an argillic horizon. Upper horizons of soils that were formed in low-carbonate parent materials on stable sites are usually noncalcareous. Infiltration of moisture has been sufficient to remove most of the carbonate in the dustfall and also small amounts that may have been in the surficial part of the alluvium. In contrast, all soils formed in high-carbonate parent materials are strongly calcareous throughout. So much allogenic carbonate occurs in the soils that the soil moisture associated with the present climate has been unable to move it from upper horizons.

Soils of the Leasburg surface (2.62) have morphologies intermediate between weakly developed soils of the Fillmore and strongly developed soils of the Picacho surface. At stable sites and in low-carbonate parent materials, evidence of il-

TABLE 36—GENERAL RELATIONS OF SOILS TO GEOMORPHIC SURFACES. "Upper piedmont slopes" designates the piedmont slopes along the mountain fronts, with precipitation range of about 25-40 cm; "lower and middle piedmont slopes" designates the piedmont slopes at lower elevations and precipitation. Entries for Jornada I and II do not include the upper piedmont slopes where they have been identified in only a few areas; Jornada designates the upper piedmont slopes that fall within the age range of Jornada I and II. Relative ages of La Mesa and Doña Ana are not known, but both are older than Jornada I.

Geomorphic surface	Age, years B.P. or epoch	Physiographic position	Soil order or great group: Low-carbonate parent materials	Soil order or great group: High-carbonate parent materials
Arroyo channel	Historical	Channel of arroyo	Entisols	Entisols
(Coppice dunes)	Historical	Valley border; basin floor; lower and middle piedmont slopes	Torripsamments	none
Fillmore	100 to 7,000	Valley border	Entisols Camborthids Haplargids	Entisols
Organ	100 to 7,000	Upper piedmont slopes	Haplustolls, Argiustolls	Haplustolls
		Lower and middle piedmont slopes	Entisols, Camborthids, Haplargids	Entisols, Calciorthids
Leasburg	Early Holocene-latest Pleistocene	Valley border	Entisols, Camborthids Haplargids, Calciorthids	Calciorthids
Isaacks' Ranch	Early Holocene-latest Pleistocene	Lower and middle piedmont slopes	Haplargids	Calciorthids
Lake Tank	Holocene and late Pleistocene	Playa	Torrerts, Haplargids	none
Picacho	Late Pleistocene	Valley border	Haplargids, Paleargids Calciorthids, Paleorthids	Calciorthids Paleorthids
Jornada II	Late Pleistocene	Lower and middle piedmont slopes	Haplargids, Paleargids Calciorthids, Paleorthids	Calciorthids Paleorthids*
Petts Tank	Late Pleistocene	Basin floor	none	Calciorthids
Tortugas	Late to middle Pleistocene	Valley border	Calciorthids Paleorthids	Calciorthids Paleorthids
Jornada		Upper piedmont slopes	Argiustolls Paleustolls	Calciustolls Paleorthids
Jornada I	Late middle Pleistocene	Basin floor	Haplargids	
		Lower and middle piedmont slopes	Calciorthids, Paleorthids Haplargids, Paleargids	none
La Mesa	Middle Pleistocene	Basin floor	Paleargids, Paleorthids, Haplargids	none
Doña Ana	Middle Pleistocene	Upper piedmont slopes	Paleargids, Calciustolls Paleorthids, Paleustolls	none

* Haplargids and Paleargids occur with presence of substantial amounts of low-carbonate materials.

luvial clay is more distinct in soils of the Leasburg surface than in soils of the Fillmore. Low-gravel soils of the Leasburg are in stage II of carbonate accumulation, and high-gravel soils are in stage II or early stage III. Only scattered small areas of the Leasburg surface are well preserved and have soils that indicate the magnitude of pedogenesis associated with the span of Leasburg time.

Soils of the Picacho surface (2.62; areas 2, 3, 7) started their development in late Pleistocene time and must have developed in part during the last full glacial. The Picacho surface is a significant pedogenic marker for several reasons. It marks the first appearance of a prominent argillic horizon in soils of the valley border. Soils of the Picacho surface are morphologically more complex: whereas soils of the Fillmore and Leas-burg surfaces have relatively minor horizons of carbonate and clay accumulation, soils of the Picacho have much greater maxima of clay or carbonate, or both; and in the Argids, there is often considerable interpenetration of carbonate and silicate clay. The transition from stage III to stage IV of carbonate accumulation in very gravelly materials is also shown in soils of the Picacho surface. Soils with petrocalcic horizons first appear in soils of the Picacho (in very gravelly materials only). The transition from the Argids to the Calciorthids and Paleorthids by *soil truncation—illustrating* one mode of genesis for these two great groups—is demonstrated by soils of the Picacho surface. The development of Paleorthids *without truncation—in* very gravelly, high-carbonate materials—is also shown by soils of the Picacho surface.

The Tortugas surface (2.62) is not extensive in the Desert Project area, and soils of Tortugas remnants have been subjected to truncation associated with landscape dissection. Fairly large remnants of the Tortugas surface do occur in several places east of the Robledo Mountains, but even here the soils have been partly truncated. Probably the best areas of demonstrable Tortugas on the east side of the valley are remnants adjacent to the Picacho and Jornada I surfaces and between them in elevation. Although the remnants are small, they are common, suggesting that the Tortugas is a valid chronologic marker. Precise statements about the pedogenic significance from the Tortugas interval to the present are difficult to make because of soil truncation. Observations of calcic and petrocalcic horizons suggest development stronger than Picacho.

Jornada I ridges are extensive on the east side of the valley border (2.53, area 4). Although some truncation has occurred on many of these ridges, the truncated areas grade to stable areas in many places so that pedogenic comparisons may be made. The soils of Jornada I have distinctly stronger morphologies than soils of the Picacho and Jornada II (see area 4). The Bt horizons of soils of Jornada I have more prominent maxima of silicate clay than do soils of Jornada II and Picacho (3.7). In very gravelly materials, carbonate horizons usually have multiple laminar horizons, in contrast to the single or discontinuous laminar horizons that are most common in soils of Jornada II or Picacho age. However, stage IV carbonate horizons have not formed in low-gravel soils of Jornada I (see La Mesa surface).

The soils of La Mesa (2.53, areas 5 and 6) are the oldest in the study area, with the possible exception of soils of the Doña. Ana surface of the piedmont slopes. The soils of lower La Mesa (area 5) demonstrate the initial development of stage IV of carbonate accumulation in low-gravel materials, and, like soils of the Picacho surface in high-gravel materials, illustrate the transition from stage III to stage IV. Soils of upper La Mesa (area 6) are thought to be older; they have complex stage IV carbonate horizons with multicyclic laminar zones.

PIEDMONT SLOPES—Terraces of several levels and ages are apparent in places along the mountain fronts. The terraces constitute a stepped sequence of surfaces with relative age relations similar to those along the valley border: age of the terraces and their soils increases with increasing elevation of the steps. Although these terraces have been studied in detail in only a few places, terraces of at least four ages are known to occur—Organ, Jornada I and II, and Doña Ana. In other areas the relative age relations are less apparent because of cuts and fills at approximately the same elevation. The terraces commonly merge downslope, resulting in complex soil-landscape relations (area 20).

Soils of the Organ surface (2.61) are in areas 8, 10, 11, 12, 14, 15, 16, 20, 21, and 22. The range in age of Organ and Fill-more alluvium is about the same. Most Organ deposits are well preserved, however, and have not been affected by down-cutting of the Rio Grande. Thus, as a whole, the maximum expression of pedogenesis is greater in soils of the Organ surface than in soils of the Fillmore. In the arid zone and in parts of the semiarid zone, these soils have stage I carbonate horizons. Soils of the Organ surface illustrate the effect of differences in precipitation on soils of the same age. As precipitation increases towards the mountains, horizons of carbonate accumulation gradually deepen in the soil. Upper horizons also darken mountainward as Aridisols in the arid zone grade to Mollisols in the semiarid zone. In the arid zone and in parts of the semiarid zone, soils formed in low-carbonate parent materials have noncalcareous, reddish-brown argillic or cambic horizons (areas 10, 14, 15, 20), but not in high-carbonate parent materials (areas 12, 16).

Soils of the Isaacks' Ranch surface (2.61; areas 9, 14) have stage II carbonate horizons, and in low-carbonate parent materials have argillic horizons. The soils are similar to soils of the Leasburg along the valley border in being about the same age and in being intermediate in morphology between soils of Holocene age and soils of late Pleistocene age.

Soils of the Jornada II surface (2.61; areas 8, 9, 12, 14, 15, 16) occur extensively on both alluvial fans along the mountain fronts and the coalescent-fan piedmont downslope. In the arid zone, soils of Jornada II are similar to and are considered to be about the same age as soils of the Picacho surface along the valley border. Their horizons of clay and carbonate accumulation are similar, and soils of both ages must have developed in part in the last full glacial. The Bt horizons in soils of Jornada II are thicker and redder than those of Isaacks' Ranch and Organ surfaces. Their carbonate horizons are also stronger; in the arid zone they are stage III in low-gravel materials and stage IV in high-gravel materials.

See areas 12, 21, and 22 for discussion of the Jornada I surface (2.53). Along the mountain fronts, in many places Jornada I and II occur in complex patterns and have not been specifically identified. They have been identified in the vicinity of the Gardner Spring radiocarbon site (area 12), where Jornada I occurs on ridge crests and has a thick K horizon with a multiple laminar horizon. Jornada II, in contrast, occurs on ridge sides and has a thinner K horizon and a single laminar horizon.

Soils of the Doña Ana surface (2.53) illustrate development of the laminar horizon and stage IV of carbonate accumulation in soils of the mountain canyons (see area 21 for discussion). On a stable remnant in lce Canyon, the soils have the reddest and most clayey Bt horizon in the project area (Gile and Grossman, 1979, p. 628). Area 22 illustrates soils of a dissected remnant of the Doña Ana surface.

BASIN FLOOR NORTH OF US-70—The gentle slopes and smooth terrain of the basin floor north of US-70 (Day 4) contrast markedly with the dissected terrain adjacent to the relict basin floor along the valley (fig. 4). Complex soil patterns due to strong dissection are absent and the soils are well preserved in many places. The area is level or nearly level. Aggradation has occurred at various times since the middle Pleistocene; surfaces and associated deposits of several ages are present (2.61).

Sediments associated with the Whitebottom surface are Historical and are generally only a few centimeters thick—too thin to be considered in the classification system (3.1). The oldest deposits of Whitebottom age have been emplaced long enough for local disruption of strata by roots and fauna.

Only minor deposits of Organ age are present in the basin floor; soil morphology is similar to that in arid parts of the piedmont slope, discussed earlier.

Soils of the Lake Tank surface (2.61, area 14) occur in two areas—Isaacks Lake playa (by far the largest of the two) and a small playa east of the New Mexico State University Ranch Headquarters. Soil age ranges widely; on the outer edges of the playa the soils are of Organ (Holocene) age. Soils in the central part of the playa exhibit considerable mixing because of shrinking and swelling (see area 14). The sediments range in age from late Pleistocene or earlier to deposits of the latest storm.

Soils of the Petts Tank surface (2.61, area 16) occur on the eastern side of the basin floor. They are of late Pleistocene age (the same as the adjacent soils of the Jornada II surface on the piedmont slopes). All soils of the Petts Tank surface are strongly calcareous throughout and lack argillic horizons because of the highly calcareous parent materials. The soils have structural B horizons and stage III horizons of carbonate accumulation.

Soils of the Jornada I surface (area 17) occur on the western part of the basin floor north of Isaacks Lake and occupy nearly all of the basin floor south of it. The soils of Jornada I are older than and are buried by the sediments and soils of the Petts Tank and Jornada II surfaces but are younger than the soils of middle Pleistocene La Mesa surface. In and near the basin floor, 'A to 1 m or more of sediments have accumulated since deposition of the rounded gravel and sand of the middle Pleistocene river alluvium. This younger sediment is finer textured than the underlying sediments and was derived from the adjacent fan piedmont upslope. The A, Bt, and part or all of the K2 horizons of Stellar soils (area 21) have formed in these finer-textured materials. All soils are nongravelly and have thick Bt and K horizons. The contact between Jornada I and II is apparent on the piedmont slopes but not in the basin floor. Proximity of this part of the basin floor to the piedmont toeslopes of the Doña Anas suggests that some of the sediment in which the A and B horizons have formed may be of Jornada II age.

Soils of an undifferentiated Jornada and La Mesa surface occur on slight ridges in the northern part of the basin floor (area 18) and in adjacent slight depressions. The soils have formed in sediments of the upper Camp Rice Formation (fluvial facies). The soils are not as prominently developed as those of La Mesa surface along the Rio Grande valley border. Petrocalcic horizons are seldom present, although there is evidence in some soils (such as pedon 61-1) that a petrocalcic horizon might once have been present and has since been fractured. The details of soil age are not known with certainty in this area but most soils are thought to fall in the age range of Jornada I and La Mesa. Parts of La Mesa in the closed basin could have been occupied by a shallow lake at some time in the Pleistocene. At that time the soils of La Mesa along the valley border may have already started to develop. Soils of La Mesa in the closed basin could, therefore, be younger than soils of La Mesa along the valley border.

3.92 General soil map

Fig. 16 is a general soil map of the project area. In this map, soils of the detailed map (in Gile and Grossman, 1979) have been grouped into 18 mapping units. Seventeen of these are soil associations and complexes; and one unit designates rock outcrop and soils. Areas of the latter unit occur in and near the mountains. The soil associations and complexes are presented according to their general physiographic position, as follows: 1) the valley border of the Rio Grande, 2) the piedmont slopes, and 3) the basin floor north of US-70.

SOILS OF VALLEY BORDER—No. *I, Bluepoint association (Torripsamment association)—These* soils occur on fans and terraces (primarily of Fillmore age) that descend to or are truncated by the floodplain and on narrow ridge crests and colluvial slopes of ridge sides. On the west side of the valley the ridges are high and steep; a structural bench has formed on gravel-capped ridges. Common saddles (formed by drainageways encroaching on ridge crests) occur in the ridges, and sideslopes range from 15 to 35 percent. Slopes are gentler on the east side of the valley where slopes of ridge sides commonly range from 3 to 10 percent.

Torripsamments (Bluepoint soils) are dominant. Torriorthents (Kokan and Yturbide soils) dominate high, narrow ridges bordering the scarp of lower La Mesa on the west side of the valley. Arizo soils (Torriorthents) are not as steep as Kokan soils and occur on many of the Fillmore terraces along the arroyo channels. Small areas of Calciorthids (mostly Whitlock soils) are preserved on some of the ridges on the east side of the valley.

No. 2, Nickel-Arizo-Kokan complex (Calciorthid-Torriorthent complex)—These soils occur in dissected terrain west of the Doña Ana Mountains and along major arroyos in the southeast part of the area. Most areas have been strongly dissected by arroyos; ridge remnants of alluvial fans and terraces, usually the Picacho surface, are prominent in many places. Narrow Fillmore terraces are commonly inset against the ridge remnants. Nearest the valley, dissection has been so severe that the original depositional slope of the fans has been substantially altered and the Picacho surface has been replaced by the younger Fillmore. Saddles are common in such areas. Longitudinal slopes along ridge crests range from approximately 2 to 5 percent; slopes of ridge sides range from approximately 5 to 35 percent.

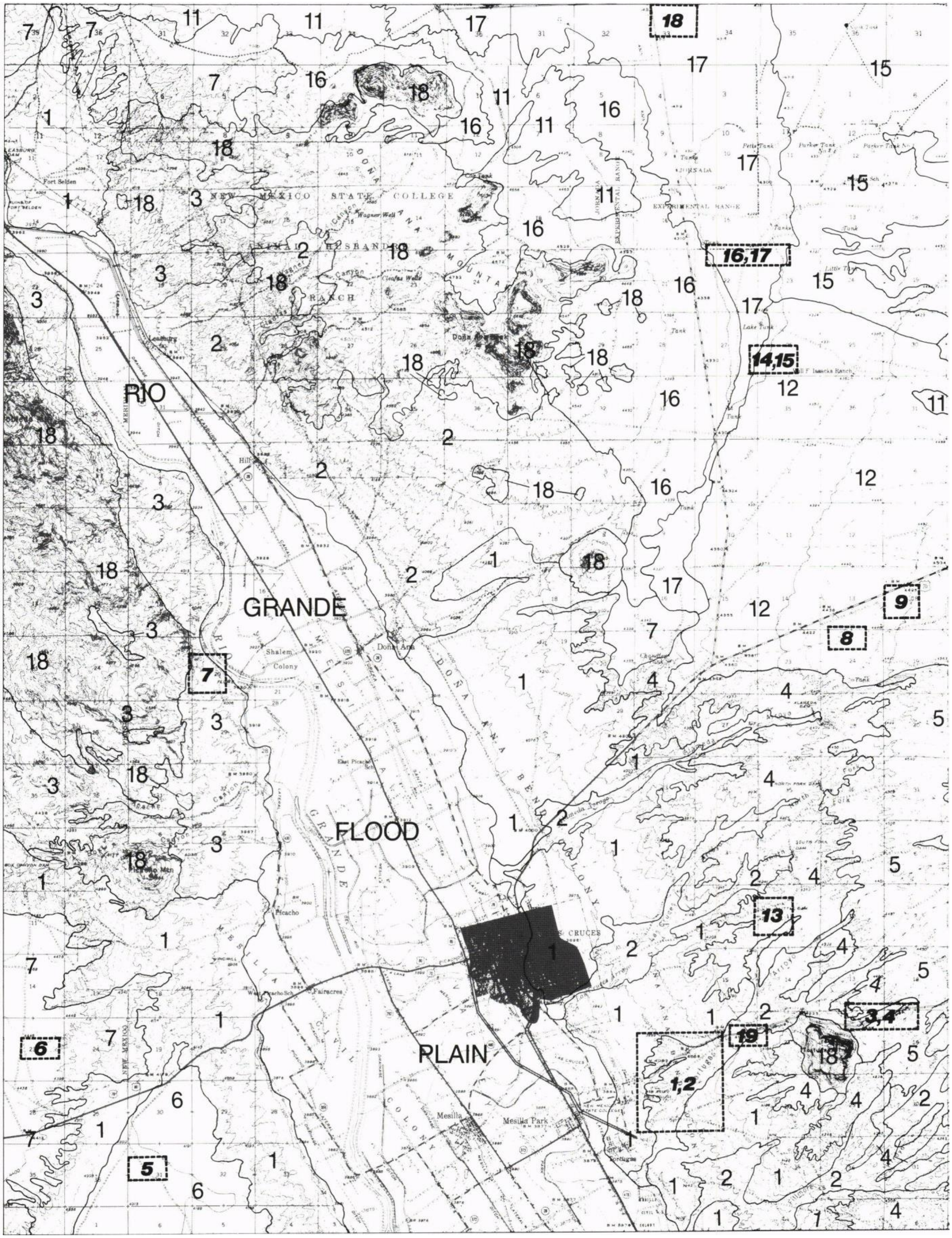
Calciorthids (Caliza and Nickel soils) dominate the ridge crests in stabler areas. The calcic horizon of these soils has been truncated on very narrow ridges, and Torriorthents (commonly Kokan soils) occur on both the ridge crests and ridge sides. Torriorthents (mostly Arizo soils) are dominant on Fillmore terraces inset against the remnants. Haplargids and Paleargids are preserved on stablest parts of the Picacho surface, mainly in the southeast part of the area.

No. 3, Tencee-Upton-Dalian complex (Paleorthid-Torriorthent complex)—This unit occurs east and south of the Robledo Mountains. In most places the area is characterized by high Picacho or Tortugas fan remnants that have been deeply dissected. Fillmore terraces are inset against the high fan remnants and are about one to several meters higher than the arroyo channels. Steep colluvial wedges occur on sides of the remnants. In places, the Fillmore sediments coalesce to form small fans beyond the lower edges of the remnants. Small areas of the Leasburg surface occur in places and are intermediate in elevation between the Fillmore and Picacho. Longitudinal slopes range from 3 to 5 percent. Most side slopes along margins of the Picacho remnants range from about 25 to 50 percent; in places they are nearly vertical.

Paleorthids (Tencee and Upton soils) are dominant on the broad crests of the Picacho remnants. Calciorthids (Weiser soils) occur on the Leasburg surface and on narrow Picacho remnants where the petrocalcic horizon has broken up because of landscape dissection and soil truncation. Torriorthents (mostly Dalian soils) dominate the Fillmore terraces and also the colluvial wedges of the sides of the Picacho remnants. Torrifluvents (mostly Glendale and Anthony soils) occur in low-gravel areas of Fillmore alluvium near the flood-plain.

No. 4, Caliza-Haplargids complex (Calciorthid-Haplargid complex)—Most areas of this mapping unit are strongly dissected, and high narrow ridges are prominent. A structural bench has formed on gravel-capped ridge crests. Saddles are common in ridge crests in the western part. The eastern part of the unit generally lacks a structural bench because gravel is less common, particularly as thick deposits at accordant elevations. Locally, slopes along ridge crests range from 2 to 5 percent; slopes of ridge sides range from 5 to 35 percent.

Calciorthids (Caliza soils) are dominant on highest, stablest ridges of the structural bench; Torriorthents (Kokan and Yturbide soils) and Torripsamments (Bluepoint soils) are dominant on ridge sides. A sinuous scarp occurs on the east side of the gravels and on the structural bench. East of the scarp the gravel passes beneath dissected paleosols (Haplargid, dissected). On ridge sides buried soils are either exposed or underlie a thin mantle of colluvium. On broadest ridge crests, Haplargids or Paleargids developed on the original depositional surface (Jornada I) have been preserved.


RIO
GRANDE
FLOOD
PLAIN
NEW MEXICO STATE COLLEGE
JORNADA EXPERIMENTAL RANGE
DONA ANA MOUNTAINS
DONA ANA BEND COLONY
MESILLA CIVIL COLONY
Fort Selden
Shalem Colony
Dona Ana
East Picacho
Picacho
Fairacres
Mesilla
Mesilla Park
Tortugas
18
16,17
14,15
9
8
7
13
3,4
19
1,2
6
5

No. 5, Monterosa-Algerita complex (Paleorthid-Calciorthid complex)—High ridges are characteristic; terraces occur below them in places, particularly in the southern part of the unit. Successively higher terraces above the arroyo channels in this terrain are Fillmore, Picacho, small areas of Tortugas, and Jornada I, which is on the highest ridges. Slopes along ridge crests range from 2 to 3 percent; ridge sides slope from 5 to 35 percent.

Calciorthids (Algerita soils) are dominant in the northern part of the area, occurring mainly on the Jornada I ridges but also on Tortugas and Picacho. Southward the parent materials are much more gravelly, causing the development of a petrocalcic instead of a calcic horizon; and the dominant soils are therefore Paleorthids (mostly Monterosa soils) instead of Calciorthids. Haplargids (Nolam soils) and Paleargids (Cruces, loamy-skeletal variant) are generally dominant on the Picacho surface with the Calciorthids and Paleorthids occurring in less stable areas where the soils have been partially truncated. Torriorthents (mostly Arizo soils) dominate the Fillmore terraces.

No. 6, Onite-Pintura complex (Haplargid-Torripsamment complex)—These soils are on lower La Mesa, a relict basin floor west of the valley. Slopes are level or nearly level between coppice dunes, which are particularly prominent in the southern part of the unit.

Haplargids (Onite, deep petrocalcic phase) with deep petrocalcic horizons are dominant. Other Haplargids are the Bucklebar and Sonoita soils; they occur in pipes that penetrate the petrocalcic horizon of Onite, deep petrocalcic phase. Bucklebar soils also occur in small depressions. Paleargids occur on several slight ridges and in places around the periphery of lower La Mesa. Torripsamments (Pintura soils) occur in coppice dunes with sandy textures to at least 1 m. Adelino soils, Camborthids, occur in an elongate depression on the west side of lower La Mesa.

No. 7, Cruces association (Paleargid association)—Soils of this mapping unit occur on and adjacent to upper La Mesa, a relict basin floor occurring west of the valley and in smaller areas near Goat Mountain and north of Fort Selden. Slopes are level or nearly level on the basin floor. Areas along the scarp and below it slope 3 to 5 percent towards the valley.

Paleargids (mostly Cruces soils) are dominant on the basin floor. Haplargids (Bucklebar soils) occur in pipes. Paleorthids

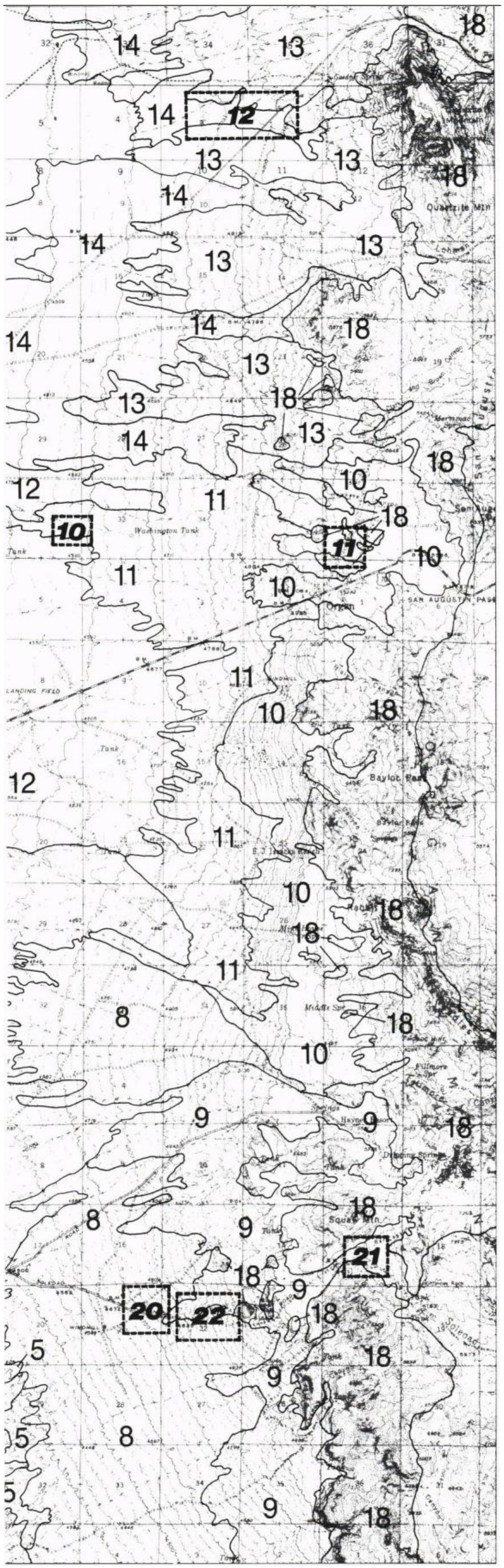


FIGURE I6—GENERAL SOIL MAP. Rectangles with numbers locate the study areas.

1 Bluepoint association.
2 Nickel-Arizo-Kokan complex.
3 Tencee-Upton-Dalian complex.
4 Caliza-Haplargids complex.
5 Monterosa-Algerita complex.
6 Onite-Pintura complex.
7 Cruces association.
8 Terino-Soledad association.
9 Boracho-Terino-Santo Tomas association.
10 Caralampi-Nolam-Aladdin association.
11 Onite association.
12 Berino-Bucklebar association.
13 Conger-Monterosa, carbonatic variant complex.
14 Glendale-Anthony complex.
15 Algerita-Dona Ana-Reagan complex.
16 Dona Ana-Onite-Anthony association.
17 Stellar-Reagan-Algerita association.
18 Rock outcrop and soils.

(Tencee soils) occur along scarps cut in valleyward margins of the remnants. Calciorthids (Jal soils) occur on ridges down-slope from the scarp.

SOILS OF PIEDMONT SLOPES—No. *8, Terino-Soledad association (Paleargid-Haplargid association)—Three* soils occur mostly on the fan piedmont in the southeast part of the area, extending mountainward in many places where they occur on fans. Gullies and arroyos are common in places, but the areas between are fairly stable. Slopes range from 2 percent in the western part of the unit to 6 percent in the eastern part, nearest the mountains.

Paleargids (Terino soils) are dominant, with fewer Haplargids (mostly Soledad, some Nolam). The change from dominantly Orthids in mapping unit 5 to dominantly Argids in this unit is caused by a decrease in landscape dissection and associated soil truncation. The argillic horizon, which has been truncated and carbonate-engulfed on the Jornada I ridges in mapping unit 5, is still preserved in mapping unit 8. The Paleargids are dominant and most continuous on Jornada I ridges, but also occur on Jornada II and Dona Ana surfaces. Soledad soils occur in scattered Holocene deposits, which have buried the older soils in many places.

No. 9, Boracho-Terino-Santo Tomas association (Calciustoll-Haplustoll-Haplargid association)—These soils occur in a belt paralleling the front of the Organ Mountains. Cobbles and pebbles are usually present on the surface and in the soil. This unit encompasses the largest area of the Dona Ana surface, the highest and oldest surface along the mountain fronts. Substantial areas of Jornada I and II surfaces are also present. They occur both as well-preserved terraces and as ridge sides of the Doña Ana remnants. The Organ surface usually occurs in general topographic lows adjacent to arroyos; in some areas just below mountain canyons Organ sediments spread out as small fans that cut into or bury older soils. Most longitudinal slopes range from approximately 5 to 15 percent, but many of the fans are dissected and ridge sides are steep, ranging up to 50 percent.

Soil patterns are complex because of variations in soil age and landscape dissection. Calciustolls (Boracho soils) are most common on the Dona Ana remnants, occurring on steep sides of many ridges and on some ridge crests. Paleargids (Terino soils) occur on broadest areas of the Doña Ana surface where argillic horizons are still preserved. Terino soils and their moderately deep variant occur on the Jornada I terraces. Haplargids (Nolam soils) occur on Jornada surfaces where the soils have a calcic horizon within 1 m of the surface; Caralampi soils are similar but lack a calcic horizon within 1 m. The latter soils are most common at highest elevations on the Jornada I and II surfaces. Haplustolls (Santo Tomas soils and their Torriorthentic variant) are on the Organ surface. Argiustolls (Earp, light subsoil variant) are on oldest and stablest parts of the Organ surface where an argillic horizon has formed in addition to the mollic epipedon.

No. 10, Caralampi-Nolam-Aladdin association (Haplargid-Haplustoll association)—This belt of soils occurs along the front of the Organ Mountains. Cobbles, stones, and in places boulders, are common on the surface and in the soils in many places south of Organ. Slopes usually range from approximately 5 to 15 percent, in places reaching 40 percent on the sides of ridges at highest elevations.

Because of considerable variation in soil age and landscape stability, soil patterns are extremely complex in most areas. Organic carbon generally increases mountainward because of higher elevation, greater precipitation, and more abundant vegetation. Haplargids (Nolam and Caralampi soils) are the most extensive soils, being dominant on stablest surfaces of Jornada age. There are smaller areas of soils on the Organ surface. Haplustolls (the loamy-skeletal Santo Tomas soils and their Torriorthentic variant) are most common in and just below the larger canyons. Other Haplustolls (the coarse-loamy Aladdin soils) are dominant in less gravelly areas, particularly in the vicinity of Organ. Argiustolls (mostly Earp, light subsoil variant) occur in scattered stabler, oldest areas of the Organ surface.

No. 11, Onite association (Haplargid association)—Most of these soils are on the Organ surface (a few are on Isaacks' Ranch surface) below soils of mapping unit 10. There are few rock fragments, and slopes range from 2 to 5 percent.

Haplargids (Onite soils) are dominant, with smaller areas of Camborthids (mostly Pajarito soils), which occur primarily at lower elevations and in slightly younger alluvium. Small areas of other Haplargids (Hap and Sonoita soils) occur at highest elevations west of the Organ Mountains. Sonoita soils also occur north of the La Mesa rim in the northwest part of the project. Soils of this unit are commonly underlain by buried soils that emerge at the land surface downslope.

No. 12, Berino-Bucklebar association (Haplargid association)—These soils occur on a broad, coalescent-fan piedmont. Slopes range from 1 percent near the basin floor to 3 percent at highest elevations.

Haplargids (Berino and Bucklebar soils) are dominant. Bucklebar soils occur on Organ and Isaacks' Ranch surfaces and are most common in drainageways. Berino soils are older (Jornada II surface), and their buried analogues underlie the soils of Organ and Isaacks' Ranch age. Torripsamments (Pintura soils) occur in dunes where sediments with sandy textures are at least 1 m thick. Torrifluvents (Pintura, thin variant) occur where the dune sediments are from 50 to 100 cm thick and overlie buried soils of finer texture.

No. 13, Conger-Monterosa, carbonatic variant complex (Paleorthid complex)—These soils occur on large fans of Jornada age, west of the San Andres Mountains. Longitudinal slopes along the ridge crests range from 2 to 5 percent. Ridge remnants are common and have sideslopes from 5 to 20 percent.

Paleorthids (mostly Conger soils and Monterosa, carbonatic variant) are dominant. Smaller areas of Calciorthids (mainly Jal soils) also occur. Most of the Calciorthids are on lower slopes, where gravel is less common and where calcic, instead of petrocalcic, horizons have formed. Calciustolls (mostly Boracho, carbonatic variant) occur on stablest sites at highest elevations.

No. 14, Glendale-Anthony complex (Torrifluvent complex) — Soils of this mapping unit occur on Organ terraces between large Jornada fans of mapping unit 13 and on a coalescent-fan piedmont downslope. Slopes range from 1 percent near the basin to 4 percent near the mountains. Scarplets occur in places and range in height from a few cm to 1 m or more.

Torrifluvents (Glendale soils) are dominant on gentler slopes in the western part of the unit. Anthony soils, also Torrifluvents, are dominant on steeper slopes in the eastern part of the unit. The soils are usually underlain by buried soils that emerge at the land surface downslope (mapping unit 15). Calciorthids (Reagan soils) also occur in some areas and illustrate incipient development of the calcic horizon in high-carbonate materials.

No. 15, Algerita-Dona Ana-Reagan complex (Calciorthid-Haplargid complex)—Most soils occur in broad drainageways, with some occurring on very slight ridges between drainageways. Scarplets, a few centimeters to 1 m high, occur in drainageways. Slopes range from 1 percent near the basin floor to 2 percent at higher elevations.

Calciorthids (Reagan, light subsoil variant) of Holocene age occur above scarps and overlie Calciorthids of Pleistocene age. Calciorthids (Algerita soils) are most common below scarps. Haplargids (Dona Ana soils) occur mainly on slight ridges (between broad drainageways) where carbonate content of the parent materials is low enough that an argillic horizon developed. Other Haplargids (Headquarters soils) occur in stabler areas, mostly in drainageways where textures are finer and organic carbon is higher.

No. 16, Dona Ana-Onite-Anthony association (Haplargid-Torrifluvent association)—These soils occur downslope from the Doña Ana Mountains, primarily on a coalescent-fan piedmont of Jornada age. Most slopes range from 1 percent near the basin floor to approximately 7 percent next to the mountains. Near the mountains, sides of the scattered ridge remnants slope from 10 to 35 percent.

Haplargids (mostly Dona Ana soils with some Tres Her - manos) occur on stablest, low-gravel areas of the Jornada surface. Paleargids (Terino and Casito soils) occur in very gravelly, stable areas. Calciorthids (Nickel soils) and Paleorthids (Delnorte soils) occur on Jornada ridges nearest the mountains. Haplargids (Onite; Onite, gravelly variant; and Soledad soils) occur on stablest areas of Organ age. Torri fluvents (Anthony soils) occur on less stable areas of the Organ surface. Small areas of Haplustolls (Aladdin soils) border the northern part of the Doila Ana Mountains.

SOILS OF BASIN FLOOR NORTH OF US-70—No. *17, StellarReagan-Algerita association (Haplargid-Calciorthid association)—This* area is level or nearly level, and much of it receives runoff from adjacent slopes of the fan piedmont. Slight ridges occur in the northern and southern part of the basin floor.

Haplargids (Stellar soils) of Jornada I age have formed in low-carbonate sediments derived mainly from the Doi·% Ana Mountains. Calciorthids (Algerita soils) of Jornada I and La Mesa age have formed in low-carbonate sediments of the ancestral Rio Grande and occur mainly in the center of the basin floor where it widens to the north. Other Calciorthids (Reagan soils) occur on the eastern side of the basin floor (Petts Tank surface) and have formed in high-carbonate sediments from the San Andres Mountains. Torrerts (Dalby taxadjunct) occur in Isaacks Lake playa and in a small playa east of the New Mexico State University Ranch.

No. 18, Rock outcrop and soils—This mapping unit consists primarily of bedrock outcrops in and adjacent to the mountains. Discontinuous areas of soils occur between the outcrops. In areas of noncalcareous bedrock the soils are dominantly Argids. Where the bedrock is high in carbonate the soils are primarily Entisols.

Part II

Field study sessions

Location of the study areas is shown in fig. 16. Large-scale soil maps on aerial photographs establish the pedogenic setting for the study areas. The aerial photographs were taken in 1936 except for areas 5 and 7. The latter photographs were taken in 1967. To assist in location of the study areas, roads that postdate the photographs have been added at appropriate places.

Names of soil mapping units indicate only major soils; other soils also occur in the mapping units. Geomorphic surface names that follow names of soil mapping units indicate dominant surfaces in the units. Geomorphic maps on a topographic base are also presented for many of the study areas. Summary tables of laboratory data for one or more soils at or near the sites to be examined are presented for most of the study areas. All of the laboratory data and descriptions of the sampled pedons are in the Desert Project Soil Monograph (Gile and Grossman, 1979). The soils were sampled and described at various times during and since 1959. Reexcavation of trenches has resulted in some differences in horizon thickness; but, in most instances, analogues of the sampled horizons are still available for study.

The tour route and a table summarizing features to be seen are presented in the first part of the text for each day's study tour. Several kinds of illustrations at various scales are used. These are to assist the participant in visualizing first the Desert Project as a whole and then the individual study areas. By studying figures the participant can 1) become oriented in terms of the general physiography and soil patterns of the Desert Project (general soil map); 2) see the soil patterns on a larger scale and their relation to geomorphic surfaces (geomorphic and large-scale soil maps); 3) visualize the study area in its stratigraphic setting (the cross section beneath or following the soil map); and, in many cases, 4) view the soils to be examined (soil photographs).

The written text for each study area is organized beneath the following headings: summary of pedogenic features; setting; soil occurrence; and study area number and title. In addition, some study areas and road logs have separate discussion sections.

SUMMARY OF PEDOGENIC FEATURES—The first paragraph summarizes major pedogenic features that are not listed in the preceding summary table and that are illustrated by the study area as a whole.

SETTING—Statements on the location, geomorphology, depth to water table (where known), and vegetation are given here.

SOIL OCCURRENCE—This section presents information on soil classification and occurrence in the vicinity of the study area.

NUMBER AND TITLE OF STUDY AREA—Discussion of the specific pedon and landscape to be examined is given here. Most study areas consist of more than one part; the components are designated a, b, c . . . f.

Day 1

Entisols and Aridisols of a stepped sequence along valley border (low-carbonate materials); valley-border Entisols and Aridisols (high-carbonate materials)

Sites to be visited are on both sides of the Rio Grande valley (fig. 17). Some features of soils to be seen on Day 1 are summarized in table 37.

SOIL CHRONOLOGY AND VALLEY-BORDER STEPPED SEQUENCE

Fig. 18 is a cross section of the stepped sequence of surfaces along the valley border (see also fig. 7). The relative ages of soils of stable surfaces are demonstrated by their position in the stepped sequence: the soils are progressively older on the progressively higher surfaces. But the situation is different in strongly dissected landscapes (area 2), where ridges are very narrow and the genetic horizons of whole soils may have been truncated. In such areas young soils can occur high in the dissected landscape, above the older soils of stable surfaces (for example, area 19).

The stages of carbonate accumulation are useful as chronological and stratigraphic markers for the soils (3.61). Table 38 summarizes the stages of carbonate accumulation for soils of the valley border. Soils of all ages except Leasburg will be seen.

Mile

0.0 Assembly point. Espina and Frenger Streets southeast of New Mexico State University Agriculture Building. *Drive south on Espina,* ascending from the river floodplain to the toe of a Fillmore fan surface. The Fillmore unit is usually separated from the Mesilla Valley floor by a low scarp formed by channel trimming of fan toeslopes during recent shifts of the Rio Grande meander belt. **0.4**

0.4 Intersection of Espina and Wells Streets. *Turn left (east) on Wells.* Tortugas Mountain straight ahead. **0.3**

0.7 Stop sign. Continue east on Wells Street across Williams Avenue. 0.1

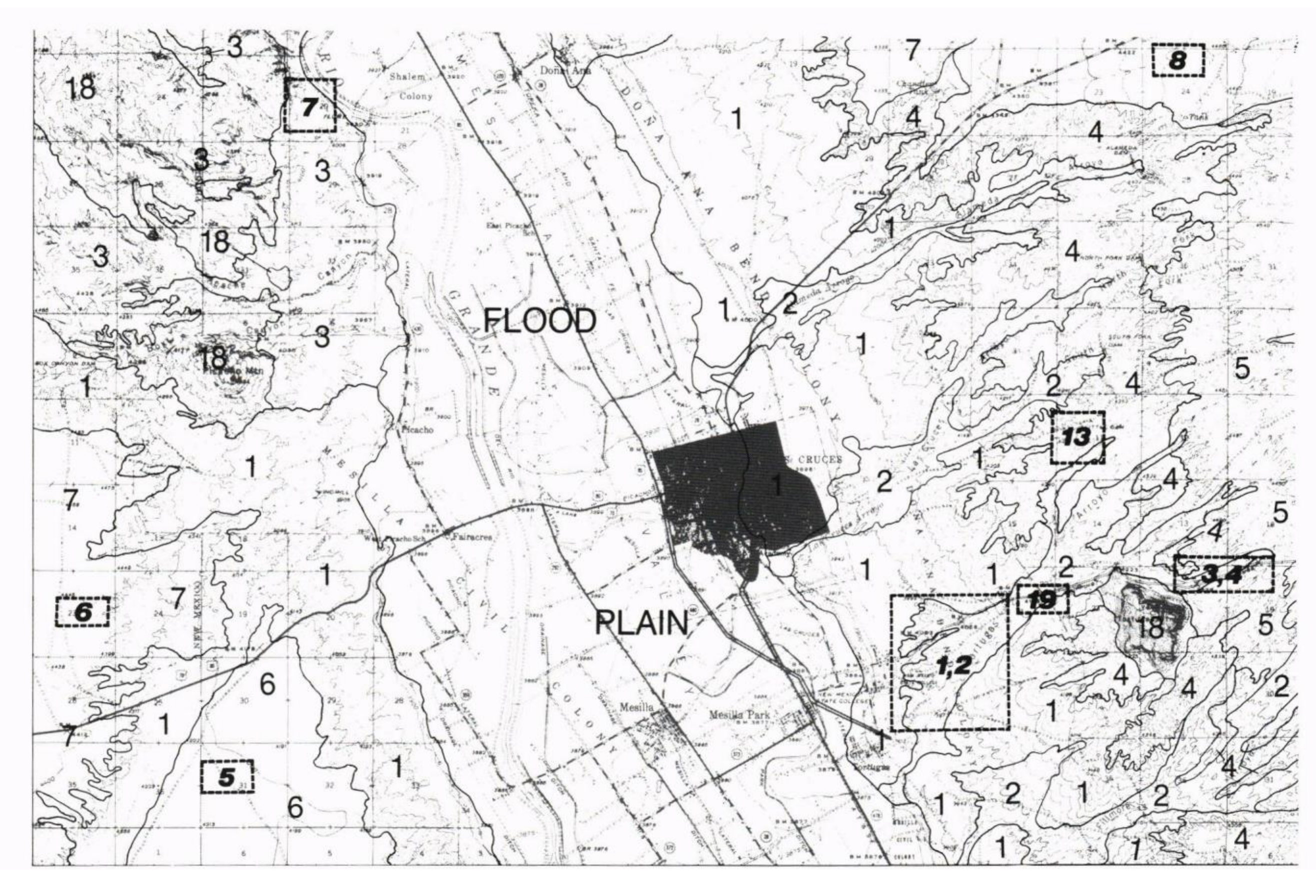


FIGURE 17—LOCATION OF STUDY AREAS 1-7, DAY 1. Explanation for this part of the general soil map (fig. 16):
1 Bluepoint association (Torripsamment association) of the Fillmore surface.
2 Nickel-Arizo-Kokan complex (Calciorthid-Torriorthent complex) of the Fillmore and Picacho surfaces.
3 Tencee-Upton-Dalian complex (Paleorthid-Torriorthent complex) of the Picacho and Fillmore surfaces.
4 Caliza-Haplargids complex (Calciorthid-Haplargid complex) of the Fillmore, Picacho, and Jornada I surfaces.
5 Monterosa-Algerita complex (Paleorthid-Calciorthid complex) of the Jornada I and Fillmore surfaces.
6 Onite-Pintura complex (Haplargid-Torripsamment complex) of La Mesa surface and coppice dunes.
7 Cruces association (Paleargid association) of La Mesa surface.
18 Rock outcrop and soils of mountain slopes and summits, undifferentiated.

TABLE 37—FEATURES **OF SOILS AND LANDSCAPES AT STUDY AREAS** 1-7, **DAY** 1. Precipitation estimated from records at University Park. Trenches are closed unless otherwise indicated; due to construction in vicinity of study area 1, the soil to be seen depends on the site available at the time of the field study. Symbols: s, sandy; c-1, coarse-loamy; f-1, fine-loamy; s-sk, sandy skeletal; l-sk, loamy skeletal; m, mixed mineralogy; c, carbonatic mineralogy; sh, shallow. All soils are thermic. Aridisols and many Entisols have an ochric epipedon, not listed here because it is not a separator of the soils concerned.

Study area	Precipitation (in., cm), elev. (ft)	Parent materials derived primarily from:	Geomorphic surface and age	Landform and percent slope	Nature of exposure	Classification: Subgroup	Classification: Family	Classification: Series	Diagnostic horizons	Stage of carbonate accumulation
1	8, 20 3,960	Noncalcareous sand; rhyolite, andesite	Fillmore Holocene	Fan, 2	South bank of abandoned arroyo	Typic Torriorthent, Torripsamment, or Torrifluvent	s-sk s, m	Bluepoint, Arizo, Yturbide, or Vinton, gravelly variant	None	I
2 a,b	8, 20 4,100	Noncalcareous sand; rhyolite, andesite	Picacho late Pleistocene	**a** Ridge crest, 2 **b** Drainageway, 4	Trench	**a** Typic Haplargid **b** Typic Calciorthid	f-1, m c-1, m	Dona Ana Whitlock	Argillic, calcic Calcic	III III
3 a-e	8, 20 4,320	Rhyolite	**a** Fillmore Holocene	**a** Terrace, 2	**a** Trench	**a** Typic Camborthid	s-sk, m	Vado, s-sk variant	Cambic	I
			b-e Picacho late Pleistocene	**b,c** Terrace crest, 2 **d,e** Terrace shoulder, 3	**b,c** Trench **d,e** North bank of arroyo	**b** Petrocalcic Paleargid **c** Ustollic Haplargid **d** Petrocalcic Ustollic Paleargid **e** Typic Paleorthid	l-sk, m, sh l-sk, m l-sk, m, sh l-sk, m, sh	Cruces, l-sk variant Nolam Casito Delnorte	Argillic, petrocalcic Argillic, calcic Argillic, petrocalcic Petrocalcic	IV III III IV
4	8, 20 4,400	Rhyolite	Jornada I late middle Pleistocene	Side of slight ridge, 2	Trench	Ustollic Paleorthid	l-sk, m, sh	Monterosa	Petrocalcic	IV
5 a-c	8, 20 4,200	Noncalcareous sand	**a** lower La Mesa middle Pleistocene	**a** Relict basin floor, nearly level	Trenches	**a** Typic Haplargid	c-l, m	Onite, deep petrocalcic phase	Argillic	III
			b (Dune)* Historical	**b** Dune		**b** Typic Torripsamment	m	Pintura	None	—
			c lower La Mesa middle Pleistocene	**c** Depression in basin floor, level		**c** Typic Haplargid	f-l, m	Bucklebar	Argillic, calcic	III
6 a,b	8, 20 4,440	Noncalcareous sand	upper La Mesa middle Pleistocene	Relict basin floor, nearly level	South bank of ditch, open	**a** Petrocalcic Paleargid **b** Typic Haplargid	l, m, sh f-l, m	Cruces Bucklebar	Argillic, petrocalcic Argillic	IV II
7 a-c	8, 20 3,950 4,000	Limestone, sandstone	**a,b** Fillmore Holocene	**a** Terrace, 5 **b** Colluvial wedge, 40	**a** North bank of arroyo **b** Cut in ridge side	**a** Typic Torriorthent **b** Typic Torriorthent	l-sk, c l-sk, c	Dalian Dalian	None None	I I
			c Picacho late Pleistocene	**c** Ridge remnant of fan, 4	**c** Trench, open	**c** Typic Paleorthid	l-sk, c, sh	Tencee	Petrocalcic	IV

*Not designated by a formal geomorphic surface name.

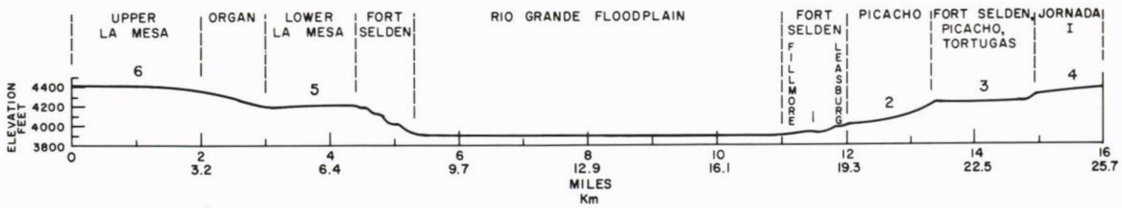


FIGURE 18—DIAGRAMMATIC CROSS SECTION OF GEOMORPHIC SURFACES, AREAS 1–6. Relative position in the stepped sequence of valley-border surfaces is shown. Study area 7 is on the west side of the valley north of the section.

0.8 University Physical Plant and Fire Department complex. *Turn right;* proceed south about 0.2 mi to northwest edge of abandoned airport facility. 0.1

0.9 STUDY AREA 1. Park and walk to study trench south of road.

STUDY AREA 1

Torrifluvents, Torriorthents, and Torripsamments of the Fillmore surface

SUMMARY OF PEDOGENIC FEATURES (see table 37)—Stage I carbonate horizon, typical of Holocene soils in the arid zone; atmospheric additions of calcium during soil development; pedogenic horizons that do not qualify as diagnostic horizons for soil classification; soil moisture and temperature for a Torriorthent.

SETTING—To the east is Tortugas ("A") Mountain, a fault block of Permian limestone. East of Tortugas Mountain, the Organ Mountains are on the skyline. The light-colored, highest peaks are monzonite; the dark-colored mass to the south is rhyolite.

Fig. 19 shows the geomorphic setting for areas 1 and 2. Area 1 illustrates soils and landscapes of the Fillmore member of the Fort Selden surface complex (2.62, table 9). The Fill-more is the youngest of the valley-border surfaces above the floodplain and arroyo channels (fig. 7). Here the Fillmore is an alluvial-fan surface at the mouth of the valley of Tortugas Arroyo. Slope is 2 percent to the west.

These sediments were derived primarily from basin-fill deposits of the Camp Rice Formation, including gravelly piedmont-slope alluvium originally derived from the southern Organ Mountains (mainly rhyolite with minor andesite and monzonite) and sandy to gravelly ancestral Rio Grande deposits of mixed lithology (but essentially no carbonates). Lenses of charcoal in Fillmore alluvium, at a depth of approximately 1 m, have been dated on both sides of the Rio Grande valley. These dates range from 2,600 to 4,000 yrs B.P. (tables 8 and 10). Nearly all soils of the Fillmore must therefore have formed under a climate very similar to the present one (Mehringer, 1967).

The water table is approximately 150 ft (45 m) below the arroyo floor (fig. 9) and has not been appreciably higher during the Holocene. Vegetation consists primarily of creosote-bush and a few prickly pear.

SOIL OCCURRENCE—Because of New Mexico State University expansion, many soils shown in fig. 20 no longer exist. In parts of mapping unit A that are still preserved, the occurrence of soils of the suborder concerned (Orthents, Psamments, or Fluvents) depends upon particle size and the amount and distribution of organic carbon (3.1). Torripsamments (Bluepoint soils), Torriorthents (Arizo soils), and Entisols (materials in arroyo channel) dominate mapping unit A as a whole (fig. 20). Torrifluvents also occur, primarily in the southwest part of the mapping unit (fig. 20), in the vicinity of study area 1. Because of continuing construction, the soil available for study at any given time depends upon the area available. For this reason, Torripsamments, Torriorthents, and Torrifluvents will all be discussed at area 1.

The materials of arroyo channels have been designated Entisols because they have not been studied in enough detail over the area of their occurrence to establish a dominant category below that of soil order. However, the sediments are genetically significant because they must be similar to the soil parent materials of adjacent older surfaces. The sediments are generally stratified and have a high proportion of sand and/or gravel. Authigenic carbonate in gravelly arroyo deposits is restricted to a few discontinuous, thin flakes on some of the pebbles. A few pebbles with thick, commonly discontinuous coatings occur in places and could only have been derived from some carbonate horizon upstream. Such thickly coated

TABLE 38—STAGES OF CARBONATE ACCUMULATION FOR SOILS OF THE VALLEY BORDER.

Stage: Nongravelly soils	Stage: Gravelly soils	Youngest geomorphic surface on which stage of horizon occurs, and age	
I	I	Fillmore	100 to 7,000 yrs B.P.
II	II, III	Leasburg	Early Holocene-latest Pleistocene
III	III, IV	Picacho	Late Pleistocene
III	IV (multiple laminar zones)	Jornada I	Late middle Pleistocene
IV		La Mesa	Middle Pleistocene

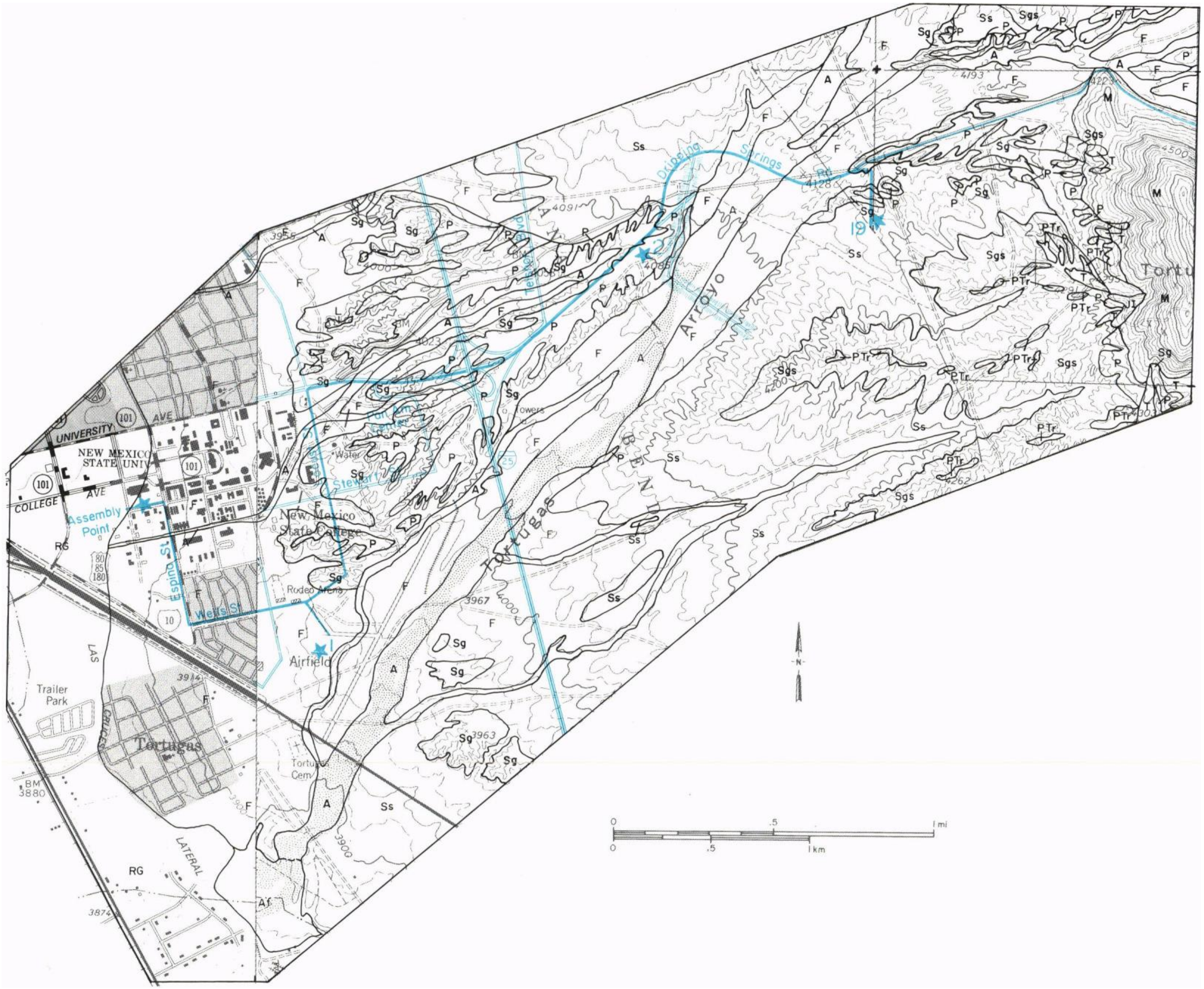


FIGURE 19-GEOMORPHIC SURFACES AND STRATIGRAPHIC UNITS, AREAS 1, 2, AND 19.

EXPLANATION

RG Rio Grande floodplain and abandoned-channel surfaces, underlain by as much as 80 ft (24 m) of upper Quaternary fluvial deposits.

A Arroyo surfaces (major channel areas). Associated sediments of Historical age partly fill channels cut into Fillmore and older units; minor inclusions of Fillmore morphostratigraphic unit; mixed lithology.

F Fillmore surface (constructional phase). Valley-border fan and terrace surfaces graded to local base level approximated by the present floodplain surface. Underlain by sandy to gravelly alluvial deposits of the Fillmore morphostratigraphic unit (Holocene); minor inclusions of arroyo-channel and Picacho alluviums; mixed lithology.

L Leasburg surface. Complex of small erosion-surface remnants of latest Pleistocene to early Holocene age; cut in Picacho alluvium; minor constructional surface inclusions and associated alluvial fills.

Sg, Ss, Sgs Fort Selden Group surfaces. Leasburg and Fillmore undifferentiated, and arroyo-tributary channels.

Sg—Complex of erosional surfaces, in ridge-sideslope and channel-floor positions, cut into gravelly Picacho fan and terrace alluvium; minor constructional-surface inclusions and associated thin colluvial-alluvial fills.

Ss—Complex of erosional surfaces, in lower ridge-sideslope and footslope positions, cut into sandy deposits of the Camp Rice Formation fluvial facies; with minor constructional surface inclusions and associated thin alluvial-colluvial fills.

Sgs—Complex of erosional surfaces, in upper ridge-sideslope and ridgecrest positions (structural benches), cut into gravelly deposits of the Camp Rice Formation fluvial facies. Includes some ridge-summit remnants of Picacho age and thin colluvial fills.

P Picacho surface (constructional phase). Valley-border fan and terrace surfaces graded to an ancestral floodplain level about 70 ft (21 m) above present valley floor. Underlain by gravelly to sandy alluvial deposits of mixed lithology of the Picacho morphostratigraphic unit (late Pleistocene).

T Tortugas surface (constructional phase). Small remnants of valley-border fan and terrace surfaces graded to ancestral floodplain levels 120 ft (36 m) or more above present valley floor. Underlain by thin, gravelly alluvial deposits of the Tortugas morphostratigraphic unit (late Pleistocene). Gravel lithology mainly limestone.

PTr Picacho-Tortugas surface complex (erosional phase). Small, relatively stable summit areas of structural benches underlain by erosion-resistant gravelly deposits of the Camp Rice Formation fluvial facies; intermediate between Fort Selden and Jornada I surfaces.

JI Jornada I surface (constructional phase). Piedmont-slope complex of middle Pleistocene age graded to ancestral basin-floor levels (La Mesa) 300 to 350 ft (91–107 m) above present valley floor. Underlain by gravelly to loamy alluvial-fan deposits of the Camp Rice Formation younger piedmont facies that overlap and intertongue with gravel and sand of the Camp Rice fluvial facies; gravel lithology mainly limestone.

M Tortugas Mountain slopes. Complex of erosion surfaces and minor slope deposits of Quaternary age on limestone of the Hueco Formation (Permian).

FIGURE 20—MAP OF SOILS IN VICINITY OF AREAS 1 AND 2. A, Bluepoint-Arizo-Entisol complex (Fillmore and arroyo channel surfaces); B, Bluepoint sand (Fillmore and Fort Selden, undifferentiated surfaces); C, Kokan-Nickel-Entisol complex (Fort Selden, Picacho, and arroyo channel surfaces); D, Whitlock sandy loam (Picacho surface).

pebbles are distributed randomly throughout the channel sediments instead of in a horizon.

Torriorthent, Torripsamment, or Torrifluvent in Fillmore alluvium

An intent of the suborder Psamments is to separate the soils that are readily susceptible to wind erosion. As gravel content increases, resistance to blowing increases because a gravelly pavement forms at the surface. Thus, separation of the Psamments from the sandy Orthents is based on gravel content. The Bluepoint soils, Torripsamments, average less than 15 percent gravel in the control section (see area 19 for another illustration of the Psamments and laboratory data). The sandy Orthents have 35 percent or more rock fragments by volume in some subhorizon between 25- and 100-cm depth.

Because the Orthents have more rock fragments, Orthents are more resistant to blowing and support wheeled vehicles better than the Psamments. Yturbide soils, Torriorthents (see 3.17 for discussion of the classification of this soil), average between 15 and 35 percent gravel in the control section; and some subhorizon in the control section has more than 35 percent rock fragments by volume. Arizo soils are sandy-skeletal, thus average more than 35 percent rock fragments in the control section.

Fig. 21 shows Torrifluvents at area 1 as it appeared in December 1976. That the soil surface has probably been disturbed is indicated by adjacent roads and nearby dump materials.

No laboratory data are available at this site, but morphological information for a pedon at the eastern side of the exposure in December 1976 is given in table 39. The soil is calcareous throughout, although effervescence with HC1 is only slight in the A horizon. The carbonate maximum starts at 11 cm depth. Thus a cambic horizon is not present because its base must be at least 25 cm below the surface and it must have less carbonate than the underlying ca horizon (3.13). (A horizon thick enough to qualify as cambic will be seen in the Camborthid at area 3a.) There is not enough carbonate for a calcic horizon, and the soil is therefore an Entisol (3.13). Organic carbon and clay contents are closely related in soil horizons (3.5). Thus, the gravelly sand underlain by fine sandy loam at a depth of 50 to 66 cm (table 39) indicates that organic carbon decreases irregularly with depth and that the soil is a Torrifluvent.

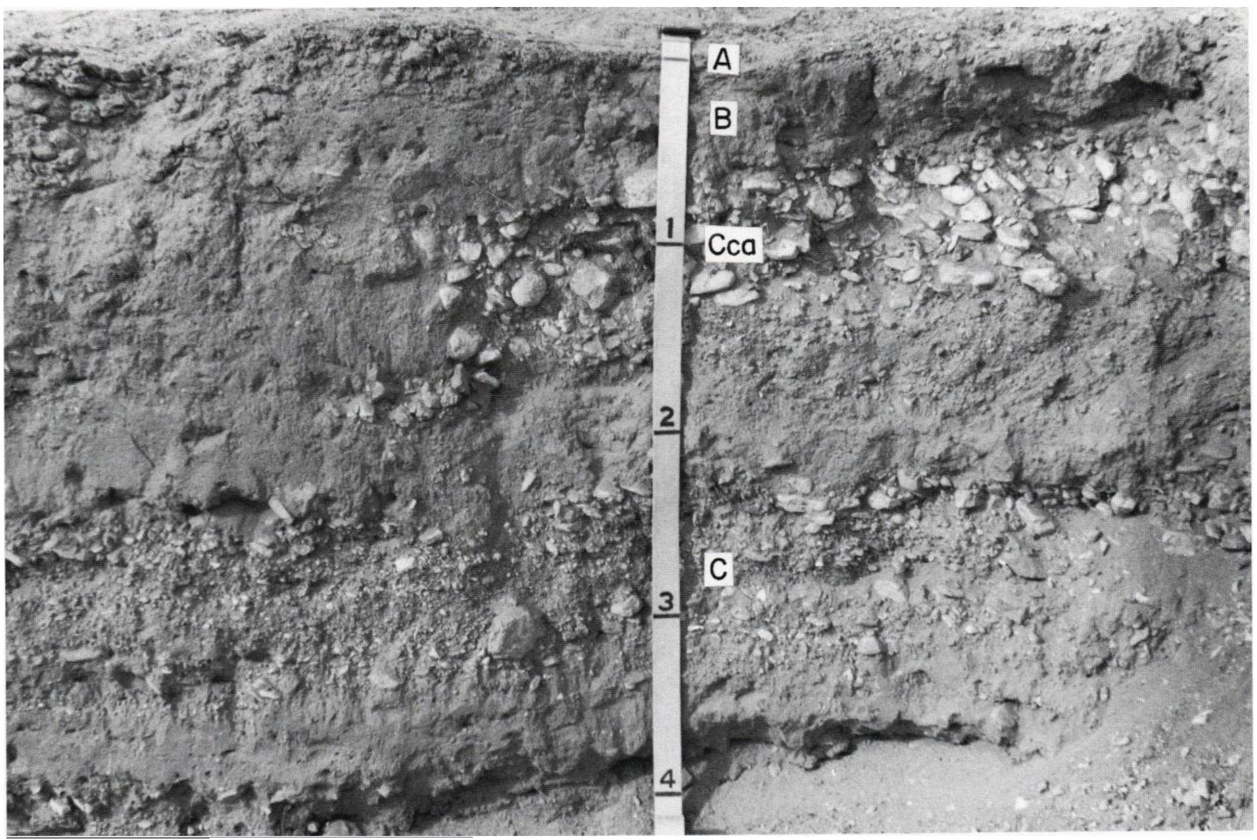


FIGURE 21-FILLMORE SURFACE AND A TORRIFLUVENT AT AREA 1. *Upper view:* landscape of a Typic Torrifluvent on the Fillmore surface; vegetation is creosotebush; La Mesa surface and Picacho Peak are on skyline. *Lower view:* Vinton, gravelly variant in Fillmore alluvium; pebbles in the gravelly stage I carbonate horizon (right, upper) are continuously coated with carbonate. Scale in feet (photographed December 1976).

However, erosion of the exposure since 1976 showed a facies change in the 50-66 cm zone. By September 1979, the fine sandy loam had graded to a zone dominated by loamy sand and sand. In this situation a regular rather than irregular decrease in organic carbon would be expected, and the soil would be a Torriorthent (Yturbide) instead of a Torrifluvent. The facies change shows the incipient nature of Torrifluvents in the vicinity of study area 1. In the project area, Torrifluvents are more extensive where finer-textured materials at depth are thicker and continuous (area 12).

The pedon at area 1 illustrates the stage I carbonate horizon typical of Holocene soils of the arid zone. Pebbles in the stage I horizon are thinly but continuously coated with carbonate, and much less carbonate is visible in the C-horizon material beneath. The carbonate coatings are largely to wholly illuvial; a few pebbles have thick but partial carbonate coatings that could only have come from some carbonate horizon upstream. The soil has formed in low-carbonate parent materials, and most of the illuvial carbonate was probably derived from calcareous dustfall (3.3 and 3.6). C-14 dates of buried charcoal, discussed earlier (table 10), indicate that the stage I horizon is of late Holocene age and that it is presently forming.

The carbonate is much more visible in the high-gravel zone than in the low-gravel facies just to the west because of the low surface area and pore space in high-gravel materials. The carbonate is easier to see on the pebble surfaces than diffused throughout fine earth in the adjacent low-gravel zone.

TABLE 39—MORPHOLOGICAL INFORMATION FOR A TORRIFLUVENT.

Horizon	Depth cm	Hue	Value/chroma Dry	Moist	Texture	Structure	Dry consistence
A	0-4	10YR	6/3	4/3	ls	m	s
B1	4-11	10YR	5.5/3	4/3	sl	m	sh
B2ca	11-17	10YR	5.5/3	4/3	sl	m	sh
2C1ca	17-36	10YR	6/2	5/3	vgls	m,sg	s,l
2C2ca	36-50	10YR	6/2	4/3	gs	m	sh
3C3	50-57	10YR	6/2	4/2	fsl	m	s
3C4	57-66	10YR	6/3	4/3	fsl	m	s
4C5	66-94	10YR	6/3	4/3	vgs,gs	m,sg	s,l
5C6	94-108	10YR	6/3.5	4/3.5	s	m	s
5C7	108-123	10YR	6.5/2	4.5/2	gs	m,sg	s,l

Soil moisture and temperature for a Torriorthent

A study of soil moisture in the Jornada Experimental Range (Herbel and Gile, 1973) illustrates soil moisture conditions for some of the soils in the area. Table 40 shows soil moisture, morphology, and setting for a Torriorthent in the experimental range; the setting at area 1 is similar. Textures of upper horizons are also similar.

During 1960-1970, soil moisture was recorded at depths of 10, 25, 40, 60, and 90 cm. The number of days when the moisture potential was between 0 and -15 bars (referred to as moist days) at each depth was determined for each year. The average number of moist days per year ranged from 129.9 days at the 10-cm depth to only 6.6 days at the 90-cm depth. During a wet year, 1961, there were 251 moist days at the 25-cm depth. Only the number of days with soil moisture at 10- and 60-cm depths was significantly correlated to annual precipitation, probably because there is runoff from the area.

The number of moist days (table 40) is sufficiently low that the Torriorthent easily meets the requirements of the torric moisture regime (3.1). The study indicates that most soils in the arid part of the study area meet the requirements of the aridic (and torric) moisture regimes. See Gile and Grossman (1979) and discussions at areas 6 and 17 for further information on soil moisture.

TABLE 40—SOIL MOISTURE, SOIL MORPHOLOGY, AND SETTING FOR A TYPIC TORRIORTHENT; complete soil description in Herbel and Gile, (1973). Days—number of days annually with the moisture potential between 0 and −15 bars.

Soil series: Canutio, loamy subsoil variant

Classification: Typic Torriorthent, coarse-loamy, mixed, thermic

Landscape position and parent material: Fan-piedmont sloping 2 percent; sediments from monzonite, rhyolite, andesite

Geomorphic surface and age: Organ, Holocene

Dominant vegetation: Creosotebush (*Larrea tridentata*)

Annual precipitation 1960–1970 (cm): Mean 20.8; range 10.5–32.5 (excluding daily amounts less than 0.63 cm)

Horizon and depth, cm	Soil morphology (in part)	Soil moisture (days) at stated depths: the mean, range, and simple correlation (r) between annual precipitation and days of moisture at each depth	
A2, 0–4	Fine, sandy loam, platy, crumb, soft, loose, noncalcareous	10 cm	129.9 29–227 0.61
B, 4–20	Gravelly sandy loam, massive, slightly hard, noncalcareous	25 cm	107.7 1–251 0.54
2C1ca, 20–33	Very gravelly sandy loam, massive, soft, calcareous	40 cm	60.8 0–304 0.56
3C2ca, 33–52	Gravelly sandy loam, blocky, slightly hard, calcareous	60 cm	58.5 0–224 0.67
3C3ca, 52–67	Gravelly sandy loam, massive, soft, calcareous		
3Btcab, 67–80	Gravelly sandy clay loam, blocky, slightly hard, calcareous	90 cm	6.6 0–41 0.52
4K & Ccab, 80–102	Gravelly sandy loam, massive, slightly hard, calcareous	20–30 cm*	108
5Btcab2, 102–123	Gravelly sandy clay loam, blocky, hard, calcareous	not measured	

*The 10 cm of the moisture control section (from 20 to 60 cm in these soils) that is wetted for the longest cumulative time.

TABLE 41—SOIL TEMPERATURES (FAHRENHEIT) FOR A TYPIC TORRIORTHENT, CANUTIO, LOAMY SUBSOIL VARIANT (unpublished data, courtesy of Carlton Herbel, Agricultural Research Service, U.S. Department of Agriculture).

Depth, cm	Temp. at 1:10 PM Aug. 16, 1968	Temp. at 1:05 PM, Jan. 1, 1972
3	108	51
8	90	42
13	84	41
18	83	44
23	83	44
30	83	40

Soil temperature was also measured for the Torriorthent in the experimental range (table 41). Note the very high temperatures at the soil surface in August. These high temperatures are thought to have caused these features in the upper few centimeters of many soils: low content of organic carbon; higher bulk density than in horizons below; and scarcity of roots and soil fauna.

En route to study area 2. *Return to Wells Street. 0.1* 1.0

Turn right; continue east on Wells. 0.2

1.2 Intersection; *turn left (north) on Locust Street.* Most of large Picacho fan remnant originally present in the area to the northeast has been removed for construction purposes. 0.2

1.4 Four-way stop. *Turn right (east) on Stewart Street.* 0.4

1.8 Intersection. *Turn left on Payne Street* and continue north around Pan American Center. 0.4

2.2 Stop sign. *Turn right (east) on University Avenue* (NM-101). Several remnants of the Picacho fan are preserved to the north. Fort Selden hillslope-erosion surfaces (mainly Fillmore) bevel Picacho deposits. 0.3

2.5 Crossing 1-25 overpass. 0.4

2.9 Intersection; Telshor Boulevard and Las Cruces Hospital to left; University Golf Course entrance to right. Continue 0.3 mi east on Dripping Springs Road (Dona Ana County road C-77) and park on south side of road. 0.3

EFFECT OF DISSECTION ON GEOMORPHIC SURFACES AND SOILS

Dissection significantly affects geomorphic surfaces and soils, particularly adjacent to large river valleys such as the Rio Grande. As a large valley evolves and drainage networks of the valley border expand, the main areas affected by tributary-stream dissection are the interfluve-summit, shoulder and backslope components of a typical hillslope sequence (2.11, fig. 3). Fig. 22 shows classes of dissection that are defined in table 42. Fig. 23 shows the position of soils and diagnostic horizons at area 2, which illustrates class 3 of landscape dissection. See area 4 for an illustration of class 4 dissection and area 13 for an example of class 5.

Boundaries between geomorphic surfaces may be readily identified in *stable areas* little affected by dissection (2.13). In dissected terrains the situation is different because large volumes of sediment have been eroded from the soils and sediments associated with a given surface; and the amount that has been removed varies from one place to another. Fig. 23 illustrates this kind of boundary between geomorphic surfaces.

At area 2 (fig. 23) the geomorphic change is from Picacho to the Fillmore surface and is identified by a combination of geomorphic and soil evidence. Dissection has resulted in a landscape dominated by ridges. The boundary between the Picacho and the Fillmore surfaces (also the boundary between Calciorthids and Torriorthents) coincides with truncation of the calcic horizon (fig. 23).

The change from one surface to another and its relation to soils is quite distinct on the sides of ridges (fig. 23) but is less obvious on ridge crests. Remnants of the Picacho surface and its soils are preserved only on broadest ridge crests. The ridge crests are nearly level transversely and have a consistent longitudinal slope of approximately 2 percent. This slope accords with the general projection of the gradient of stable arroyo-terrace remnants of the Picacho surface to the east. The interfluves are crossed by small drainageways that truncate upper horizons of the soils and of the uppermost part of Picacho alluvium. However, saddles (which would indicate breaching of the Picacho surface and all horizons of its soils) are absent. The scattered small drainageways do not completely truncate the lowermost diagnostic horizon (the calcic horizon).

Removal of all evidence of the Picacho surface and its soils is accomplished by continuation of the dissection process. Further dissection beyond class 3 is marked by rounding of ridge crests, narrowing of ridge remnants, development of saddles, and truncation of the calcic horizon. Then the Fill-more surface and its soils occur on ridge crests as well as on ridge sides.

DESERT PAVEMENT AND DESERT VARNISH

This site also illustrates another feature present at the surface of many desert soils—a *desert pavement.* This term designates a surface dominated by coarse fragments, which may be due to several factors. In very gravelly materials the pavement is caused by the presence of pebbles in the deposit. But many soils have prominent concentrations of pebbles at the surface and few or no pebbles for a few centimeters beneath the surface. Springer (1958) postulated that the pebbles are lifted slightly when the soil swells after it is moistened. The soil shrinks when it dries, forming cracks in the fine earth. Pebbles cannot move into the cracks because of their size, but fine earth can. If this process is repeated many times, swelling of the fine earth when it is wetted would lead to upward thrust. Over time, many pebbles would move to the surface, resulting in a subsurface zone free or nearly free of pebbles. Freezing and thawing would produce a similar effect (Springer, 1958). Since both wetting-and-drying and freezingand-thawing cycles are common in the project area, these processes are at least partly responsible for surficial concentrations of gravel where it is underlain by nongravelly horizons.

In other instances the concentration of pebbles is due to erosion of fine earth—apparently the case at study area 2, where drainageways have incised Picacho alluvium. Erosion of the fine earth has resulted in a concentration of gravel (termed lag gravel) on the surface, and this constitutes the desert pavement.

Black coatings, called *desert varnish,* occur on many pebbles at the soil surface. Engel and Sharp (1958) and Hooke and others (1969) have found desert varnish to consist primarily of iron and manganese oxides. More recently, Potter and

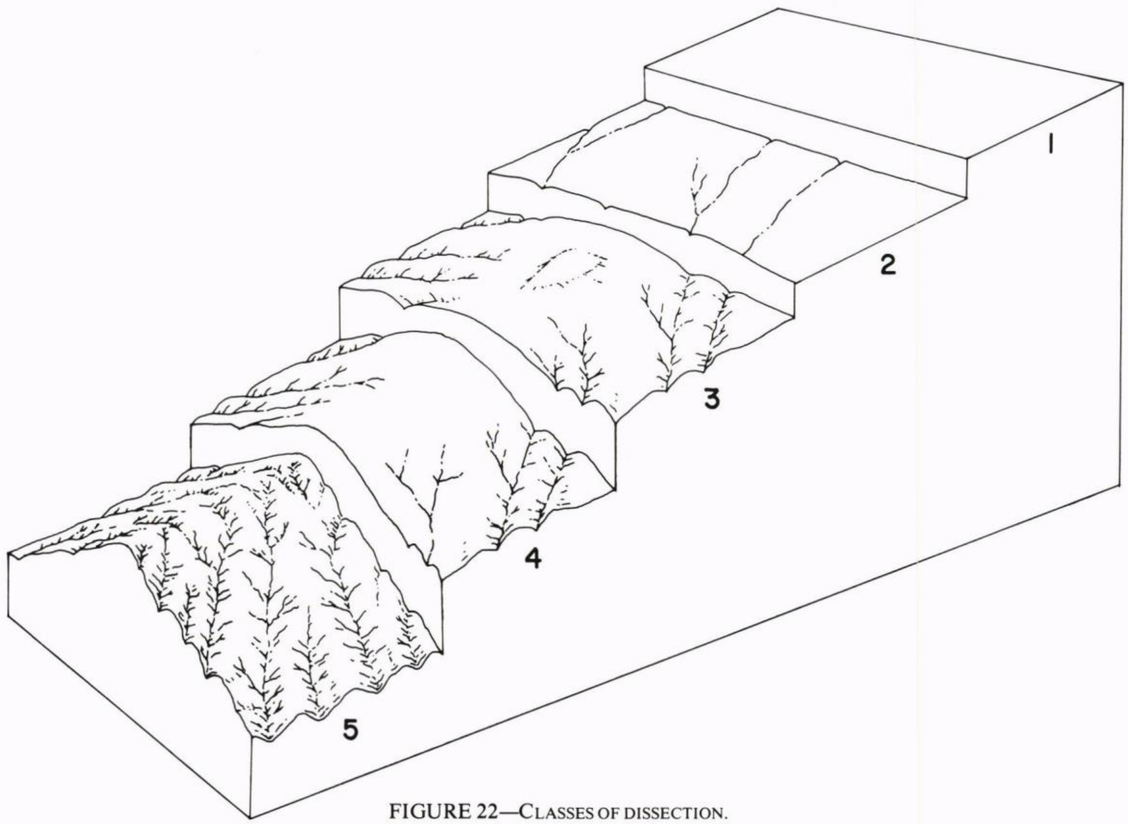


FIGURE 22—CLASSES OF DISSECTION.

Rossman (1977) found varnish in the Mojave Desert to consist primarily (more than 70 percent) of clay minerals, with the remainder dominantly iron and manganese oxides dispersed throughout the clay. They indicate that the varnish clay contains major amounts of discrete illite and mixed-layer illite-montmorillonite, with small amounts of kaolinite and, in some instances, chlorite. They believe that the varnish material is derived from sources external to the rock because they found varnish in places where it could not have formed by alteration of the underlying material (such as quartz). Clay in dustfall may be a source of some of the varnish material.

3.2 STUDY AREA 2. *Cross fence and walk south* to the westernmost of two trenches (fig. 20).

STUDY AREA 2

Haplargids and Calciorthids of the Picacho surface

SUMMARY OF PEDOGENIC FEATURES (table 37)—Reddishbrown and red parts of the Bt horizon as a marker of the argillic horizon in desert soils; all subhorizons of the argillic horizon have some macroscopic carbonate; carbonate engulfment of the lower part of a formerly thicker argillic horizon, a typical feature of Argids of Pleistocene age; soil truncation and genesis of Calciorthids; the calcic horizon, diagnostic at the great group level in the Calciorthids and at the series level in the Haplargids; radiocarbon age of morphologically oldest carbonate in a soil on the Picacho surface.

TABLE 42—CLASSES OF DISSECTION ALONG AND NEAR THE VALLEY BORDER.

Class	Character of landscape and soils
1	These areas may be level (as in a basin floor) or sloping (as on a fan piedmont), but they are marked by the absence of incised drains and by the preservation of essentially all soil horizons. All diagnostic horizons are present and soil classification has not been changed by dissection and associated soil truncation.
2	These areas are dissected by drains a few centimeters to a meter or more deep, but interfluves between the drains are level transversely. Diagnostic soil horizons have been truncated only in the drains. Classification of soils between the drains has not been changed by truncation associated with the dissection. Intervals between drains commonly range from about 50 to 200 m.
3	Essentially no part of the interfluve is level transversely; ridge crests are rounded. In the arid part of the study area, argillic horizons (if present in adjacent undissected sites) have commonly been truncated or carbonate engulfed, although a few islands of soils with argillic horizons may remain. Other diagnostic horizons (calcic or petrocalcic horizons) are still present. These areas are usually characterized by slight ridges, but the ridges are not deeply dissected or steep except along their margins.
4	Ridges are prominent. Major genetic horizons—the calcic or petrocalcic horizons—are still preserved on ridge crests. Slope of ridge sides commonly ranges from 10 to 40 percent. On soils and landscapes older than late Pleistocene, calcic or petrocalcic horizons also may be present on ridge sides that slope less than about 20 percent. Saddles (formed by joining of drainageways in ridge sides) in ridge crests are not present or are very sparse, and a consistent longitudinal slope usually occurs along ridge crests.
5	Saddles are common in ridge crests; the original ridge crests have been largely or wholly obliterated. Slope of ridge sides usually ranges from 20 to 50 percent. Calcic or petrocalcic horizons occur only in scattered, best-preserved places along the ridge crests. There is no consistent longitudinal slope along ridge crests because of the numerous saddles. Substantial downwearing of former ridge crests has occurred in the most advanced stages, and soils of both ridge crests and ridge sides are Entisols.

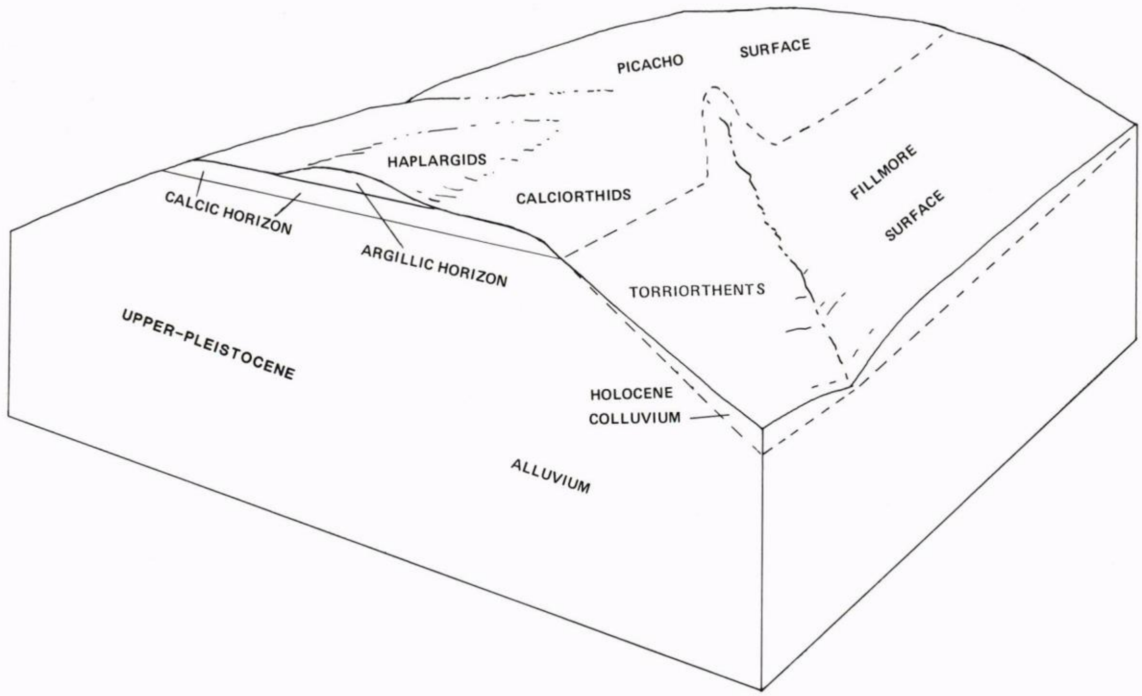


FIGURE 23—BLOCK DIAGRAM OF SOILS AND GEOMORPHIC SURFACES, AREA 2. The Argids and Orthids occur on the late Pleistocene Picacho surface and have pedogenic evidence (argillic horizons and/or calcic horizons in stage III of carbonate accumulation) of soils of that age. The Argids occur on small, remnantal ridge crests, level transversely, that have been relatively little affected by the dissection. The Orthids occur on rounded ridge crests and in and near drainageways, where the argillic horizon has been truncated and/or carbonate engulfed. The Orthents occur on the Holocene Fillmore surface of ridge sides, where both the calcic and argillic horizons have been truncated and have stage I carbonate horizons typical of Fillmore age. The area illustrates class 3 dissection (table 42, fig. 22).

SETTING—Study area 2 is on a ridge remnant of the Picacho surface (figs. 19, 20, and 23). The ridge summit was originally part of a large fan of the ancestral Tortugas Arroyo, graded to a river base level about 70-90 ft (21-27 m) above the present floodplain (fig. 7). The exposure shows late Pleistocene Picacho alluvium (2.62, table 9). Parent materials are essentially the same as at area 1. The gravel fraction consists mainly of rhyolite originally derived from the Organ Mountains, with minor amounts of andesite, monzonite, and rounded pebbles of mixed lithology. The fan is strongly dissected, and narrow ridges are prominent. The ridge crest approximates the original Picacho surface; ridge sides are erosional backslopes of the Fillmore-Arroyo surface complex. The water table in this immediate area is at a depth of 230 ft (70 m; fig. 9). It has been no more than 100 ft (30 m) higher during and since the Picacho episode of fan deposition. Slope along the ridge crests is approximately 2 percent. Vegetation consists of creosotebush and ratany.

SOIL OCCURRENCE—Soil occurrence is shown in the soil map (fig. 20). The soil pattern is a result of differences in particle size and in the degree of soil truncation, which determines the presence or absence of the diagnostic argillic and calcic horizons. In this desert area the argillic horizon is characterized by a reddish-brown or red, low-carbonate fabric in which sand grains (and pebbles, if present) are coated with oriented clay. The argillic horizon is diagnostic for the Haplargids; the underlying calcic horizon is diagnostic for the Calciorthids only if the argillic horizon has been truncated and/or carbonate-engulfed.

A few very small areas of Haplargids (Dona Ma soils) are still present in the centers of best preserved ridge crests (fig. 23). Usually, however, the argillic horizon is absent and the calcic horizon is therefore diagnostic for classification. Thus the Picacho remnant as a whole is occupied primarily by Calciorthids. Whitlock soils dominate the central portion of the remnant. Nickel soils are dominant in most other areas where the Picacho surface is still preserved, with Caliza and its sandy variant occurring in places, depending upon texture of the control section (3.15). Kokan soils dominate ridge sides of Fillmore age, below the point at which the diagnostic calcic horizon has been truncated (fig. 23).

Area 2a—Typic Haplargid (Dona Ana) in Picacho alluvium

The Haplargids (Dona Ma soils) occur only in the central, best-preserved part of the ridge crest (fig. 23). They have an argillic horizon with some macroscopic carbonate in all subhorizons. On Picacho ridges eastward that have been less rounded by dissection, much of the upper part of the argillic horizon is noncalcareous. At area 2a the argillic horizon has only a few remnantal noncalcareous spots.

The small amount of Bt material in this soil is a result of several factors. Thin upper horizons have been removed by landscape dissection and associated soil truncation. This brought once-deeper, partially carbonate impregnated parts of the argillic horizon closer to the surface. The development of small drainageways increased slopes and consequently runoff, leading to decreased depths of wetting and resultant carbonate accumulation at shallow depths. Carbonate filaments in the upper part of the argillic horizon are morphologically similar to those at area 1, are at similar depth, and are thought to be of the same (late Holocene) age.

A small pipe (3.75) of Bt material occurs in the west end of the trench. Such pipes do not occur in soils of Holocene age and must have formed largely in the Pleistocene. Pipes of this size and morphology are typically found in soils of late Pleistocene age (area 9a). Although this pipe has no clay skins, some pipes do have prominent clay skins and are evidence of clay illuviation in the Pleistocene (area 9a). These small pipes may have several origins; one seems to be the filling of large cavities of former roots by materials more pervious than the adjacent horizon. Pipes of middle Pleistocene age are commonly much larger than this (area 6).

Beneath the Bt horizon is a K horizon (3.13) that is in stage III of carbonate accumulation. The K horizon is whitened virtually throughout by pedogenic carbonate.

Most or all of the carbonate in this soil must be of atmospheric origin because the parent materials contained little or no carbonate, and contributions from the ground water must have been negligible because of deep water tables noted earlier. Occasional reddish-brown volumes in the upper part of the K horizon suggest that the argillic horizon once extended deeper and has since been engulfed by carbonate. This feature is very common in the project area, as demonstrated by both morphology and laboratory data (study areas 3, 5, 6, 8, 9, 15, 17, and 20).

Area 2b—Typic Calciorthid (Whitlock) in Picacho alluvium

A small drainageway occurs just east of area 2a. Truncation and carbonate engulfment of the argillic horizon increase with increasing distance downslope from the ridge crest, and the argillic horizon is not present at area 2b. The prominent calcic horizon still remains, however, and is diagnostic for Calciorthids because the argillic horizon is not present. Obliteration of the argillic horizon and the shift from Argids to Orthids—a change at the suborder level of soil classification—has clearly been caused by soil truncation.

The Whitlock pedon at area 2b illustrates a Calciorthid in a small drainageway—a position of substantial truncation near the central portion of the fan remnant. Whitlock 60-2 (fig. 24, table 38) illustrates Whitlock in a stabler part of the landscape—between drainageways. An argillic horizon (such as at area 2a) is not present. The K1 horizon of Whitlock 60-2 contains a very few bits (1-3-mm diameter) of Bt material (but less than 10 percent) and the soil has therefore been classified as a Calciorthid (3.13). Laboratory data show a distinct maximum of silicate clay in the K horizon (table 43), suggesting that an argillic horizon might once have been present but is now masked by strong carbonate accumulation.

A radiocarbon date for inorganic carbon was also obtained from Whitlock 60-2. The intent was to obtain a date as old as possible for a soil on the Picacho surface, as indicated by the morphology and horizon position. The innermost carbonate coating in the lower part of the carbonate horizon should represent carbonate emplaced early in the history of this soil. Carbonate at that depth should be less subject to youthening by moisture subsequent to accumulation of the carbonate. Carbonate adhering to pebbles less than 19 mm in diameter from the 2K32 horizon was dated, and a C-14 age of 29,000 + 1,400 - 1,200 yr s B.P. was obtained. The date is not considered to be absolute, but it does agree with the postulated late Pleistocene age of this soil, and the radiocarbon age is much older than dates obtained for carbonate in soils known to be of Holocene age (3.83 and study areas 10, 12, and 20).

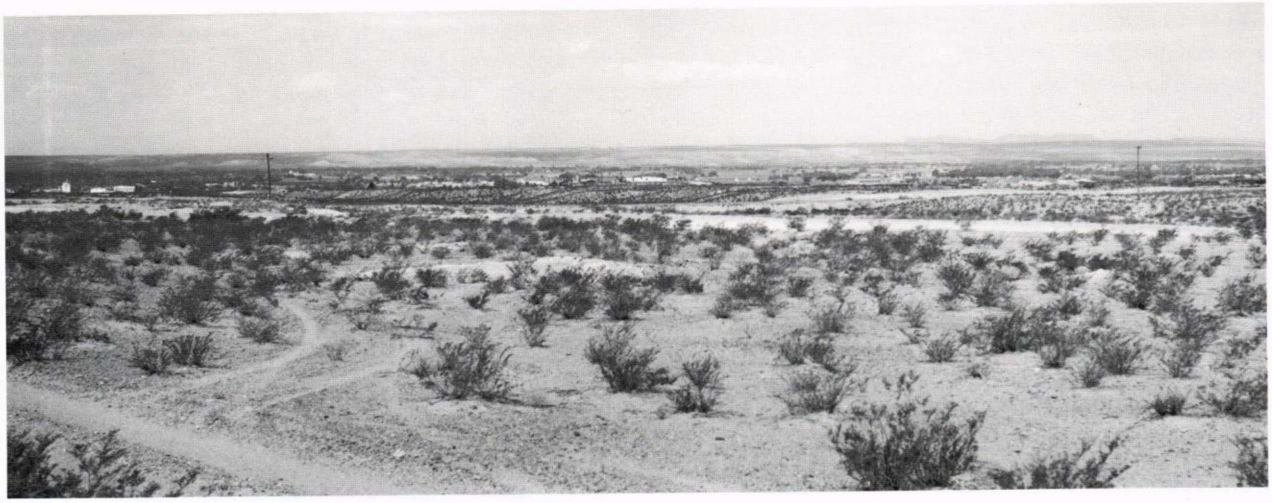
INITIAL DEVELOPMENT OF THE USTOLLIC ARIDISOLS

Most soils of the valley border—the most arid part of the project area—have too little organic carbon to meet the Ustollic requirements. Organic carbon is higher along the mountain fronts, and most soils are either Ustollic Aridisols or Mollisols. Between these two areas is a tension zone in which several factors, discussed below, can determine the classification.

TABLE 43—LABORATORY DATA FOR A TYPIC CALCIORTHID (WHITLOCK 60-2) with evidence of a carbonate-engulfed, former argillic horizon; sand, silt, and clay on a carbonate-free basis.

Horizon	Depth	Sand	Silt	Clay	>2 mm vol.	Carbonate	Organic carbon
	cm						
A	0-5	62	19	20	30	5	0.19
Bca	5-10	54	19	27	2	10	0.23
Kl	10-23	53	17	30	5	16	0.23
Kl	23-36	63	15	22	5	23	0.20
K2	36-58	58	14	27	3	21	0.20
K31	58-89	71	15	10	10	10	0.24
2K32	89-122	86	6	7		16	
3Cca	122-137	82	10	8		5	

Organic carbon 2.5 kg/sq m to 89 cm



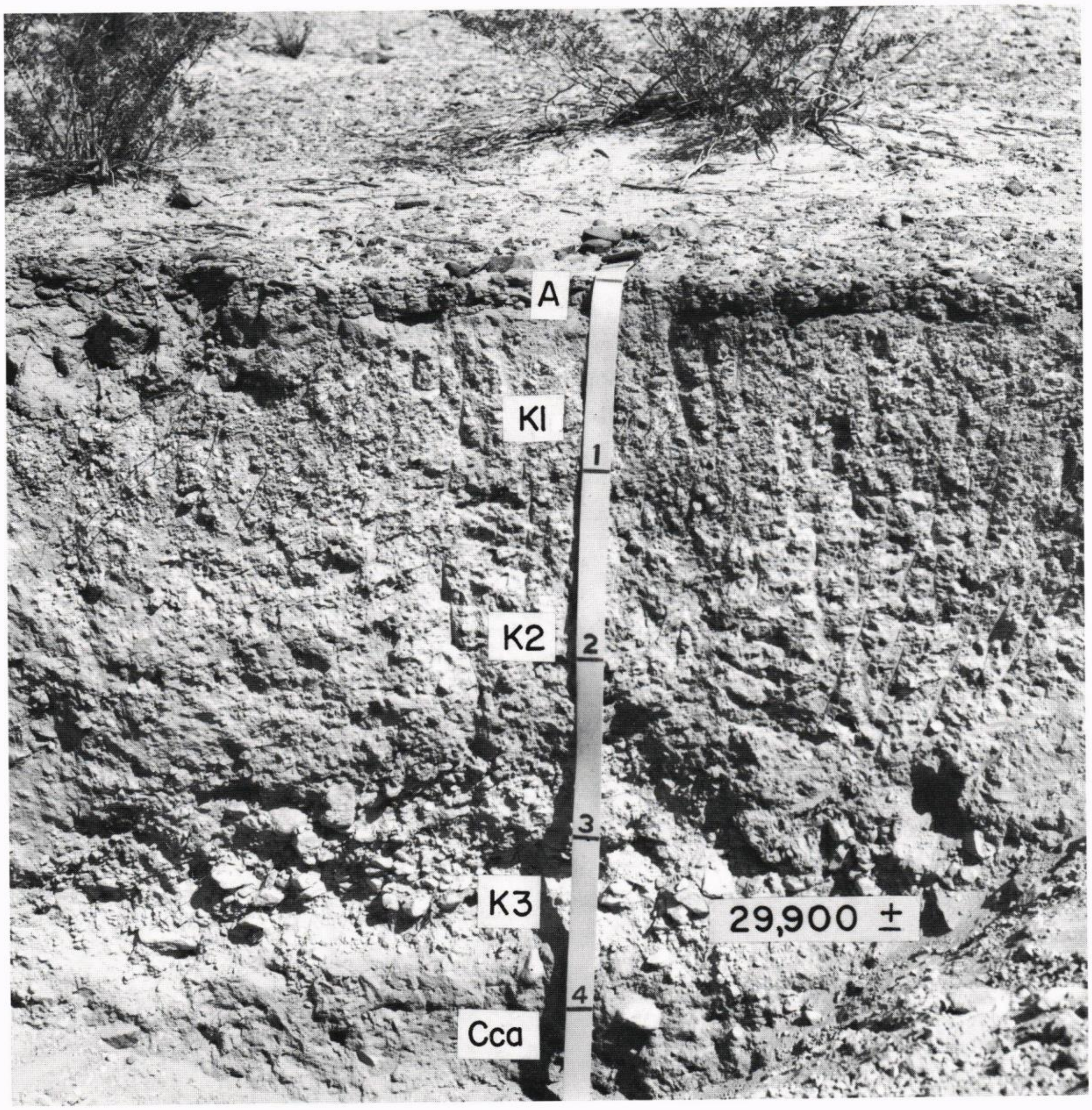


FIGURE 24—PICACHO SURFACE AND A CALCIORTHID AT AREA 2. *Upper view:* landscape of a Typic Calciorthid, Whitlock 60-2, on the Picacho surface; vegetation is creosotebush; La Mesa surface on the skyline. *Lower view:* Whitlock 60-2, in stage III of carbonate accumulation; soil formed in Picacho fan alluvium. The date marks location of radiocarbon-dated material. Scale in feet (photographed April 1966).

In general, Aridisols with few or no coarse fragments may be readily classified as Typic or Ustollic because organic carbon content is closely related to clay content (3.5). However, differentiating these subgroups becomes more complex where substantial amounts of coarse fragments are present. Differentiation is more complex because it is the fine earth that is analyzed and reported; and fine earth is concentrated by numerous coarse fragments. Thus, the Ustollic subgroups first develop in materials high in coarse fragments, and a shift from low-gravel to high-gravel materials can result in a concomitant shift from Typic to Ustollic Aridisols.

Different depths of the petrocalcic horizon can also cause Typic-Ustollic variation because different thicknesses of soil may be used for classification (3.12). Hence, depth-related differences in organic carbon can affect the classification. For example, in some soils the upper few centimeters of very gravelly materials contain less organic carbon than horizons beneath because of higher temperature and fewer roots in the surficial zone.

Composite samples for analyses of organic carbon and particle-size distribution were taken at several places in the vicinity of study areas 3 and 4 to study the character and distribution of the Ustollic subgroups in that area (table 44). One of these soils is Casito 60-1, which will be seen at area 3d.

En route to study area 3. *Continue east* on Dripping Springs Road. 0.3

3.5 Route skirts north abutment of Tortugas Dam, a flood- and sediment-control structure built in 1961-62 by the Soil Conservation Service in cooperation with the Elephant Butte Irrigation District. This point is near the apex of the Picacho fan. Upstream the Picacho comprises alluvial terraces and valley-sideslope surfaces inset below Tortugas and Jornada I remnants. 0.3

3.8 Crossing Tortugas Arroyo channel. 0.3

4.1 Road fork; *bear left on Dripping Springs Road.* Study area 19 (Day 4) to right. 0.1

4.2 Rise to surface of Picacho alluvial terrace; monzonite spires of Organ Mountains ahead on skyline. Ridge to the south, extending west of Tortugas Mountain, is capped with channel gravel of Camp Rice Formation fluvial facies. Prominent structural benches are developed on this erosion-resistant unit on both sides of the Mesilla Valley. Small remnants of the Jornada I and Tortugas surfaces are preserved on the south and west flanks of the mountain both as sideslope erosion surfaces and fan toeslopes graded to levels at or slightly below the structural benches. 0.8

5.0 *Slow.* Blind curve ahead around north tip of Tortugas Mountain. 0.2

5.2 Outcrops of lower Permian limestone on right (2.44). The route ahead is mainly on the Picacho surface, here an alluvial terrace at the toe of Tortugas Mountain slopes. Contribution of limestone from this fault-block uplift to fill units is negligible. 1.0

6.2 STUDY AREA *3. Stop on right (south) edge of road.*

TABLE 44—ORGANIC CARBON AND PARTICLE-SIZE DISTRIBUTION ANALYSES FOR THREE PALEARGIDS AND ONE PALEORTHID; sand, silt, and clay on a carbonate-free basis. Cruces variant and Terino discussed at areas 3b and 3c; Delnorte at area 3e; and Casito at area 3d. Petrocalcic horizon shallower than 40 cm but deeper than 18 cm, except for Terino, where petrocalcic horizon deeper than 40 cm.

Depth cm	Sand %	Silt %	Clay %	Organic carbon %	>2 mm vol. %
Cruces variant, Petrocalcic Paleargid					
0-18	57	23	20	0.42	60
Delnorte, Typic Paleorthid					
0-18	57	28	15	0.51	30
Casito 60-1, Petrocalcic Ustollic Paleargid					
0-18	62	22	15	0.64	55
Terino, Petrocalcic Ustollic Paleargid					
0-38	56	19	25	0.69	60

STUDY AREA 3

Camborthids of the Fillmore surface; Haplargids, Paleargids, and Paleorthids of the Picacho surface

SUMMARY OF PEDOGENIC FEATURES (table 37)—Chronosequence of soil development in terraced terrain; pedogenesis under Holocene and full-glacial climates; engulfment of Bt material by carbonate; soil truncation and the Argid-Orthid transition in soils with petrocalcic horizons; incipient petrocalcic horizon and effect of facies changes and content of rock fragments on its development; initial development of Ustollic subgroups.

SETTING—A distinct terraced terrain occurs in this area (figs. 25-27). With increasing elevation the surfaces are: arroyo channel—Fillmore, Picacho (on which the road is located), and, in a few places, small remnants of the Tortugas and Jornada I or dissected Jornada I on highest ridge crests (figs. 25, 27).

To the west, a narrow band of alluvial-fan sediments nearly encircles and was derived from Tortugas Mountain (limestone). Except for these sediments, the alluvial parent materials in the immediate vicinity were derived almost wholly from rhyolite of the Organ Mountains and older basin and valley fills of the source watershed. On the ridge side north of the road and beyond the arroyo, a thin layer of colluvium mantles erosional slopes cut below ridge-summit remnants of the Jornada I and Tortugas(?) surfaces into the piedmont facies of the Camp Rice Formation. Camp Rice basin fill in this area is characterized by a sequence of sheet-like bodies of gravelly to loamy alluvium, with soils commonly developed in the upper part of each sedimentary unit. These deposits become thinner and finer grained to the west, overlapping the fluvial facies near Tortugas Mountain. The water table is about 225 ft (69 m) below the surface (fig. 9).

Son, OCCURRENCE—Characteristic soils occur on each surface in this terraced terrain. The pattern of soils (figs. 26, 27) is determined by differences in soil age, particle size, and degree of soil truncation. Entisols (primarily Arizo soils) and a few Camborthids (Vado, sandy-skeletal variant, and Pajarito soils) and weak Haplargids (Soledad soils) occur on the Fillmore surface. The Camborthids and weak Haplargids occur only in highest, stablest positions that lack drainageways. Soils of pre-Fillmore surfaces are too strongly developed for the Camborthids and have argillic, calcic, and/or petrocalcic horizons. Argids with argillic horizons that do not have macroscopic carbonate in all subhorizons (Terino, Nolam, and Hap soils and Cruces, loamy-skeletal variant) occur in stablest areas of the Picacho surface. Paleargids (Terino soils and Cruces, loamy-skeletal variant) have petrocalcic horizons that in places are in stage IV of carbonate accumulation but

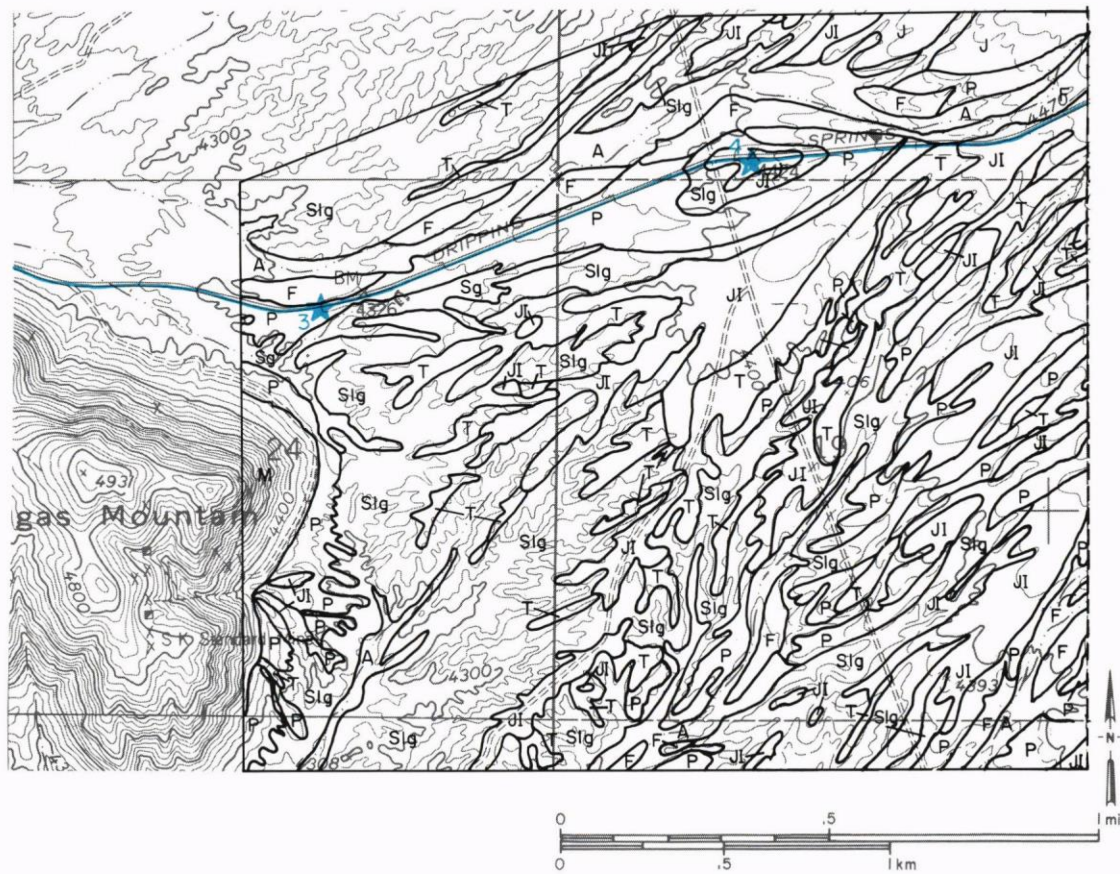


FIGURE 25—GEOMORPHIC SURFACES AND STRATIGRAPHIC UNITS, AREAS 3 AND 4.

EXPLANATION

A Arroyo surfaces (major active channel areas of the valley border). Associated sediments of Historical age partly fill channels cut into older units; minor inclusions of Fillmore morphostratigraphic unit.

F Fillmore surface (constructional phase). Valley-border terrace surfaces underlain by gravelly alluvial deposits of the Fillmore morphostratigraphic unit (Holocene); minor inclusions of arroyo-channel and Picacho alluviums.

Sg, Sig Fort Selden surfaces—Leasburg and Fillmore undifferentiated and arroyo-tributary channels.

Sg—Complex of erosional surfaces, in ridge-sideslope and channel-floor positions, cut into gravelly Picacho and older alluviums; minor constructional-surface inclusions and associated thin colluvial-alluvial fills.

Slg—Complex of erosional surfaces in ridge-sideslope positions, cut into loamy to gravelly piedmont-slope deposits of the Camp Rice Formation (with buried soils) that overlap and intertongue(?) with the Camp Rice fluvial facies south of Tortugas Mountain. Contains minor inclusions of Picacho and Tortugas surface remnants.

Picacho surface (constructional phase). Valley-border terrace surfaces underlain by gravelly alluvial deposits of the Picacho morphostratigraphic unit (late Pleistocene).

T Tortugas surface. Several levels of erosion-surface remnants of late Pleistocene age that are intermediate in position between Picacho and Jornada I surfaces and are cut in the younger piedmont-slope facies of the Camp Rice Formation; small remnants of fan and arroyo-terrace surfaces at the base of Tortugas Mountain and associated deposits of the Tortugas morphostratigraphic unit.

JI Jornada I surface (constructional phase). Piedmont-slope complex of middle Pleistocene age graded to basin-floor levels approximated by the youngest parts of La Mesa surface. Underlain by gravelly to loamy alluvium of the Camp Rice Formation—younger piedmont facies that overlaps and intertongues with gravel and sand of the Camp Rice fluvial facies near Tortugas Mountain.

J Jornada I and **II** piedmont-slope surfaces and associated deposits—undifferentiated (see fig. 88).

M Tortugas Mountain slopes. Complex of erosion surfaces and minor slope deposits of Quaternary age on limestone of the Permian Hueco Formation.

NOTE: Lithology of all units (except M and alluvial deposits on the slopes of Tortugas Mountain) reflects the Soledad Rhyolite composition of source watersheds in the Organ Mountains.

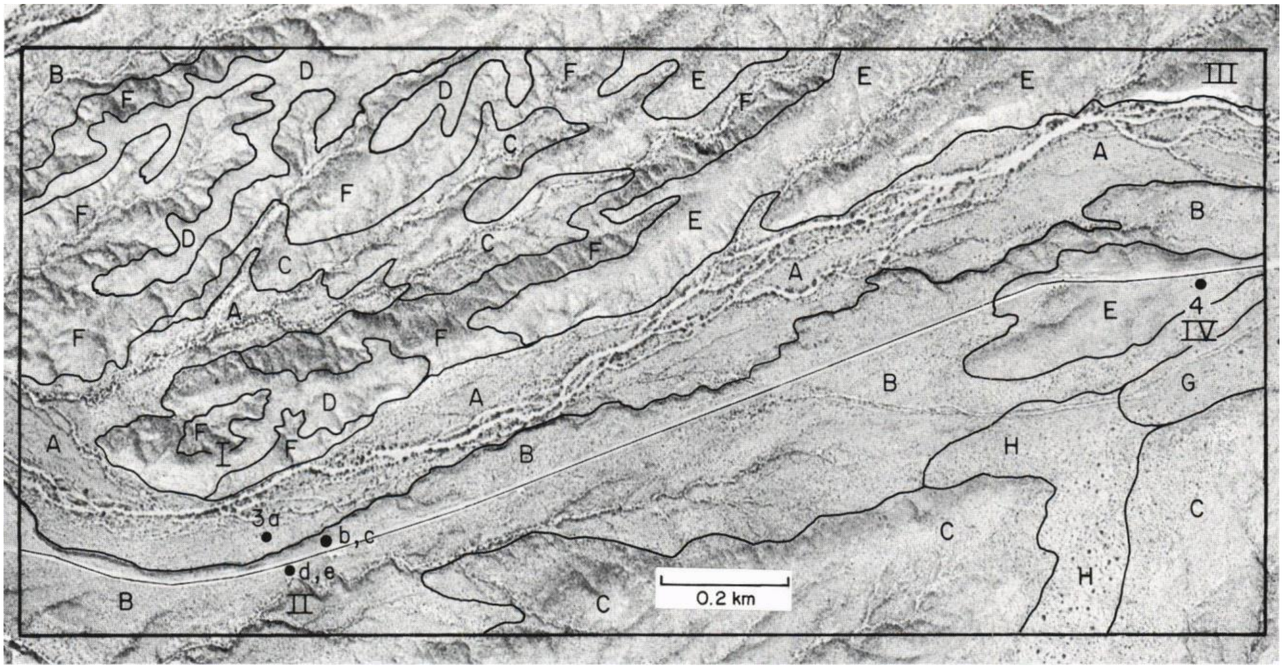


FIGURE 26—MAP OF SOILS IN VICINITY OF AREAS 3 AND 4. A, Arizo-Entisol complex (Fillmore and arroyo-channel surfaces); **B,** Nolam complex (Picacho surface); C, Calciorthids and Paleorthids (Jornada I and younger surfaces); **D,** Typic Calciorthids (Tortugas and younger surfaces); E, Monterosa complex (Jornada I and younger surfaces); **F,** exhumed soils (complex of exhumed, mostly beveled surfaces once buried by Jornada I and older sediments and smaller areas of surfaces younger than Jornada I); **G,** Sonoita sand (eolian accumulation on Picacho surface); **H,** Hueco sand (eolian accumulation on Jornada and Picacho surfaces). I-II and III-IV locate cross sections (figs. 27 and 29).

more commonly are in late stage III, in which the horizon has been plugged or nearly plugged by the accumulated carbonate. Haplargids (the loamy-skeletal Nolam soils and the fine-loamy Hap soils) occur where the carbonate horizon is not continuously cemented; they have calcic, but not petrocalcic horizons. Casito soils occur in slightly truncated areas on the Picacho surface, near drainageways and arroyos, and have argillic horizons with some macroscopic carbonate in all subhorizons. Delnorte soils, Paleorthids, occur on ridge shoulders downslope from the Casito soils.

Because of dissection, the argillic horizon and the Argids usually do not occur on Tortugas and Jornada I ridges, which are rounded and dominated by Calciorthids. Where the Jornada I and Tortugas ridges have been substantially (several meters or more) lowered by valley incision, buried soils are commonly at or very near the surface (fig. 27). Buried soils are so common in the project area and so closely related to the soil and landscape history that they were studied as a matter of course. Buried soils of various ages will be seen and discussed at areas 4, 5, 8, 9, 12, 13, 14, 15, 16, and 20.

Area 3a—Typic Camborthid (Vado variant) in Fillmore alluvium

The Fillmore alluvial terrace, several feet above the arroyo channel, is here inset against the Picacho terrace fill just south. Slope is 2 percent to the west. Vegetation consists mainly of creosotebush and a few ratany and whitethorn.

The Camborthid Vado sandy-•skeletal variant is shown in the north end of the pit. Development of this soil started in the Holocene after the very gravelly alluvial parent materials were deposited by arroyo waters. These pervious, very gravelly materials should allow ready infiltration of moisture. The soil has a thin A2 horizon; a reddish-brown Bt horizon that lacks enough clay increase for an argillic horizon but is thick

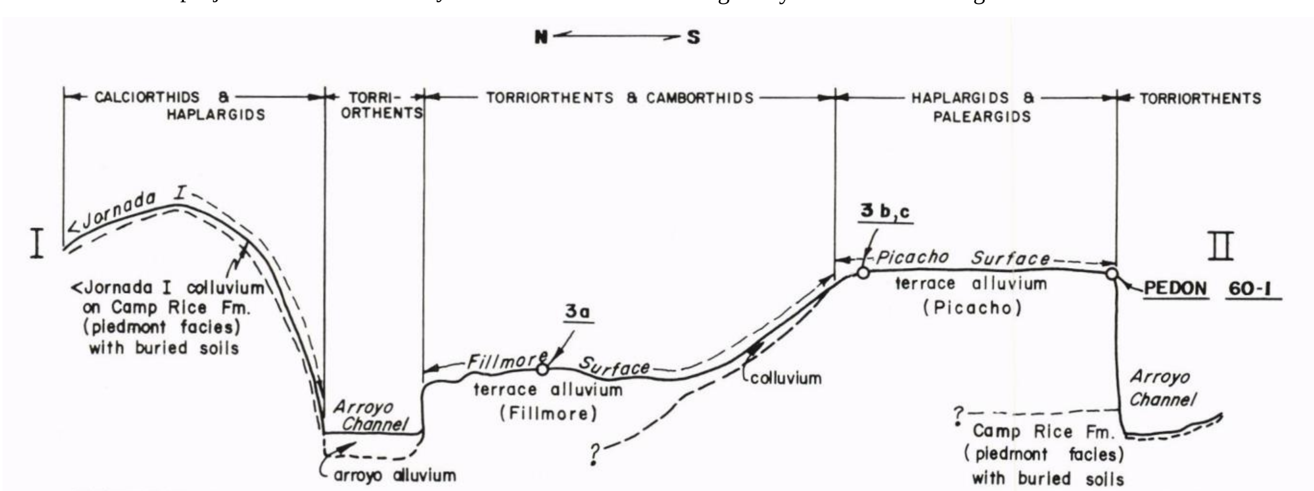


FIGURE 27—DIAGRAMMATIC CROSS SECTION OF SOILS, GEOMORPHIC SURFACES, AND SEDIMENTS, AREA 3 (I–II on soil map, fig. 26).

enough and otherwise qualifies for a cambic horizon; and a stage I carbonate horizon with thin, discontinuous carbonate coatings on pebbles. Clay contents of the A and B horizons are 7.2 and 8.7 percent respectively (unpublished data, National Soil Survey Laboratory, Lincoln, Nebraska).

Some of the clay and much of the carbonate in this soil probably were derived from atmospheric sources. Grayish color of the A2 horizon, together with the reddish-brown color of the underlying Bt horizon, suggests loss of clay and iron from the A2 and its accumulation in the Bt horizon. The soil morphology and the Holocene age indicate that silicate clay and carbonate are slowly accumulating in this soil as a present feature of pedogenesis.

Area 3b—Petrocalcic Paleargid (Cruces variant) in Picacho alluvium

Here the Picacho surface is a terrace inset below a remnant of the Jornada I surface on a ridge crest to the south. Slope is 2 percent. Vegetation is creosotebush.

The trench along the north edge of the road shows some of the soils typical of the transversely level central portion of the terrace remnant. In this stablest part of the Picacho landscape upper horizons are best preserved. In such places, the argillic horizon is noncalcareous in its upper part. The Petrocalcic Paleargids (Cruces, loamy-skeletal variant) are shown on the west side of the pit (fig. 28). The reddish-brown argillic horizon is distinct and noncalcareous in its upper part. The petrocalcic horizon is in its incipient stages and barely qualifies as one. The horizon is essentially plugged, but no laminae have formed. Pinkish and reddish parts in its upper subhorizon suggest carbonate engulfment of the lower part of a formerly thicker argillic horizon.

Comparison with the Camborthid of the Fillmore surface suggests current pedogenesis in soils of the Picacho surface that started their development in late Pleistocene time. There are similarities in overall horizonation. Soils on stablest sites of both surfaces have thin A2 horizons ranging from about 2 to 5 cm thick, B horizons that are reddish brown in part, and A horizons and upper parts of B horizons that are commonly noncalcareous. This morphological similarity, together with oriented clay coatings on sand grains and pebbles, indicates that silicate clay is very slowly accumulating in the upper part of the Bt horizon of Argids on the Picacho surface at the present time. Similarly, the weak carbonate accumulation (filaments and thin pebble coatings) in the lower part of the Bt horizon is also a present feature of pedogenesis. This carbonate accumulation is similar to that in Camborthids of the Fillmore surface in terms of morphology, depth, and horizon arrangement.

Although evidence exists for pedogenesis in the Holocene, the main features of the soils of Pleistocene age are the prominent horizons of clay and carbonate accumulation. Pedologic and geomorphic evidence indicates that both horizons must have formed largely in the Pleistocene.

Area 3c—Ustollic Haplargid (Nolam) in Picacho alluvium

The soil on the east side of the pit is an Ustollic Haplargid (Nolam). This soil and the one at Area 3b show the effect of rock fragments and a facies change on carbonate cementation. Because of low total pore space in very gravelly materials, less carbonate is required to cement them than is required for nongravelly materials. On the east side of the pit where gravel content is lower, only a calcic horizon is present and the soil is a Haplargid instead of a Paleargid.

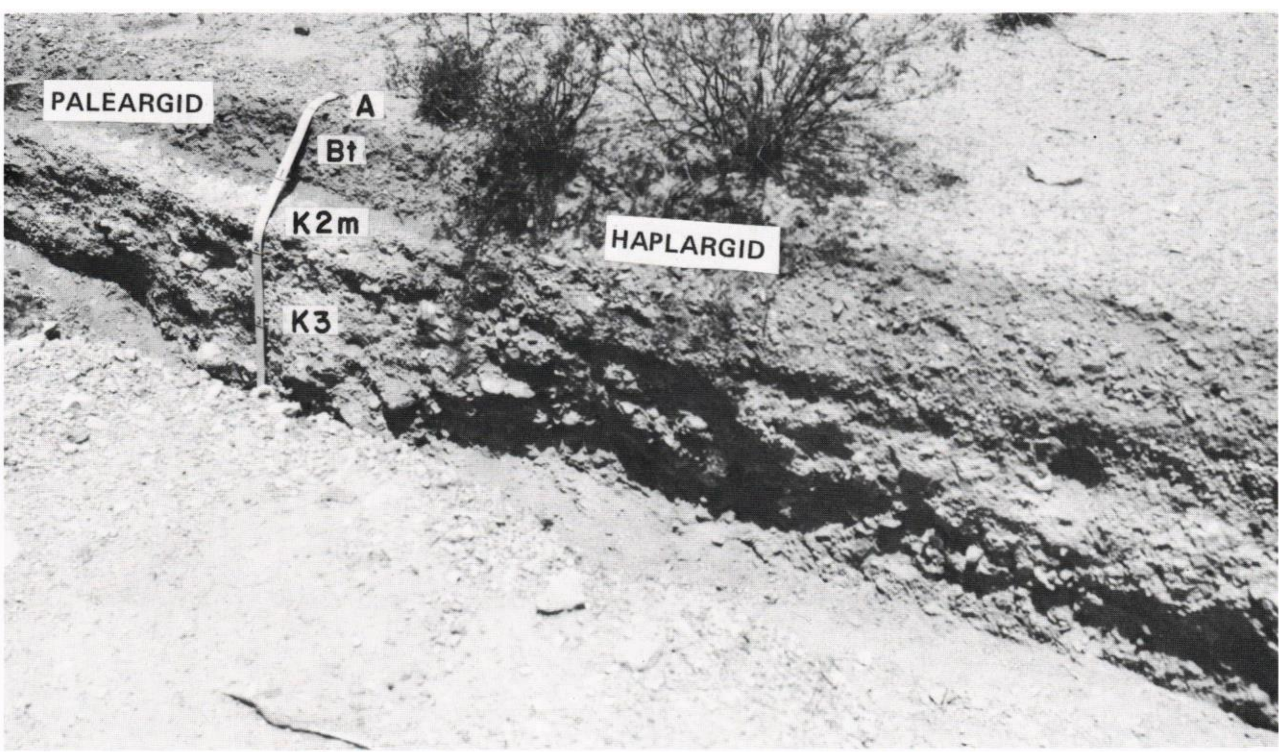


FIGURE 28—PALEARGID AND HAPLARGID ON PICACHO SURFACE AT AREA 3. Profile of a Paleargid (at area 3b) and a Haplargid (at area 3c) on Picacho surface. The Petrocalcic Paleargid, Cruces variant, is at left and is in late stage III of carbonate accumulation. The petrocalcic horizon (K2m) changes to a calcic horizon (right side of tape) due to a decrease in gravel content, and the soil changes to Ustollic Haplargid, Nolam. The latter soil is also in stage III of carbonate accumulation but has much less cementation than the Paleargid. Scale in feet (photographed 1972).

The two creosotebushes on the north edge of the pit show the effects that roots can have on the argillic horizon. Note that the reddish-brown argillic-horizon material appears mixed and is calcareous in the vicinity of the roots. Roots have not prominently disturbed the argillic horizon everywhere; but the argillic horizon here is particularly susceptible to disturbance because it is near the edge of the terrace and an area of soil truncation. Also, high gravel content restricts the volume of fine earth available for rooting.

These soils and soils at area 3d and 3e illustrate a three-step transition from the Argids to the Orthids, one that is common on Picacho remnants in this general position along the valley border: 1) Argids with upper subhorizons free of macroscopic carbonate occur in the central, best-preserved part of the terrace remnants (areas 3b, c); 2) Argids with macroscopic carbonate in all subhorizons of the argillic horizon occur on shoulders (rounded edges) of the terraces (area 3d); and 3) Orthids, without an argillic horizon, occur further downslope (area 3e).

Area 3d—Petrocalcic Ustollic Paleargid (Casito) in Picacho alluvium

This is a shoulder of the Picacho terrace and exposure of Picacho alluvium in the north bank of the arroyo. The terrace fill occupies the floor of a broad, ancient valley cut into the piedmont-slope facies of the Camp Rice Formation. Slope is 2 percent. Vegetation is creosotebush.

A cut in the north bank of the arroyo shows Paleargids, Paleorthids, and Calciorthids. Laboratory data for the sampled Paleargid (Casito 60-1) are given in table 45.

The shoulder of the remnant has been truncated, with effects similar to those discussed at area 2. Macroscopic carbonate occurs in all subhorizons of the argillic horizon. The dominant feature of pedogenesis at present seems to be carbonate accumulation, mainly as thin pebble coatings similar to those in Cruces variant but higher in the profile. Not enough carbonate has accumulated to completely mask the argillic horizon. Volumes of Bt material are still preserved as zones of red or reddish-brown fine earth between the pebbles. Reddish-brown or pinkish parts found in the upper part of the petrocalcic horizon suggest that the argillic horizon once extended deeper but that its lower part has been engulfed by carbonate. This interpretation is supported by the extension of the silicate-clay maximum into the K horizon (table 45).

The Picacho surface is an important marker for carbonate horizons because its soils illustrate the initial development of the plugged and laminar horizons in gravelly materials. The horizon along most of the exposure has been plugged or nearly plugged by illuvial carbonate, is in late stage III of carbonate accumulation, and illustrates the petrocalcic horizon in its incipient form. In a few places a thin laminar horizon has formed above the plugged horizon and illustrates stage IV of carbonate accumulation (3.6). For other examples of incipient development of horizons, see area 9a (the calcic horizon in low-carbonate materials), areas 12b and 16a (the calcic horizon in high-carbonate materials), and area 15c (the argillic horizon).

Area 3e—Typic Paleorthid (Delnorte) in Picacho alluvium

The Typic Paleorthids, Delnorte soils, are just downslope from area 3d and are on the upper part of the ridge side on the southwestern side of the exposure. Organic carbon was not determined, but these Paleorthids are Typic instead of Ustollic because the upper boundary of the petrocalcic horizon is shallower than 18 cm. Paleorthids lack the reddish-brown or red Bt material that occurs in Paleargids; it has been truncated, masked by carbonate accumulation, and/or mixed by soil biota. These soils are usually strongly calcareous throughout and have very gravelly B horizons, with carbonate coatings on pebbles, overlying petrocalcic horizons. As in the Casito soils, the dominant feature of current pedogenesis appears to be illuviation of carbonate (primarily as grain coatings) in the B horizon.

Another example of the effect of a facies change is shown in the eastern part of the exposure, where a change from Paleorthids to Calciorthids coincides with a facies change from high-gravel to low-gravel materials.

En route to study area 4. *Continue east on Dripping Springs Road.* **0.7**

6.9 Route leaves Picacho terrace and starts ascent across Picacho and Tortugas(?) valley-sideslope surfaces to a ridge remnant of Jornada I surface, part of the ancient basin landscape that existed prior to middle to

TABLE 45—LABORATORY DATA FOR A PETROCALCIC USTOLLIC PALEARGID (CASITO 60-1); sand, silt, and clay are carbonate-free; B2tca is discontinuous horizon; data from 0-18 cm are from composited samples taken within 5 m of sampled pedon.

Horizon	Depth	Sand	Silt	Clay	>2 mm vol.	Carbonate	Organic carbon
	cm						
A2ca	0-6	66	19	14	40	1	0.32
B2tca	6-28	64	17	19	65	8	0.67
K2m	28-43	66	18	16		23	0.28
K3	43-64	65	21	15		21	0.17
C3ca	64-79	70	18	12		11	0.12
2C4ca	79-104	53	27	15		9	0.08
B2tca	18-30	65	12	23		11	0.53
Composited samples	0-18	62	22	15			0.64

Organic carbon 0.9 kg/sq m to 28 cm

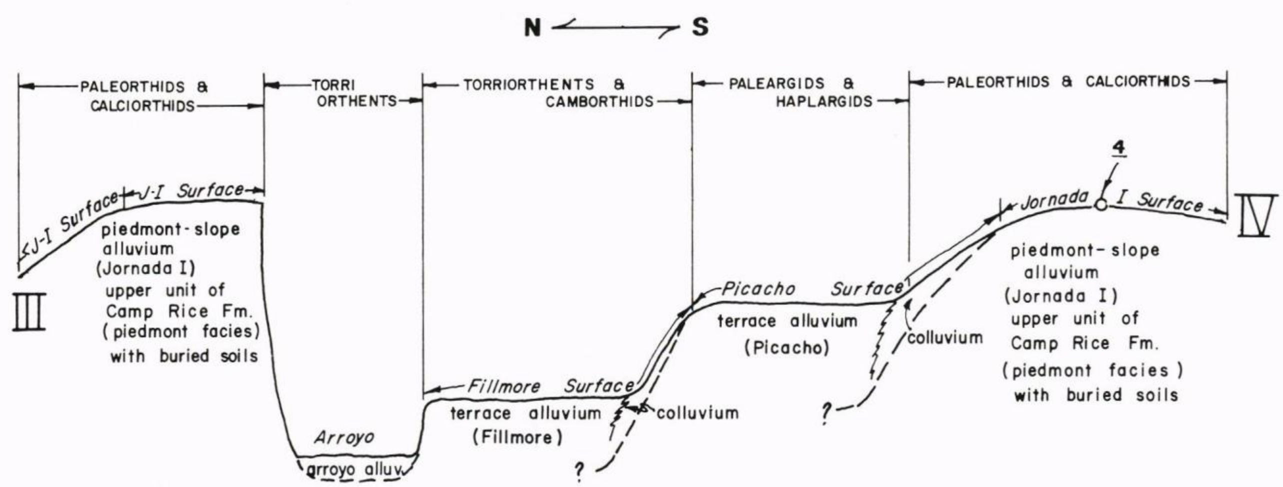


FIGURE 29—DIAGRAMMATIC CROSS SECTION OF SOILS, GEOMORPHIC SURFACES, AND SEDIMENTS, AREA 4 (III–IV on soil map, fig. 26).

late Pleistocene valley incision. The Jornada I surface was apparently graded to a local base level in the approximate position of lower La Mesa. 0.2

7.1 STUDY AREA 4. *Park south of road at powerline crossing.*

STUDY AREA 4

Paleorthids of the Jornada I surface

SUMMARY OF PEDOGENIC FEATURES (table 37)—Obliteration of the argillic horizon and genesis of Paleorthids by soil truncation on a regional scale; cambic horizon, not diagnostic because of petrocalcic horizon; stage IV carbonate horizon with multiple laminar horizons; disintegration of upper sub-horizons of the laminar horizon; value of the K horizon as a chronologic and pedogenic marker in soils; radiocarbon ages of carbonate beneath laminar horizons.

SETTING—This ridge-crest area (figs. 25, 26, and 29) is a remnant of the extensive Jornada I fan-piedmont surface (fig. 30), which has been deeply dissected by arroyos graded to the various entrenchment stages in the Rio Grande valley. Sediments beneath the Jornada I surface belong to the youngest member of the Camp Rice Formation (2.53, fig. 7). They form a body of middle Pleistocene piedmont-slope deposits, locally as thick as 80 ft (24 m), that overlaps the upper part of the Camp Rice fluvial facies a short distance to the west. Small areas of possible Tortugas surface form an intermediate level between the Picacho and Jornada I surfaces; one of these areas is crossed by the road just west of this stop. The Fillmore and arroyo-channel surfaces occur in the topographic low to the north.

The water table is about 200 ft (61 m) below the surface (fig. 9). Considering 1) that this site (elevation approximately 4,425 ft, 1,350 m) is approximately 125 ft (38 m) above the highest ancestral Rio Grande base level and 2) that the basin fill is permeable, it is reasonable to assume that the upper part (10 m or more) of the piedmont slope facies has never been within the zone of saturation. Furthermore, the site has not received surface runoff from adjacent slopes since early (Tortugas) stages of valley incision.

SOIL OCCURRENCE—Soil distribution at area 4 and vicinity is shown in the soil map (fig. 26). The soil pattern here is similar to that in the vicinity of area 3 with the following exceptions: In area 4 the Jornada I deposits are thicker than they are to the west; and buried soils, which have been extensively exhumed north of area 3, are still deeply buried in most

FIGURE 30—VIEw NORTH FROM AREA 4. The long even slope on the skyline is the Jornada I surface. The cut in the center is in upper Camp Rice Formation piedmont sediments, with buried soils, below the Jornada I surface (photographed 1972).

places. However, in places they may be seen in arroyo cuts, such as the one just north that may be seen from here (fig. 29, left; fig. 30). Several buried soils are exposed in the south-facing arroyo bank. The cut is in Camp Rice Formation sediments beneath the Jornada I surface. Reddish-brown argillic horizons can be seen above light-colored horizons of carbonate accumulation.

In most places the Tortugas and Jornada I surfaces are dominated by Paleorthids (primarily the loamy-skeletal Monterosa and Delnorte soils with some of the loamy Simona soils). Thus the significance of stable surfaces to soil occurrence is shown in this area as well as at areas 2 and 3; the argillic horizon is usually not present in soils of the rounded ridge crests of the Tortugas and Jornada I.

Other differences from area 3 (fig. 26) are the occurrence of Sonoita soils, which have formed primarily in a sediment that overlies the Picacho surface and that appears to be at least partly of eolian origin, and of Hueco soils, which have developed partly in a sediment of apparent eolian origin. This sediment overlies the Picacho and Jornada I surfaces.

Ustollic Paleorthid (Monterosa) in Camp Rice alluvium

This soil has a cambic horizon and a petrocalcic horizon. An argillic horizon was probably present at one time but has been obliterated by a combination of soil truncation, carbonate engulfment, and mixing by soil biota (see area 18 for discussion of obliteration of argillic horizons by soil fauna). Argids do occur eastward on stabler remnants of the Jornada I surface.

The petrocalcic horizon of this Paleorthid contrasts with the petrocalcic horizon of soils of the Picacho surface (areas 3b, d, e) in having multiple laminar horizons of stage IV, instead of mostly stage **III** with only occasional stage IV. Horizons of carbonate accumulation are also thicker and contain more carbonate than do soils of the Picacho surface (tables 45, 46). Slight illuviation of carbonate as grain coatings, primarily in the upper part of the B horizon, appears to be the dominant process of pedogenesis at present.

The stage IV horizon at area 4 reflects the great age of this soil and illustrates the value of the K horizon as a pedogenic and chronologic marker. In contrast, the overlying B horizon is youthful-appearing and does not suggest great age.

The uppermost laminar horizon has commonly been broken and the fragments mixed in varying degree with fine earth. This situation is typical on these high Jornada I ridges and is thought to be due to changes caused by soil truncation (3.6). Two Paleorthids (pedons 60-10 and 61-10) were sampled on the ridge crest to the north and one to the southwest (table **46).** The first two illustrate the effect of rock fragments on organic carbon content and the gradation from Typic Paleorthids (low-gravel materials) to Ustollic Paleorthids (high-gravel materials). Composited samples near Monterosa 66-2 suggest local variations of organic carbon due to vegetation differences.

Radiocarbon ages of carbonate beneath laminar horizons of two Paleorthids were determined. Pebble coatings from the K22m horizons of Monterosa 66-2 and Monterosa 67-2 have a C-14 age of about 25 and 20 kyrs respectively. Thus, while these soils started their development in middle Pleistocene time, carbonate age in the K22m horizons is much younger. Occasional cracks in the petrocalcic horizons of these soils must have been well within reach of wetting during full-glacial times, and such wetting would result in a younger C-14 age (3.83).

En route to study areas on the west side of the Mesilla Valley. *Return on Dripping Springs Road to University A venue.* **4.2**

11.3 Stop sign at Telshor Boulevard. *Proceed west on University Avenue* (NM-101) to I-10. **0.4**

11.7 1-25 overpass. New Mexico State University Pan-American Center on left. **0.5**

12.2 Traffic light at Locust Street. **0.3**

12.5 Traffic light at Solano Street. **0.2**

12.7 Traffic light at Espina Street. New Mexico State University Agriculture Building 2 blocks south, at edge of river floodplain. **0.4**

13.1 Traffic light at El Paseo Road. Start crossing 1844 meander belt of the Rio Grande. Prepare to turn left. **0.3**

13.4 Traffic light-University Avenue and Valley Drive. *Turn left on Valley Drive and bear right to I-10 West access loop.* **0.1**

13.5 I-10 West-(Deming) entrance. Curve right and *enter westbound lane.* For the next 2 mi the route continues on the 1844 river meander belt (U.S. Reclamation Service, 1914). This path was abandoned after major floods of the Civil War period, when the river shifted to near its present position on the west side of the valley. The modern channel has been straightened and diked since 1915 as part of the Elephant Butte Irrigation Project and is now essentially a canal for irrigation and flood-water conveyance. Floodplain gradient in the Mesilla Valley is about 4.5 ft/mi. **1.4**

14.9 NM-28 overpass. Old Mesilla to left. **0.4**

15.3 Burn Lake to right; a sand-and-gravel pit reclaimed for recreational use. Material for interstate highway construction was produced from point bar and channel deposits of the 1844 meander belt to a depth of about 30 ft. Wood from these deposits yields Historical C-14 dates (table 10). Late Quaternary river deposits from 60 to 80 fit (18-24 m) thick underlie the entire floodplain area and are overlapped on both sides of the valley by Fillmore and Historical arroyo fans. The valley fill rests on thick sand and gravel deposits of the basal Camp Rice Formation, together forming a major aquifer system with large quantities of good-quality water in storage (King and Hawley, 1975). **1.8**

17.1 Rio Grande bridge. Picacho and Robledo Mountains flank the Mesilla Valley to the northwest (vicinity of area 7). Bench-like footslopes extending valleyward from the mountain bases form the "Picacho terrace" of Dunham (1935). This complex geomorphic unit was subdivided into Picacho and Tortugas geomorphic surfaces by Ruhe (1962, 1964, 1967). **1.5**

LA MESA SURFACE AND ADJACENT STRUCTURAL BENCHES

Large remnants of La Mesa surface (middle Pleistocene) occur west of the Rio Grande (fig. 31). Here La Mesa is a relict basin floor ranging from 300 to 500 ft (90 to 150 m) above the floodplain; and it is a constructional surface on the Camp Rice fluvial facies (2.4). Extensive geomorphic surfaces of late Pleistocene age (such as the Picacho surface seen at area 2 and 3) have not formed below La Mesa south of Pica-

TABLE 46—LABORATORY DATA FOR USTOLLIC PALEORTHIDS (MONTEROSA 61-10, MONTEROSA 66-2) AND A TYPIC PALEORTHID (SIMONA 60-10); sand, silt, and clay on carbonate-free basis; carbonate-cemented fragments not included in the >2 mm figure. Data from 0-18 cm are from composited samples from Delnorte pedon on north side of sampling trench and between creosotebushes; Monterosa 66-2 located next to a creosotebush.

Horizon	Depth	Sand	Silt	Clay	>2 mm vol.	Carbonate	Organic carbon
	cm						
Simona 60-10							
Aca	0-5	64	22	15	20	8	0.50
Bca	5-20	73	18	9	20	13	0.43
K2Im	20-23	69	17	14	35	67	0.16
K22m	23-43	72	17	11	30	62	0.24
K23m	43-74	86	10	5	50	35	0.14
K3	74-104	86	9	5	50	21	0.09
Cca	104-127	84	10	7	40	7	0.02
Organic carbon, 0.9 kg/sq m to 20 cm							
Monterosa 61-10							
Aca	0-5	64	22	15	20	8	0.49
Bca	5-23	61	22	17	40	33	0.74
K2m	23-36	75	13	11	25	52	0.41
K31	36-56	85	8	7	30	26	0.32
K32	56-81	88	6	6	35	24	
Organic carbon, 1.4 kg/sq m to 23 cm							
Monterosa 66-2							
A2	0-4	73	17	10	20	tr	0.35
B2lca	4-13	66	16	18	40	5	0.71
B22ca	13-23	63	16	21	30	29	0.81
K1	23-36	63	17	21	10	43	0.64
K21m	36-43	71	13	17	60	53	0.79
K22m	43-64	70	12	17	40	35	0.29
K31	64-84	79	9	13	60	28	0.13
K32	84-107	81	8	12	70	17	0.33
Clca	107-135	83	6	11	50	14	0.15
C2ca	135-165	89	5	6	60	6	0.09
Composite	0-18	57	28	15	30		0.51
Organic carbon, 2.6 kg/sq m to 36 cm							

cho Mountain because the contributing watershed, which heads only in the margin of La Mesa, is too small for the development of large constructional surfaces in a valley-border position.

Camp Rice fluvial sediments associated with La Mesa surface commonly contain gravelly strata that are resistant to erosion. Dissection of the sediments has resulted in the development of structural benches with topographically accordant ridge crests below the valley-rim scarp (2.22; figs. 4b, 6, 31).

Slopes of the valley border west of Las Cruces are much steeper than on the east side of the valley, and geomorphic surfaces between La Mesa and Fort Selden are absent (fig. 18). For this reason the effect of dissection in terms of soil truncation has been more severe than on the east side (fig. 22; areas 2,3, and 4). In area 4, truncation and carbonate engulfment of the argillic horizon have resulted in extensive areas of Calciorthids and Paleorthids because carbonate horizons beneath the argillic horizon become diagnostic for classification if the argillic horizon is not present. However, on the western valley border, Calciorthids occur only in a few places, where remnants of the thick carbonate horizon of La Mesa soils are preserved as thin calcic horizons in surficial deposits of the structural benches. This scarcity of occurrence illustrates the extreme effect of dissection because in most places all diagnostic horizons have been truncated and Holocene Torriorthents are now forming in the exhumed gravelly materials of the Camp Rice Formation. The Torriorthents have thin, brown B horizons and stage I horizons of carbonate accumulation.

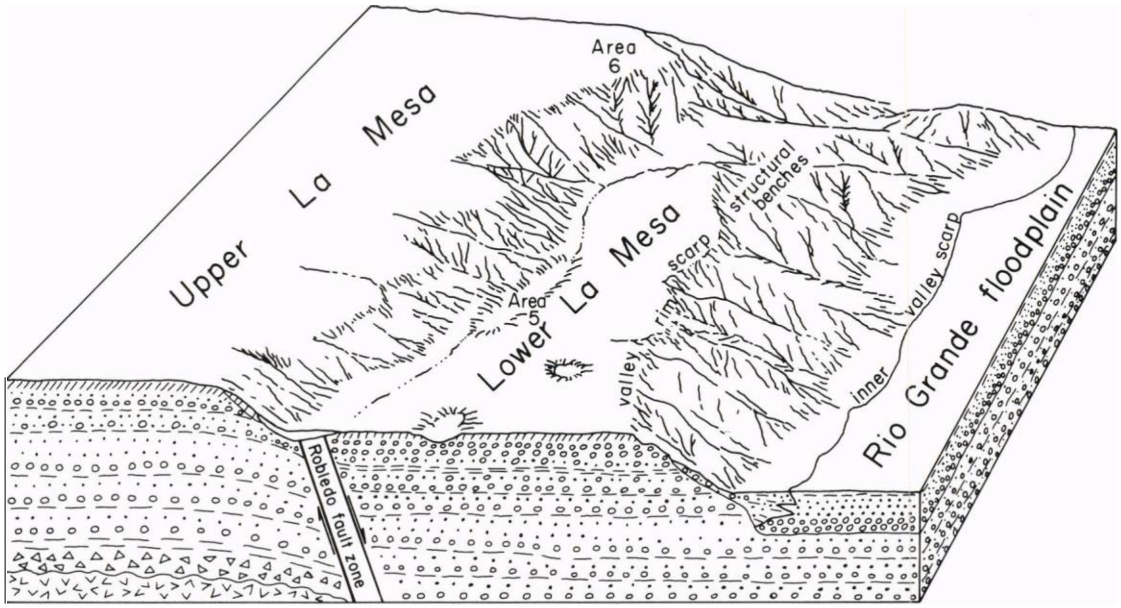


FIGURE 31-BLOCK DIAGRAM OF LOWER AND UPPER LA MESA, AREAS 5 AND 6.

Soils of a structural bench on the east side of the valley will be seen at area 13.

18.6 West edge of floodplain; start ascent of west valley sideslope. Roadcuts ahead in sandy to gravelly deposits of the Camp Rice fluvial facies with minor fine-grained zones. Valley sideslopes cut on the basin fill and discontinuous alluvial and colluvial veneers belong primarily to the Fort Selden unit. 0.8

19.4 Roadcuts ahead in the upper, mixed-rounded gravel member of the Camp Rice. A few fossils of middle Pleistocene vertebrates have been recovered from deposits in this area. 0.2

19.6 Airport exit ahead; *keep right;* prepare to leave interstate in 0.6 mi. 0.2

19.8 Ascend to lower level of La Mesa geomorphic surface. 0.4

20.2 *Take US-70 East exit; bear right.* Road curves to northeast; prepare for left turn. 0.3

20.5 *Turn left,* across westbound lane of US-70, onto frontage road to Municipal Airport. 0.1

20.6 Proceed west, paralleling interstate; prepare for left turn. 0.6

21.2 *Turn left on ranch road through underpass.* Turnoff is located at toe of scarp separating the upper and lower levels of La Mesa. Cuts at the underpass expose a thin scarp-toeslope deposit of Holocene alluvium (Organ) over a buried soil. 0.2

21.4 Road fork; *bear right* (southeast). 0.4

21.8 *Cross fence line and bear right towards windmill.* The water table is about 325 ft (99 m) below the surface in this area or about the same level as ground water beneath the adjacent floodplain (fig. 9). 0.2

22.0 Road fork; *turn left.* Proceed southeast across La Mesa to area 5. 0.5

22.5 STUDY AREA 5.

STUDY AREA 5

Haplargids of lower La Mesa surface;
Torripsamments of coppice dunes

SUMMARY OF PEDOGENIC FEATURES (table 37)-Engulfment of Bt material by carbonates; argillic horizon with some macroscopic carbonate in all subhorizons; very thick, nearly plugged stage III carbonate horizon; accumulation of sodium; in a depression the argillic horizon has no macroscopic carbonate in upper subhorizons, carbonate accumulation is deeper, and there is only slight accumulation of sodium; coppice dunes, which represent a drastic change in relief, soils, and vegetation in less than 100 yrs.

SETTING-Lower La Mesa is a relict basin-floor surface (fig. 31). It expands to a broad plain, about 25 mi (40 km) wide at the International Boundary 35 mi (56 km) to the south. La Mesa is a fluvial plain constructed by the ancestral Rio Grande prior to cutting of the present valley system. Here the surface is formed on gravel and sand of the upper Camp Rice Formation (fig. 6). Parent sediments are generally noncalcareous or only slightly calcareous. North of I-10, lower La Mesa is terminated by a complex scarp formed partly by faulting and partly by river-valley incision. The scarp separating lower La Mesa from the upper La Mesa area to the west marks the southwest extension of the east Robledo fault zone (Seager and others, 1981). Tectonic displacement along this zone was probably initiated in the late Tertiary (Seager, 1975) and has continued episodically into the late Quaternary (Ruhe, 1962; Hawley and Kottlowski, 1969). Movement of the fault involving hundreds of feet (100 m or more) of displacement of the Camp Rice Formation occurred during the interval of La Mesa surface development in early to middle Pleistocene time. Upper La Mesa represents an older Camp Rice fluvial plain that probably was uplifted with the Robledo fault block much earlier than deposition of the surficial gravel and sand of lower La Mesa.

Coppice dunes (area 5b) occur over most of lower La Mesa. Vegetation is mostly on the dunes and consists of mesquite and occasional four-wing saltbush. Many areas between dunes are barren. The water table in this vicinity is 300-330 ft (90-100 m) below the surface (figs. 6 and 9).

SOIL OCCURRENCE-Soil distribution in the vicinity of area 5 is shown in the soil map (fig. 32). Haplargids (Onite, deep petrocalcic phase) and Torripsamments (Pintura soils) of coppice dunes are dominant. Haplargids (Bucklebar soils) are dominant in depressions; Sonoita soils are in pipes. The occurrence of pipes cannot be predicted because the slope of the land surface extends smoothly across them.

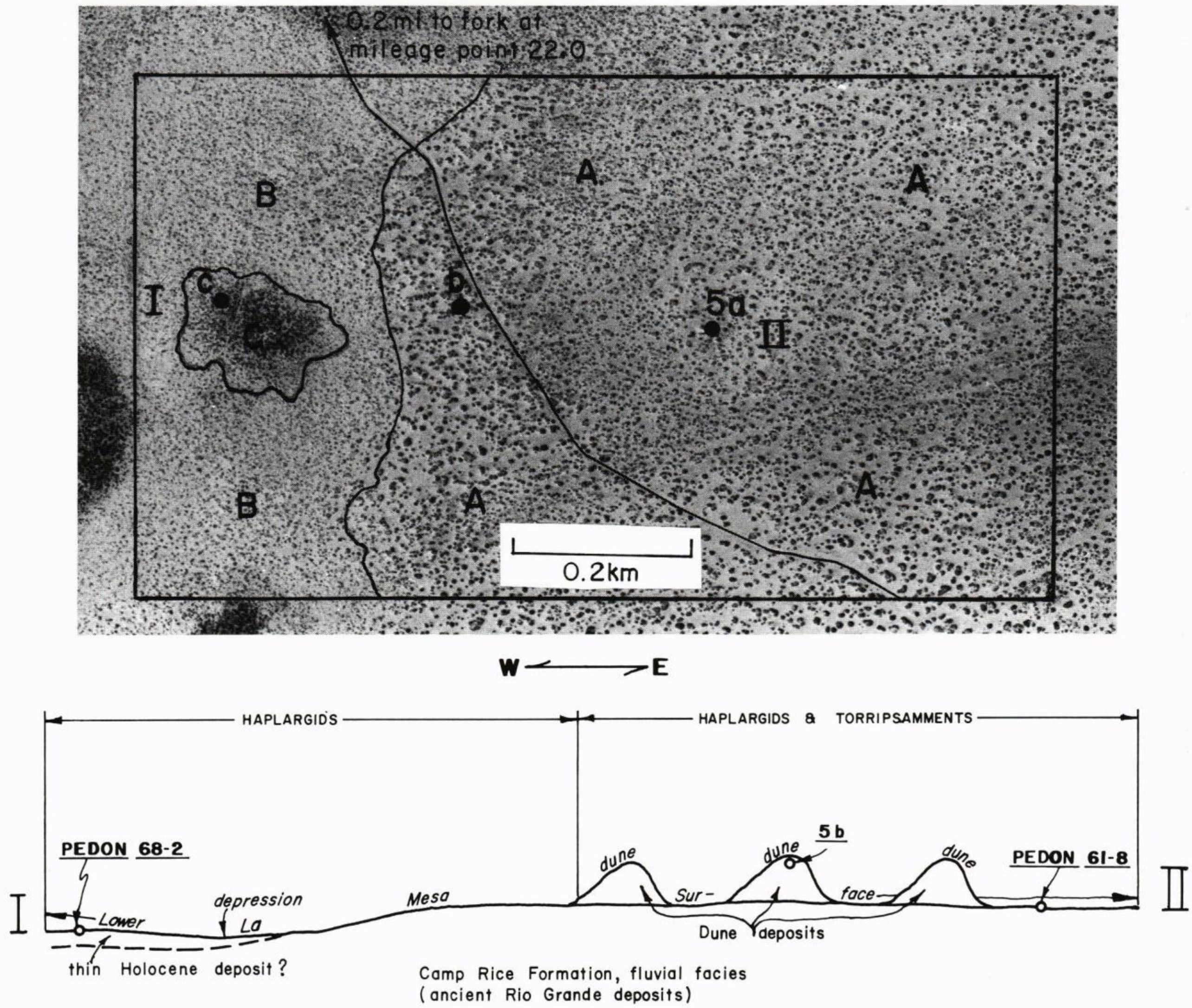


FIGURE 32—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 5. *Upper view:* map of soils; **A**, Onite-Pintura complex (lower La Mesa surface and dunes); **B**, Onite, deep petrocalcic phase (lower La Mesa); **C**, Bucklebar, overflow phase (depression on lower La Mesa). I–II locates cross section. *Lower view:* diagrammatic section of soils, surfaces, and sediments (I–II on soil map).

The minimum size of a polypedon is more than 1 sq m (Soil Survey Staff, 1975). Thus many coppice dunes are large enough for a polypedon. Psamments must have sandy particle size to a depth of at least 1 m; these are the Pintura soils. Torrifluvents (Pintura, thin variant) occur where the dune material is 50-100 cm thick over buried Argids. Dunes with sandy textures thinner than 50 cm have not been separated in this study but could be separated at the phase level if desired.

Area 5a—Typic Haplargid (Onite, deep petrocalcic phase) in the upper Camp Rice Formation (fluvial facies)

This soil has an argillic horizon with some macroscopic carbonate in all subhorizons and a thick, stage III petrocalcic horizon at depths ranging from about 1 to 11/2 m. Because most Onite soils occur on piedmont slopes and are much thinner than this ancient soil, the latter is designated Onite, deep petrocalcic phase to distinguish it from the others. Laboratory data are in table 47. Fig. 33 shows pedon 61-8; the sampling trench for this pedon was filled with waste from a meat-packing plant and for this reason has not been reexcavated. The illustrative pedon for area 5a is just east of the sampled pedon.

Morphology of this soil reflects long-continued illuviation, primarily of carbonate, but with some silicate clay. In the argillic horizon, reddish-brown Bt material alternates with light-colored carbonate nodules. Sand grains in the reddish-brown parts are coated with oriented clay. Scattered pinkish, low-carbonate volumes occur in the upper part of the K horizon. Their presence suggests that the upper part was once part of the Bt horizon but is now almost completely engulfed by carbonate—an interpretation supported by continuation of the silicate clay maximum into the K horizon. Presence of a second clay maximum below the first suggests the possibility of a deposit after pedogenesis had started.

The transition from stage III to stage IV of carbonate accumulation in low-gravel materials occurs in soils of lower La Mesa and is similar in this respect to the stage III-stage IV transition in high-gravel materials on the much younger Picacho surface. Here the carbonate horizon is nearly carbonate-plugged but lacks a laminar horizon at its top (stage IV). Laminar horizons do occur in places, as in soils of several slight ridges and along the edge of lower La Mesa, where depth to the carbonate-plugged horizon is less than 1/2-$^{3}/4$ m and so within reach of more frequent wetting.

Soils of pipes and depressions contain less exchangeable sodium than do other soils (table 47) because of more frequent deep wetting in depressions and pipes. Onite 61-8 meets

TABLE 47—LABORATORY DATA FOR TYPIC HAPLARGIDS ON LOWER LA MESA SURFACE; sand, silt, and clay on a carbonate-free basis.

Horizon	Depth	Sand	Silt	Clay	Organic carbon	Car- bonate	Exchange- able sodium percentage (ESP)	Elec- trical conduc- tivity	†
	cm	%	%	%	%	%	%	mmhos/cm	
Onite phase 61-8									
A	0-5	87	5	8	0.2	2		0.4	
A3	5-13	87	5	8	0.2	3		0.4	
B1t	13-23	85	5	10	0.2	4		0.5	
B21tca	23-41	80	5	15	0.2	12		0.7	
B22tca	41-56	82	4	14	0.2	12	13	2	1.1
B22tca	56-71	82	4	14	0.09	10		6	
K11	71-99	84	4	12	0.08	11		7	
K12	99-117	85	5	10		15	15	9	0.7
2K21m	117-145	80	7	13		40		9	
2K22m	145-170	80	7	13		51	29	8	0.3
2K23m	170-203	72	7	22		44			
2K31	203-236	74	9	17		41			
2K32	236-267	73	10	17		31			
3C1ca	267-287	78	8	15		19			
3C2ca	287-318	84	6	10		11			
3C3	318-340	96	1	2		2			
Organic carbon: 2.2 kg/sq m to 99 cm									
Sonoita 72-3 (in pipe)									
A	0-4	81	6	13	0.2	tr	2	0.8	6.0
B11tca	4-23	79	7	13	0.3	tr	2	0.6	6.0
B12tca	23-57	81	9	11	0.2	1	2	2	5.7
B13tca	57-82	85	7	9	0.1	2	3	3	3.5
B14tca	82-104	80	6	14	0.05	1	5	2	2.6
B21tca	104-131	75	5	21		3	7	1	1.8
B22tca	131-154	80	4	16		1	9	1	1.5
B3tca	154-186	84	4	13		tr	15	2	1.3
Organic carbon: 2.5 kg/sq m to 104 cm									
Bucklebar 68-2 (in depression)									
A2	0-5	62	19	19	0.5	tr	0.1*		
B1t	5-15	65	13	23	0.4	tr	0.1		
B2t	15-33	73	9	18	0.3	tr	0.1		
B21tcab	33-58	74	9	17	0.2	2	0.2		
B22tcab	58-79	82	4	14	0.2	3	0.1		
B23tcab	79-99	83	4	13	0.1	3	0.2		
K11b	99-127	85	3	12		11	0.2		
K12b	127-157	86	3	12		11	0.2		
K13b	157-183	88	2	10		13	0.2		
K14b	183-190	88	3	9		10	0.2		
K2b	190-218	80	6	14		17	0.3		
Organic carbon: 3.3 kg/sq m to 99 cm									

* Values for Bucklebar 68-2 are me/100g of extractable sodium. Maximum ESP would be 4 percent for the K2b.

† To approximate the ratio of exchangeable calcium over sodium plus magnesium, $\frac{\text{CEC} - (\text{exch K} + \text{Mg} + \text{Na})}{\text{exch (Na} + \text{Mg)}}$, where CEC is cation exchange capacity by method 5A6a (Soil Conservation Service, 1972).

the chemical criteria for a natric horizon (table 47) but not the morphological requirements.

Laboratory data for the soils of lower La Mesa (table 47) suggest the entrapment of sodium and soluble salts, as well as carbonate in the precipitation, under certain conditions. The soils and landscape suggest the features responsible for these accumulations. The area is level; and, prior to the recent development of coppice dunes, surface horizons apparently had coarse textures. These features should provide optimum conditions for infiltration of precipitation and the ions in it. Plugged or near-plugged horizons, after their development, should serve as a trap for the retention of ions in the soil solution and prevent them from moving to greater depths. Also, depth to the plugged horizon is commonly substantial (nearly a meter or somewhat more than a meter), so that the zone is thick enough to permit the accumulation (shallow depth to petrocalcic horizons might result in lateral movement of the sodium and soluble salts into and through pipes). See area 6.

Walk westward through the coppice dunes to area 5b, which is just west of the main road (fig. 30).

Area 5b—Typic Torripsamment (Pintura) in coppice dunes

Coppice dunes appear as dark spots on aerial photographs (fig. 32) and are thickly covered with vegetation, mostly mes-

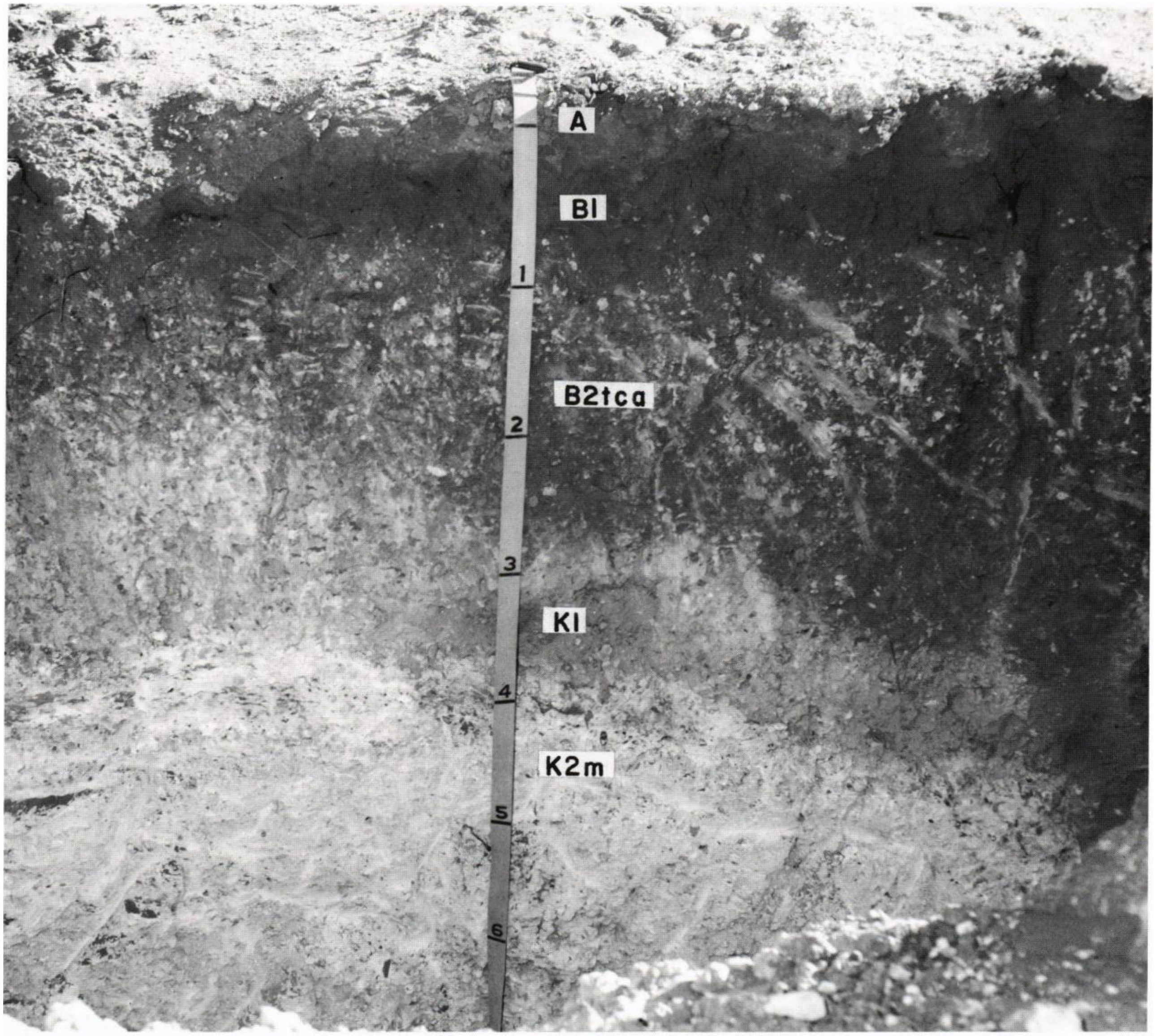


FIGURE 33-HAPLARGID ON LOWER LA MESA SURFACE NEAR AREA 5a. Profile of upper horizons of a Typic Haplargid (Onite phase 61-8) on lower La Mesa surface near area 5a. The K2m horizon is in late stage III of carbonate accumulation. The downward slope in the K2m horizon at right is along the edge of a pipe. Scale is in feet (photographed 1974).

quite. The dunes are also shelters for desert wildlife. Fig. 34 shows a dune landscape near area 5b.

Morphology of the dune materials contrasts markedly with the ancient soils of La Mesa (area 5a), which are buried beneath the dunes. No A or B horizon is apparent in the dune materials, which are stratified and fresh-appearing. However, roots and occasional fillings of faunal burrows (fig. 35) indicate some mixing of the eolian sediments.

Melton (1940) states ". . . on the disappearance of grasses and other effective sand binders with climatic change, overgrazing, etc., remaining clumps of shrubbery may trap a noticeable amount of blowing sand. Mesquite bush . . . grows vigorously on loose sand and is not readily killed by slow sand burial. Sand which falls within the bush may thus stay for a considerable time. If this process continues, a mound of sand eventually is built and held together by the coppice. . . . Shrub-coppice dunes supported by mesquite bush are present in vast numbers in southeastern New Mexico and in adjoining districts in the southern High Plains."

Coppice dunes in the project area are most common where surficial texture is sand, loamy sand, or light sandy loam; and where there is little or no gravel. The dunes are very young; land survey notes (U.S. Bureau of Land Management, Santa Fe, NM) indicate that dunes in this area largely formed and a drastic change in vegetation occurred between 1885 and 1920 (Gile, 1966a). The land survey notes also indicate similar relations in other areas (Buffington and Herbel, 1965; York and Dick-Peddie, 1969). Buffington and Herbel (1965) stated, "Seed dispersal, accompanied by heavy grazing and periodic droughts, appeared to be the major factor affecting the rapid increase of shrubs."

In the project area, soils in the dunes may be divided into two main kinds according to their color (table 48). One kind has 5YR hue (dry color commonly 5YR 5/4), which is caused by thin coatings of oriented clay and associated iron oxides on the sand grains. The other kind has 10YR hue (dry color commonly 10YR 5/3) and the grains lack the 5YR coatings.

The reddish-brown clay coatings contribute substantially to the clay content (table 48); compare the clay content of Pintura 68-1 with that of Pintura 66-11, in which the sand grains lack the 5YR coatings. In a pedon similar to Pintura 68-1, the innermost parts of the clay coatings on the sand grains are

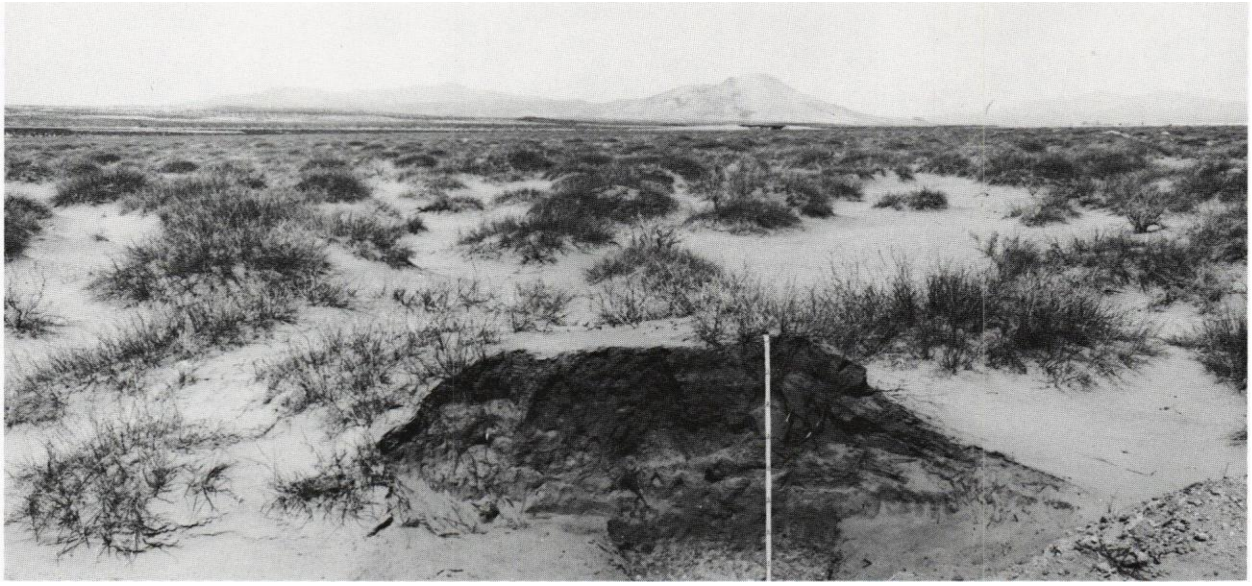


FIGURE 34 -LANDSCAPEOFCOPPICE DUNES AND INTERDUNE AREAS NEAR AREA 5b. Torripsamments are in the dunes, which are Historical and overlie middle Pleistocene La Mesa surface and Typic Haplargids. The Haplargids are at the surface between the dunes. Vegetation on dunes is mostly mesquite; there are a few four-wing saltbush; photographed in winter (February 1966) when leaves were off. Interdune areas are essentially barren of vegetation. Dominant wind movement is from the southwest (left to right). See fig. 35 for closeup of foreground dune; scale in feet.

TABLE 48-LABORATORY DATA FOR TYPIC TORRIPSAMMENTS OF TWO COPPICE DUNES. Pintura 68-1 is east of the Rio Grande valley near the Jornada Road. Pintura 66-11 is on the east side of the valley border, west of Tortugas Mountain. Sand, silt, and clay for the B22tcab and K 1 b horizons of Pintura 68-1 on a carbonate-free basis; other horizons on a carbonate-containing basis; tr(s), trace CaCO, detected by qualitative procedure more sensitive than quantitative procedure used; -(s), none detected by sensitive qualitative tests (6E2; Soil Conservation Service, 1972).

Horizon	Depth	Sand					Silt	Clay	CaCO3 equiv	Organic carbon
		2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05				
	CM									
Pintura 68-1, 5YR hue										
Cl	0-33	tr	1	8	52	25	5	9	tr	0.18
C2	33-102	tr	3	14	50	19	6	8	tr	0.21
C3	102-122	tr	2	13	56	17	4	8	tr(s)	0.21
Ab	122-142	tr	4	16	50	17	6	7	tr(s)	0.25
Bltb	142-152	tr	6	20	46	12	5	11	tr(s)	0.28
B2ltcab	152-168	1	6	17	41	13	8	14	tr(s)	0.23
B22tcab	168-190	3	6	14	36	13	11	17	4	0.35
Klb	190-206	3	7	14	34	12	8	22	14	0.21
Organic carbon, 2.7 kg/sq m to 102 cm										
Pintura 66-11, 10YR hue										
Cl	0-28	tr	13	33	42	6	3	3	-(s)	0.15
C2	28-58	1	15	31	39	6	4	4	tr (s)	0.15
B2b	58-84	2	16	27	35	9	6	5	tr (s)	0.13
B3cab	84-109	2	15	27	36	9	6	5	1	0.10
Clcab	109-137	3	15	26	37	8	6	5	2	0.10
C2cab	137-163	4	21	30	36	3	3	3	1	0.06
C3b	163-188	3	21	30	36	4	3	3	tr	0.06
Organic carbon, 2.1 kg/sq m to 109 cm										

FIGURE 35—CLOSEUP view OF DUNE AND TORRIPSAMMENT. Closeup of foreground dune (fig. 34) and Typic Torripsamment (Pintura). The resistant layers apparently mark former crusted surfaces of the dune, which has built upward mainly during spring dust storms. Knife marks base of the coppice dune sediments, most of which accumulated between 1885 and 1922. Scale in feet (photographed February 1966).

resistant to removal by the procedure for particle-size determination; patchy coatings of reddish-brown clayey material still remained on the grains. Treatment with dithonite-citrate removed all of the clay, the sands were left white, and clay content increased by approximately 1 percent (Gile and Grossman, 1979).

Dunes with 5YR hue occur in areas with reddish-brown argillic horizons. Dunes with 10YR hue occur along the valley border; underlying sediments were initially deposited by the ancestral Rio Grande and contain very little clay (table 48). Size of sand in the dunes is very similar to that of underlying horizons (table 48). Also, dunes with 5YR hue occur only where adjacent soils have 5YR hue, and the dunes with 10YR hue occur only where adjacent soils have 10YR hue. These factors indicate that the dune materials were derived largely from nearby soils.

Walk westward to the depression at area 5c.

Area 5c—Typic Haplargid (Bucklebar 68-2) of a depression in the upper Camp Rice Formation (fluvial fades) with apparent thin overlay

Lower La Mesa has scattered depressions with level floors. The depressions appear on the airphotos as dark patches, which are caused by greater density of mesquite. Typic Haplargids, Bucklebar soils, occur in the depressions.

Laboratory data for Bucklebar 68-2 are in table 47. In contrast to Onite phase at area 5a, Bucklebar 68-2 has more silt in upper horizons; noncalcareous upper horizons; and a deeper carbonate horizon. These differences are thought to be caused by run-in from adjacent areas. The increase in silt in upper horizons (table 47) apparently reflects sedimentation, possibly of Holocene age, in the depression.

En route to study area 6. *Return to airport frontage road.* **1.3**

23.8 Frontage road; *turn left.* Continue west, ascending scarp separating upper and lower La Mesa. 0.3

24.1 Crossing approximate position of east Robledo fault zone. Late Quaternary alluvial and colluvial cover masks offset beds here and to the south. However, sandstone dikes and steeply dipping Camp Rice beds along the fault zone are exposed in the dissected valley-border terrain 1 mi to the north. Prepare for right turn. **0.4**

24.5 *Turn right* through cattle guard onto graded Bureau of Land Management road to Apache and Box Canyons. Cross Fort Selden backslope complex cut on Camp Rice sand and gravelly sand with local strong zones of carbonate accumulation. **0.5**

25.0 Road intersection; *turn right* (north). Continue across backslope and shoulder elements of valley-rim scarp cut on Camp Rice deposits. **0.4**

25.4 Crossing dissected edge of the upper La Mesa plain. The calcrete caprock associated with petrocalcic horizons of upper La Mesa soils crops out ahead in a series of small scarp reentrants. **0.6**

26.0 Dip in road at end of drainage trench for Las Cruces Municipal Airport. *Turn around ahead and park* north of dip on west edge of road. **0.1**

26.1 STUDY AREA 6. *Cross fence and walk along north edge of trench* to point about 800 ft (245 m) west of road.

STUDY AREA 6

Paleargids and Haplargids of upper La Mesa

SUMMARY OF PEDOGENIC FEATURES (table 37)—Haplargids in large pipes, adjacent to Paleargids between pipes; engulfment of Bt material by carbonates; thick stage IV carbonate horizon with multiple laminar horizons; attapulgite and sepiolite in high-carbonate horizons but not in pipe; thick Bt horizon and stage II carbonate horizon in pipe; thick laminar lining in lower part of pipe.

SETTING—Upper La Mesa is essentially a constructional surface developed on sands and pebbly sands of the Camp Rice Formation fluvial facies (figs. 6 and 31). Vertebrates have not been collected from the upper basin fill in this area; and uranium-trend dating of the surficial sediments has not yet provided information on absolute ages. However, this soil landscape is one of the oldest in the Desert Project area. The surface occupies an area of about 30 sq mi, has a slight gradient to the south, and is a true *mesa* in the sense that it is a tableland cut off on all sides by slopes that descend to lower and younger surfaces. The east, west, and possibly south boundary scarps seem to be basically fault scarps with significant erosional modification on the south and east. The north (Box Canyon) scarp is clearly erosional in origin. Upper La Mesa has been effectively separated from the influences of both high water table and runoff from adjacent uplands since early stages of Rio Grande valley entrenchment and since initial uplift of the surface along the boundary faults, whichever occurred first.

Upper La Mesa may be older than lower La Mesa. The time of stabilization could conceivably range as far back as 1.5 m.y. Older conglomeratic sandstones of the Camp Rice fluvial facies are displaced (downthrown to the east) at least 200 ft (60 m) along the Robledo fault zone east of Picacho Mountain. In the upthrown block these beds crop out as horizontal strata that pass beneath the upper La Mesa surface. They are dragged down along the fault zone but are not exposed in the downthrown (lower La Mesa) block. At one locality along the exposed fault zone, undisturbed Camp Rice gravels that form the lower La Mesa surficial fill seem to be angularly unconformable on the steeply dipping sandstone beds described above. In other places they appear to cross the southward projection of the fault zone without noticeable displacement.

The last major movement along the Robledo fault probably occurred during, rather than subsequent to, Camp Rice Formation deposition. Moreover, after faulting, the locus of river deposition would have shifted east to the downthrown block, with basin aggradation continuing for an unknown length of time in that position.

Vegetation consists mainly of snakeweed, mesquite, and *Yucca elata.*

SOIL OCCURRENCE—Soil occurrence in the vicinity of area 6 is shown in the soil map (fig. 36). Diagnostic features of the soils are the argillic and petrocalcic horizons and depth to the petrocalcic horizon if present. The shallow Petrocalcic Paleargids, Cruces soils, tend to be dominant in areas where soils are most susceptible to erosion, such as adjacent to scarps or on slight ridges. Other Petrocalcic Paleargids (Cacique and Hueco soils, in which depth to the petrocalcic horizon is 50-100 cm) are dominant in areas less susceptible to erosion—away from scarps and ridges and in slight depressional areas. Typic Haplargids (Bucklebar soils) are found in pipes.

Area 6a—Petrocalcic Paleargid (Cruces 61-7) in upper Camp Rice sediments

Location of this soil (table 49) along the south bank of a trench is shown in figs. 37 and 38. General horizonation is similar to that of Argids seen earlier, but these soils have more prominent horizons of carbonate accumulation because of the great age of the upper La Mesa surface. Morphological comparisons with younger soils indicate that development of these soils also proceeded through stages of carbonate accumulation until finally the horizon plugged and laminae developed.

The pedon has the characteristic reddish-brown argillic horizon. Nearly all of the clay in the B22t horizon is oriented around the sand grains. The silicate clay maximum (table 49) extends into the horizon of carbonate accumulation (as it does in many younger Argids), indicating carbonate engulfment of a formerly thicker argillic horizon. Despite the great age of this soil, the argillic horizon contains approximately 40 percent of weatherable minerals; little difference occurs with depth, indicating a lack of rigorous weathering during soil development.

The mineralogy was studied by Vanden Heuvel (1966). Attapulgite and sepiolite occur in the middle and lower K horizon, with the attapulgite concentrated above the sepiolite (table 50). The maxima in both occur below the silicate clay bulge, which is in the uppermost K horizon. The regional occurrence of these minerals in the southern Great Plains has been reviewed by McLean and others (1972). Frye and others (1974) discuss the occurrence in caliche of central-eastern New Mexico. Attapulgite and sepiolite contain structural magnesium. Total analyses (Gile and Grossman, 1979) confirm a bulge in magnesium in the zone (K22m-K32) where attapulgite and sepiolite are concentrated. Thin sections show that both minerals occur as aggregates and coatings concentrated in channels and also as a network of fiber-like particles in the matrix. In the C horizon, much of the attapulgite occurs as coatings on sand grains. From these observations Vanden Heuvel (1966) concludes:

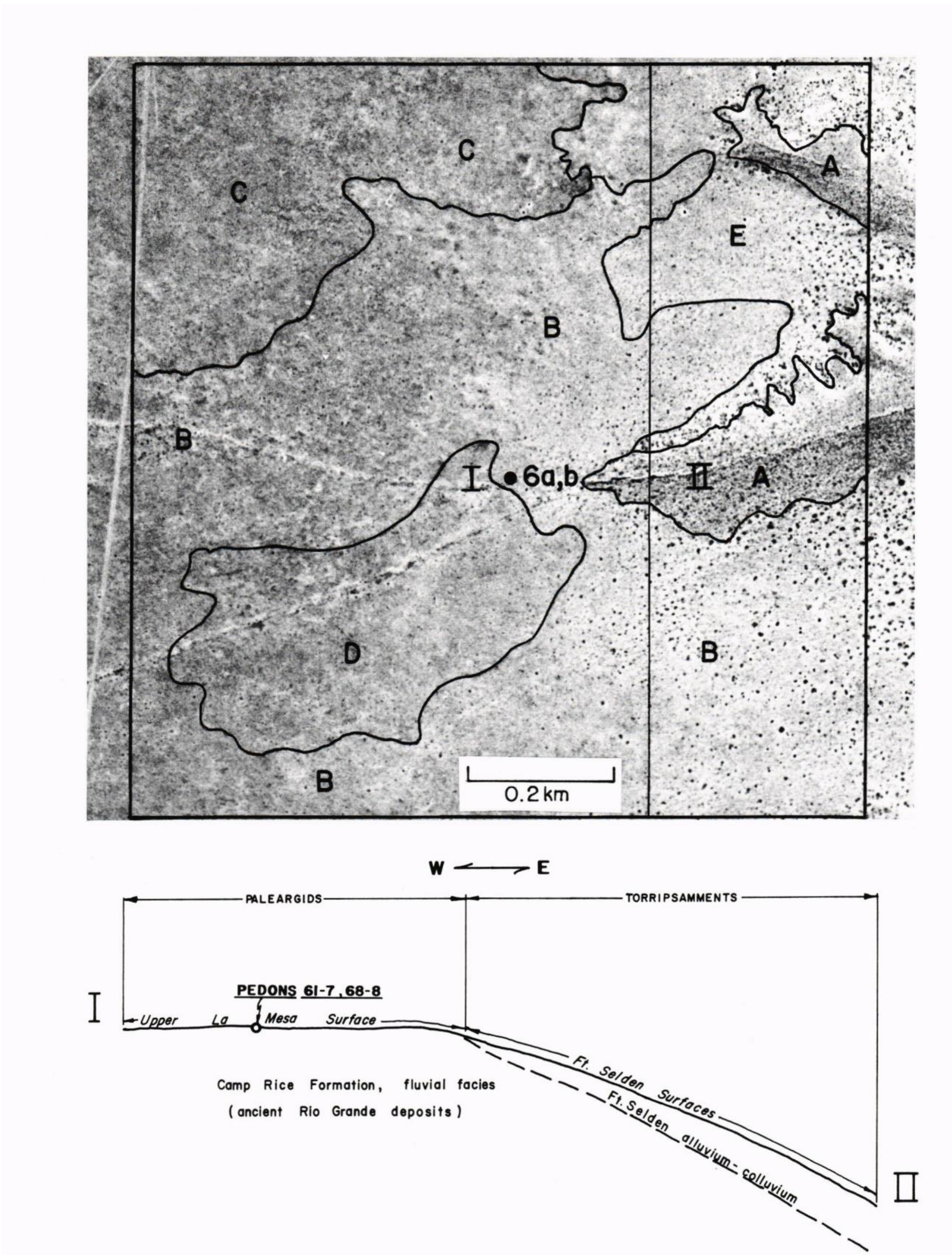


FIGURE 36—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 6. *Upper view:* map of soils; **A,** Bluepoint sand (Fort Selden surface); **B,** Cruces fine sandy loam (La Mesa surface); **C**, Cruces-Hueco complex (La Mesa surface); **D,** Cruces-Cacique complex (La Mesa surface); **E,** Simona fine sandy loam (La Mesa surface). I-II locates cross section. *Lower view:* diagrammatic section of soils, surfaces, and sediments (I-II on soil map).

FIGURE 37—UPPER LA MESA SURFACE AND PALEARGID AT AREA 7. *Upper view:* airport trenches on upper La Mesa and landscape, looking west. The Sleeping Lady Hills are on the skyline, right. The Paleargid and a Haplargid (pedons 61-7 and 68-8) are in the right-hand trench (see below). Photographed 1959. *Lower view:* the Petrocalcic Paleargid, Cruces 61-7, is at indentation at left, with spoil bank above the Typic Haplargid, Bucklebar 68-8, to the left of the area shown. Photographed May 1961.

TABLE 49—LABORATORY DATA FOR A PALEARGID AND A HAPLARGID ON UPPER LA MESA; sand, silt, and clay on a carbonate-free basis. Infiltration, unconfined compressive strength (UCS), and bulk density from Gile (1961); pedon is about 1 m west of Cruces 61-7; tr(s), trace $CaCO_3$ detected by qualitative procedure more sensitive than quantitative procedure used; -(s), none detected by sensitive qualitative tests (6E2: Soil Conservation Service. 1972).

Horizon	Depth	Sand	Silt	Clay	Carbo-nate	Organic Carbon	Infiltra-tion	UCS Dry	Bulk Density
	cm	%	%	%	%	%	inches/hr	psi	g/cc
Petrocalcic Paleargid (Cruces 61-7) adjacent to pipe									
A	0-5	85	5	10		0.25			
B1t	5-18	87	4	9		0.13	5.9	175	1.78
B1t	18-25	82	6	13		0.17			
B21t	25-36	80	5	15	1	0.14			
B22tca	36-48	77	6	17	16	0.24	4.9	85	1.68
K21m	48-74	68	9	23	75	0.15	0.05*	7880*	2.22
K22m	74-102	71	11	18	65	0.05	0.5	1070	1.93
K23m	102-150	75	6	19	51	0.06			
K31	150-185				52				
K32	185-236				41				
C1ca	236-272	89	6	5	13				
C2	272-353	91	4	5	2				
Typic Haplargid (Bucklebar 68-8) in pipe									
A	0-5	76	6	18	tr(s)	0.23			
B1t	5-30	73	7	20	2	0.19			
B21tca	30-48	78	4	18	6	0.11			
B22tca	48-79	82	4	14	3	0.04			
B23tca	79-114	78	8	14	10	0.04			
K&B	114-157	81	8	10	10	0.02			

* Laminar part. The nonlaminar part has an UCS of 3290 psi.

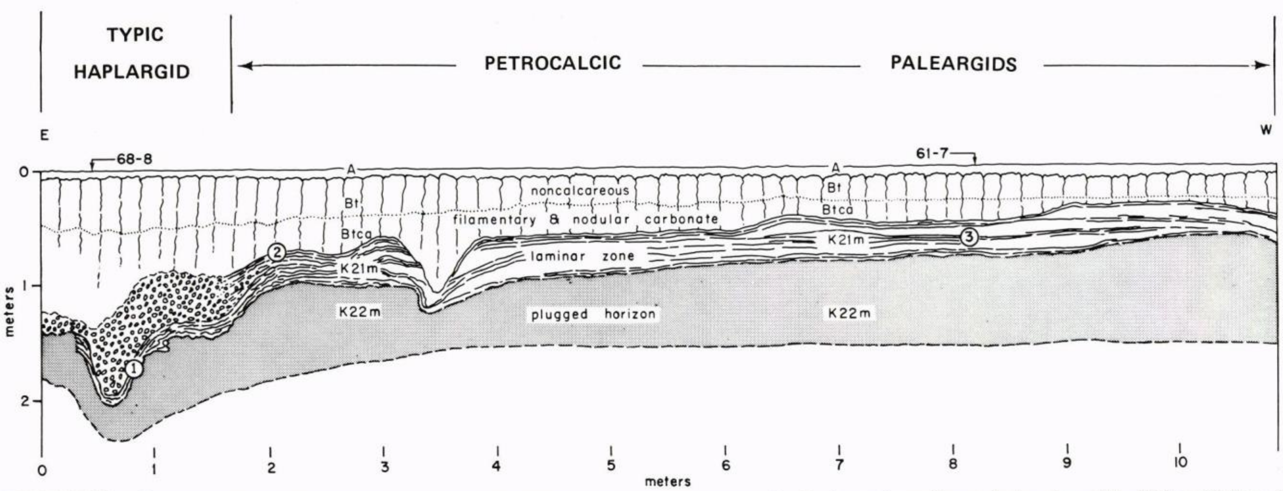


FIGURE 38—CROSS-SECTION DIAGRAM OF SOIL FEATURES IN AIRPORT TRENCH, AREAS 6a, b. Location of sampled pedons (Bucklebar 68-8 and Cruces 61-7) indicated. 1, 2, 3 designate horizons dated by radiocarbon method (table 51).

TABLE 50—CLAY MINERALOGY OF CRUCES 61-7; clay extracted without prior carbonate removal for 1 hr with pH 5 NH_4OAc at room temperature; xxxx—dominant; xxx—abundant; xx—moderate; x—small; d—detected (from Vanden Heuvel, 1966).

Horizon	Clay mineral				
	Montmorillonite	Mica	Kaolinite	Sepiolite	Attapulgite
A	xx	xx	x		
B1t	xx	xx	x		
B21t	xx	xx	x		
B22tca	xx	xx	x		
K21m laminar	xx	d?	x		xx
K21m nonlaminar	xx		x		xxx
K22m	x		x		xxxx
K23m	x	d?	x	xxx	xx
K31	x		d	xxxx	x
K32	x		d	xxxx	x
C1ca	xx		x		xx
C2	xxx		xx		x

> the sepiolite and attapulgite crystallized in the soil during the period of caliche formation. . . . Then, during periods of higher rainfall when the caliche was partially dissolved along solution channels, the sepiolite, attapulgite, quartz, feldspar and other mineral grains were concentrated, the sepiolite and attapulgite forming aggregates and coatings. . . During subsequent drier periods, fresh calcite then crystallized in the solution channels, but in some cases at least, only partially filled them.

Another interpretation is that much of the attapulgite and sepiolite may have been emplaced prior to appreciable carbonate accumulation; thus carbonate could have filled between and pushed apart the aggregates and fiber-like bodies to form a network in the matrix. The channels mentioned may be parts with low initial carbonate accumulation. For example, they could represent former root channels that existed early in the history of the soil and that never completely filled with fine earth after the overlying horizons were carbonate-plugged.

Attapulgite and sepiolite form under saline, lacustrine conditions (Parry and Reeves, 1968; McLean and others, 1972). Thus the attapulgite and sepiolite in Cruces 61-7 may have formed in deposits of small ponds on upper La Mesa, possibly during times of high water tables, prior to entrenchment of the Rio Grande. Dolomite would be expected to have formed under such conditions. Dolomite is present in only trace amounts if at all in clay from the zone where sepiolite is common in Cruces 61-7. However, McLean and others (1972) found only calcite to be present with sepiolite in some instances, and attapulgite tended to occur with calcite. The attapulgite and sepiolite in Cruces 61-7 may have an eolian origin. Evaporation of nearby small lakes on La Mesa may have resulted in an eolian source. Whatever the origin of the attapulgite and sepiolite, their location in and beneath the plugged horizon indicates that these materials accumulated early in the history of this soil. No attapulgite or sepiolite was found in the large pipe at area 6b. Their absence may be due to deep flushing of the pipe by water during full-glacial times (fig. 8).

Table 51 contains the C-14 ages for the upper part of the K horizon of this pedon and also for two laminar horizons lining a nearby pipe (fig. 37). The differences between the inorganic and organic carbon ages are discussed in 3.83. Carbonate in the upper part of the plugged horizon does not have greater C-14 age than the laminar horizon. Similar relations were found in other soils (3.83) and apparently reflect deposition of younger carbonate and/or youthening of older carbonate by solution and reprecipitation due to moisture moving through cracks in the laminar horizon, perhaps during a full glacial.

The similarity in ages for the upper and lower parts of the middle laminar horizon suggests that it formed rapidly. The organic carbon dates of 21 kyrs coincide with the early part of the late Wisconsinan full glacial.

The C-14 ages and location of former water tables provide evidence for the source of carbonate in the soil. The present water table is approximately 330 ft (100 m) below the surface of upper La Mesa (fig. 9). A C-14 age of 21 kyrs was obtained from organic carbon in the middle of the laminar zone of Cruces 61-7 (table 51). About 20,000 yrs ago, the water table in the sandy, permeable sediments beneath this soil must have been graded to the Picacho surface in the Rio Grande valley (approximately 250 ft, 75 m below the surface of upper La Mesa, fig. 6). Hence, carbonate in and above the dated horizon could not have come from the water table and could have come only from atmospheric additions. Further, the erosion

TABLE 51—C-14 AGES OF INORGANIC AND ORGANIC CARBON FROM CRUCES 61-7 AND ADJACENT PIPE.

Location and horizon	Morphology of dated carbonate	C-14 age inorganic	C-14 age organic
		kyrs	kyrs
Cruces 61-7 (#3, fig. 38)			
K21m	Upper hard part of laminar horizon from the middle of the laminar zone	29	21
	Lower hard part of laminar horizon from the middle of the laminar zone	30	21
K22m	Upper part of the plugged horizon	28	
Pipe			
Upper lining of pipe, laminar horizon (#2, fig. 38)	Laminar carbonate	21	
Lower lining of pipe, laminar horizon (#1, fig. 38)	Laminar carbonate	32	

cycle associated with initial entrenchment of the Rio Grande must have lowered any water tables in the sandy sediments of La Mesa adjacent to the valley. Soil formation in these ancient sediments must have proceeded essentially free of any ground-water-table effects subsequent to early entrenchment of the Rio Grande. This entrenchment apparently took place in late middle Pleistocene. Thus, much of the carbonate accumulation in lower horizons could also be of illuvial origin. Since the parent materials contained essentially no carbonate, the carbonate contents by analysis (table 49) may be an approximate measure of illuvial carbonate emplaced since soil development started.

The development of Cruces 61-7 may have proceeded approximately as follows. An early feature of development seems to have been the formation of a thick **B** horizon and an associated horizon of carbonate accumulation. In places, sepiolite and attapulgite—possibly deposited in small ponds on La Mesa prior to downcutting of the Rio Grande—may have been redistributed and pushed apart by carbonate accumulation. The relatively high effective moisture associated with pluvial climates of middle Pleistocene and the sandy parent materials should have resulted in thick zones of leaching and the development of thick **B** horizons and underlying horizons of carbonate accumulation. Subsequent carbonate accumulation apparently engulfed the lower part of the **B** horizon, finally plugging it and causing the formation of the lowermost laminar horizon of the laminar zone. Development of the laminar horizon must have caused an upward displacement of then-overlying horizons for a distance approximating the thickness of the laminar horizon.

Carbonate-plugging and laminar-horizon formation probably proceeded most rapidly during the Pleistocene pluvials because more moisture would have been available for carbonate movement. Rapid development of the laminar horizon is indicated by the similar C-14 ages (both inorganic and organic) for the upper and lower parts of the middle laminar horizon of Cruces 61-7 (table 51).

Soil moisture of a Paleargid

A study of soil moisture in the Jornada Experimental Range (Herbel and Gile, 1973; table 52) illustrates soil-moisture conditions for a Petrocalcic Paleargid on a broad, nearly level basin floor north of the Desert Project. The Paleargid and its landscape have the features for favorable moisture conditions discussed in chapter 3.4, and they combine to make the deeper horizons moist longer than in any other soil studied (Herbel and Gile, 1973). Such ideal conditions for moisture penetration and retention result in a moisture regime that is too moist for Aridisols and particularly for the Petrocalcic Paleargids (3.11, table 52). Petrocalcic Paleargids are dry in all parts of the moisture-control section more than three-fourths of the time (cumulative) that the soil tempera-

TABLE 52—SOIL MOISTURE, SOIL MORPHOLOGY, AND SETTING FOR A PETROCALCIC PALEARGID; complete soil description in Herbel and Gile (1973). Days are number of days annually with moisture potential between 0 and -15 bars.

Soil series: Hueco

Classification: Petrocalcic Paleargid, coarse-loamy, mixed, thermic

Landscape position and parent material: Nearly level basin-floor sediments of mixed origin

Geomorphic surface and age: La Mesa, middle Pleistocene

Dominant vegetation: Mostly black grama *(Bouteloua eriopoda);* scattered mesa dropseed *(Sporobolus flexuosus)* and soaptree yucca *(Yucca elata)*

Average annual production: Perennial grasses, 346 kg/ha

Annual precipitation (cm) 1961-1970: Mean 18.9; range 11.5-34.9 (excluding daily amounts less than 0.63 cm)

Horizon and depth, cm	Soil morphology (in part)	Soil moisture (days) at stated depths; the mean, range and simple correlation (r) between annual precipitation and days of moisture at each depth	
C, 0-5	Sand, loose, soft, single grain, massive, noncalcareous	10 cm	193.9 64-321 0.51
A2, 5-10 Blt,	Fine sandy loam, massive, soft, non-calcareous	25 cm	212.2 99-336 0.64
10-23 B21t,	Fine sandy loam, massive, slightly hard, noncalcareous	40 cm	158.5 32-333 0.67
23-36 B22tca,	Fine sandy loam, massive, slightly hard, noncalcareous	53 cm	116.8 0-350 0.70
36-46	Fine sandy loam, massive, slightly hard, calcareous	68 cm	96.5 0-278 0.71
B3ca, 46-71	Sandy loam, blocky, slightly hard, cal careous	20-30 cm*	212
K1, 71-79	Very gravelly sandy loam, crumb, loose, calcareous	not measured	
K2m, 79-90	Carbonate-cemented material, massive, extremely hard, calcareous	not measured	

"The 10 cm of the moisture control section (from 20 to 60 cm in these soils) that is wetted for the longest cumulative time.

ture at a depth of 50 cm is 5° C or higher (Soil Survey Staff, 1975). Moisture data for the studied Petrocalcic Paleargid (table 48) show that its moisture control section on an average basis is moist for a much longer period of time than is allowed under the definition above. The Petrocalcic Ustalfic Paleargids are more moist than the Petrocalcic Paleargids (Soil Survey Staff, 1975) but intergrades to the Alfisols are thought to be out of place in this desert area. Thus, the soils are classified as Petrocalcic Paleargids, recognizing the need for additional soil-moisture data and, possibly, for a change in the definition of the aridic moisture regime.

The average annual precipitation during 1961-70 was 18.9 cm (table 52). During that period, soil moisture was recorded at depths of 10, 25, 40, 53, and 63 cm. The top of a petrocalcic horizon was at 68 cm depth. The average number of days when the soil moisture potential was between 0 and -15 bars ranged from 212.2 at the 25-cm depth to 96.5 at the 68-cm depth. During the driest year, 1965, there was moisture at the 25-cm depth March 1-April 27 and September 20-November 1. There was moisture at the 25-cm depth for the entire year in 1961, except June 11-July 10. At the 53-cm depth, no moisture between 0 and -15 bars potential was recorded for 3 of the 10 yrs. At the 68-cm depth, no moisture at this potential was recorded for 5 of the 10 yrs. The data show that the laminar horizon at the top of the petrocalcic horizon is being wetted at times under the present climate.

Area 6b—Typic Haplargid (Bucklebar 68-8) in upper Camp Rice sediments

Pipes (3.75) have been observed only in soils of Pleistocene age and must therefore have formed primarily in the Pleistocene. Many pipes of middle Pleistocene basin floors are particularly large (area 6b; fig. 37). These pipes, which consist mostly of Bt material, must have been deeply leached during times of maximum effective moisture in the Pleistocene, moving carbonate to substantial depths. In contrast, petrocalcic horizons of adjacent Petrocalcic Paleargids were plugged with carbonate and funneled water into the pipes. Typic Haplargids occur in the pipes, where the petrocalcic horizon is absent or below 1 m depth. The boundary between the Haplargids and the Paleargids is prominent in exposures but cannot be seen at the land surface because the slope and the landform are the same across both.

Bucklebar 68-8 was sampled in a large pipe near Cruces 61-7 (fig. 32, table 49). The pipe extends deeply on the south side of the trench but is not present at all on the north side. Note the steeply dipping laminar structure along the edge of the pipe indicating that the north edge of the pipe must have sloped steeply. The south edge of the pipe probably rises a few feet south of the trench.

The lowermost laminar horizon in the pipe and the Bt material in the lower part of the pipe indicate that the pipe was once kept free of carbonates by deeply percolating water. Subsequent drier regimes were apparently responsible for the accumulations of illuvial carbonate in the pipe. Continuity of the Btca horizon across all horizon sequences in and adjacent to the pipe indicates that its carbonate is younger than that in horizons below. Lateral merging of the cellular-appearing horizon (in the lower part of the pipe) with the upper part of the multiple laminar horizon indicates that the two formed at approximately the same time. It also shows that the cellular horizon is younger than the lower portion of the multiple laminar horizon. Relative ages of inorganic carbon (sites 1 and 2, table 51, fig. 37) support this general chronological scheme.

The carbonate morphology and depths in the pipe have chronological implications. The stage I filamentary carbonate in the B21tca horizon must be the youngest. Judging from similarities of depth and morphology to carbonate accumulation in soils of Fillmore age, filamentary carbonate in the B21tca horizon was probably emplaced in late Holocene time and carbonate is slowly accumulating there at the present time.

The stage II carbonate nodules are known to be older than stage I. In this area, carbonate nodules have not formed in soils less than about 6,000 yrs old. When compared to underlying accumulations, a climatic change to drier conditions is suggested by this nodular carbonate, which is not only higher in the profile but also forms a distinct maximum by analysis (table 49). Carbonate nodules in the B22tca horizon may have formed mainly during the interval of approximately 7,500-12,000 yrs ago, which had times of greater effective moisture than now but less than the full-glacial interval. Similar stage II horizons at similar depths will be seen in the Haplargids of the Isaacks' Ranch surface (study area 9).

A still-earlier time of carbonate accumulation is indicated by the cellular-appearing horizon of carbonate accumulation that underlies the stage II nodular zone (fig. 37). Carbonate in this horizon must have been emplaced by water that moved quite deeply but not as deeply as water involved in emplacement of the older, underlying laminar horizon.

Morphological comparison of soils of lower and upper La Mesa

The major soils of upper and lower La Mesa are similar in several respects. Soils of both surfaces have Bt horizons and thick Km horizons that grade through nodular K3 horizons into C-horizon material. The Bt horizons contain similar amounts of silicate clay; lower subhorizons commonly contain nodules of carbonate-cemented, former B-horizon material. However, the soils do have certain morphological differences that are attributed to an age difference between lower and upper La Mesa. The Km horizon of the Onite phase (dominant on lower La Mesa) lacks a laminar horizon; and, although some Km horizons of lower La Mesa soils do have laminar horizons, they are commonly single and show no evidence of fracture and recementation. In contrast, Km horizons of upper La Mesa soils commonly have multicyclic laminar zones that consist of a number of laminar horizons, often separated by nonlaminar, carbonate-cemented material. Evidence also exists for fracture, weathering, and recementation in laminar horizons of some soils on upper La Mesa. Pipes that penetrate the K horizons of upper La Mesa soils are usually thickly (several millimeters to several centimeters) lined with laminar carbonate whereas linings in pipes of lower La Mesa soils have been observed only where the K horizon is shallow, and such linings are very thin. Pipes of upper La Mesa soils have more complex morphologies and contain evidence of a greater number of cycles of carbonate accumulation than do pipes of lower La Mesa soils.

Alluvial parent materials of lower La Mesa soils may be significantly younger than those of upper La Mesa soils. Soil development on lower La Mesa may therefore have started later in middle Pleistocene time; and thus the reason for the observed morphological differences in the soils could be a significant difference in their ages.

En route to study area *7. Return to frontage road- US-70 intersection.* **1.4**

27.5 Cattle guard; *turn left (east) on frontage road.* **0.4** 27.9 Double stop signs. *Turn left on eastbound lane of US-70 towards Las Cruces.* **0.3**

28.2 Start descent from lower La Mesa to Mesilla Valley floor. Valley sideslopes are primarily Fort Selden surfaces, with discontinuous alluvial and colluvial cover on bevelled Camp Rice deposits. Loamy to clayey zones separating thick sand and gravel layers may represent floodplain sediments within an aggradational sequence dominated by coarse channel deposits. **1.4**

29.6 Descending to floodplain level across a narrow fan-toeslope belt primarily composed of the Fillmore unit. Stable remnants of late Pleistocene valley-border surfaces (Tortugas and Picacho) are rare or absent in this geomorphic setting characterized by small drainage basins with steep slopes on sandy basin fill. **0.7**

30.3 Canal crossing; prepare for left turn. **0.4**

30.7 Fairacres. *Turn left on NM-430.* Continue north on floodplain. **0.5**

31.2 Lone peak at the valley edge to the northwest (2.44) is Picacho Mountain. The summit area is intrusive rhyolite, while the lower slopes are older volcanic rocks of the Palm Park Formation with a thin cover of Camp Rice fan and river deposits and younger colluvium. The Palm Park consists mainly of volcanic mudflow breccias of andesite-latite composition. A tuff breccia from the Palm Park sequence on the north side of Picacho has been K-Ar dated at 43 m.y. The rhyolite has not been dated, but K-Ar dating of similar intrusive rocks in the northern Robledo area indicate a probable age of about 35 m.y. (Seager and others, 1981). **0.8**

32.0 Village of Picacho to left is located on toe of a Fillmore alluvial fan. Note good views to the west of a prominent series of benches along the foot of the Picacho-Robledo Mountain block. These surfaces are the type Picacho terrace of Dunham (1935). They have a gentle valleyward gradient (generally more than 3 percent) and terminate in bluffs rising approximately 75-125 ft (23-38 m) above the valley floor. This complex of relict fan and erosion surfaces graded to higher base-level positions of the ancestral Rio Grande has been subdivided into the Tortugas and Picacho geomorphic surfaces by Ruhe and associates. These units and associated deposits will be further discussed at study area 7. **2.2**

34.2 Route rises on Fillmore fan surface at mouth of Apache Canyon. Bluffs to left are composed of partly cemented fan gravels of the Tortugas unit with a thin cap of Picacho axial river deposits. The latter wedge out a short distance west of the bluff line and are overlapped by Picacho fan alluvium. The Tortugas deposits fill broad valleys cut in fluvial sand and gravel of the Camp Rice Formation. **1.3**

35.5 Rise to surface of another Fillmore fan; prepare for left turn. **0.2**

35.7 *Turn sharp left onto graded road;* continue west across levee towards Robledo Mountains. **0.2**

35.9 Road fork; *bear right* and continue north along west edge of valley floor. Cross complex of Fillmore and Historical arroyo surfaces at the foot of bluffs ascending to Picacho fan remnants. The river has recently impinged on the valley border, trimming the toes of Fillmore fans and initiating an episode of arroyo incision. **0.5**

36.4 Gate. *Proceed across small arroyo valley; turn vehicles around and park on west edge of road* just north of arroyo. **0.2**

36.6 STUDY AREA 7.

STUDY AREA 7

Torriorthents and Paleorthids of the Fillmore and Picacho surfaces; the Shalam Colony radiocarbon site

SUMMARY OF PEDOGENIC FEATURES (table 37)-Dated charcoal beneath genetic horizons of Holocene soils; soils formed in high-carbonate parent materials; lack of reddish-brown B horizons found in low-carbonate parent materials of stable sites; radiocarbon ages of organic and inorganic carbon in a laminar horizon of soil formed in high-carbonate parent materials.

SETTING-This is the Shalam Colony radiocarbon site. Two charcoal horizons in Fillmore fan deposits have been dated at this locality (figs. 39, 40). The landscape in this study area is typical of highly dissected basin and valley terrains occurring at many places in the Southwest where mountainous areas are near valleys of major streams. Evidence of repeated cycles of valley entrenchment, partial backfilling, near-graded conditions, and renewed entrenchment is well exhibited in this area. Similar features have been noted elsewhere in the middle Rio Grande basin and in parts of the Colorado River system.

The general gravelly composition of the arroyo-fan and terrace alluvium reflects the proximity of the Robledo Mountain block, here composed of intertonguing limestone and red-bed siltstones and sandstone of Permian age cut by intrusive bodies of middle to late Tertiary rhyolitic to basaltic rocks (2.43). The tongues of ancient river deposits in both the Camp Rice and older valley-fill sequences are generally sandy with interbedded silt-clay and gravel zones.

Rising in stepped sequence above present arroyo channels along the northern Mesilla Valley are numerous remnants of older valley fills ranging from thin erosion-surface veneers to fan and terrace deposits. These units cover irregular surfaces cut in older valley fill, Camp Rice basin fill, and locally bedrock of the mountains. Valley fills rest primarily on deeply eroded, sandy river beds of the Camp Rice Formation.

At the time of initial valley entrenchment (Tortugas interval), Camp Rice fluvial deposits filled almost the entire valley between the Robledo and Doña Ana Mountains to a level more than 300 ft (100 m) above the present floodplain. Camp Rice piedmont alluvium was confined to very narrow belts along the basin margins. The Tortugas to Fillmore sequence of valley fills represents at least three major episodes of deep valley entrenchment, each followed by intervals of significant aggradation. The Tortugas unit, of pre-Wisconsinan-late Pleistocene age, has a maximum thickness of at least 100 ft (30 m) in areas of large fans north and south of this site. Coarse piedmont gravels interfinger valleyward with tongues of river sand and gravel. Picacho deposits as much as 50 ft (15 m) thick partly fill a valley cut into the Tortugas unit. Picacho fan alluvium also has valleyward tongues of river sediments and appears to range in age from late pre-Wisconsinan to mid-Wisconsinan.

Picacho fans of the valley border tend to be well developed and preserved east of the Robledo Mountains, despite deep

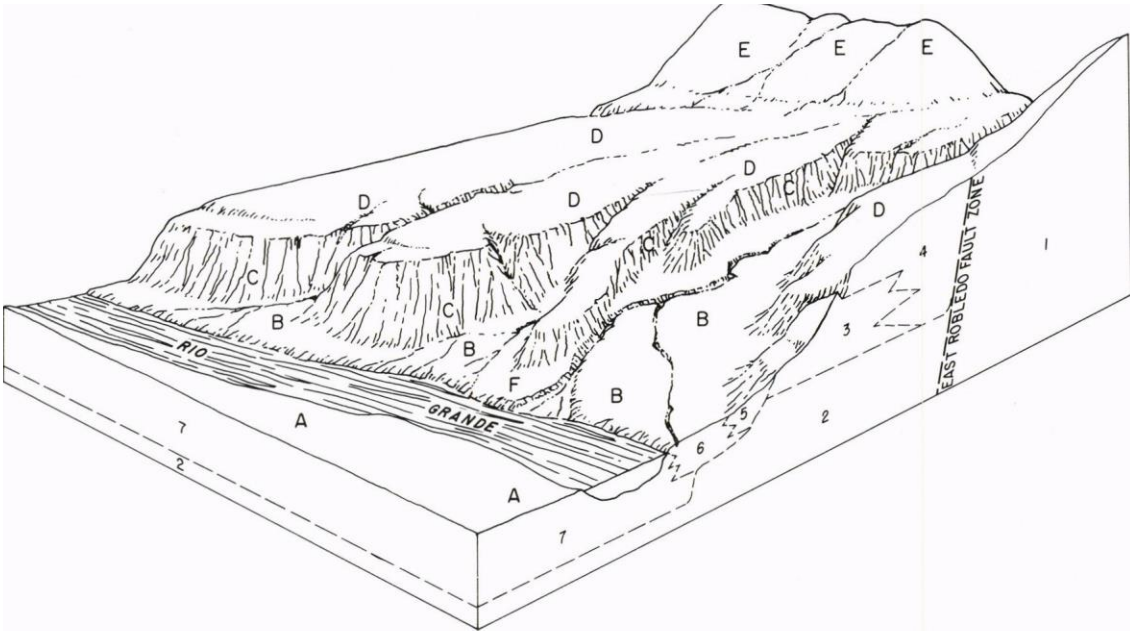


FIGURE 39—BLOCK **DIAGRAM OF THE GEOMORPH C SETTING, AREA** 7, showing soil-landscape relationships in an area of the Tencee-Upton and Dalian complexes near the Shalam Colony radiocarbon site. Soil mapping units: A, soils of the Rio Grande floodplain; B, Dalian complex (Fillmore and arroyo-channel surfaces); C, Dalian very gravelly sandy loam (Fill-more ridge side, colluvium); D, Tencee-Upton complex (Picacho surface); E, Torriorthents and sedimentary rock outcrop (mountain slopes and summits); F, location of charcoal horizons. Geologic units: 1, bedrock (sedimentary); 2, upper Camp Rice Formation, fluvial facies (ancient river alluvium); 3, Picacho River alluvium; 4, Picacho alluvium; 5, Fillmore colluvium; 6, Fillmore alluvium; 7, Rio Grande deposits (late Quaternary river alluvium) and soils. Rio Grande floodplain units not included in study area.

entrenchment of arroyos and proximity to the Rio Grande. The Robledo Mountains consist primarily of calcareous sedimentary rocks. The high-carbonate alluvium from these rocks contributed to the preservation of these fans by furnishing ample carbonate for development of the stage IV carbonate horizon. This horizon (area 7c) is apparently a significant factor in preservation because fans of the same age on the west side of the valley (but formed in low-carbonate parent materials) have commonly been rounded by dissection, are much less prominent, and have soils generally lacking stage IV horizons.

The youngest major valley deposit, the Fort Selden unit of late Wisconsinan and Holocene age, comprises the inner fill of valleys of the river and its arroyo tributaries. Valley-border subdivisions include the older Leasburg and the younger Fill-more units. Fillmore alluvium of Holocene age and river sediments of the inner valley together make up the bulk of Fort Selden deposits. Metcalf's (1967, 1969) studies of molluscan faunas in Mesilla Valley fills indicate that the episodes of widespread valley incision and partial backfilling coincided with waxing and waning parts of late Quaternary glacial cycles. The last major river-entrenchment episode presumably occurred during the late Wisconsinan full glacial, probably between 17,000 and 23,000 yrs ago. The C-14-dated depositional record of the Holocene Epoch demonstrates that drier interglacial intervals (like the present) in this region have been dominated by encroachment of arroyo fans onto river flood-plains and basin slopes and by slow episodic aggradation of valley and basin floors.

The Torriorthent and section of Fillmore terrace alluvium that will be examined in area 7a are located southwest of the road, approximately 400 ft (120 m) upstream from the radiocarbon site. About 55 ft (16 m) of Picacho alluvium (fan gravels over river beds) are locally exposed in the scarp as cending to the Picacho surface. Most sideslopes are mantled with a wedge of Fillmore colluvium and are part of a back-slope to toeslope continuum of hillslope surfaces (fig. 3, 2.11). Area 7b is in Fillmore colluvium that overlaps horizontally stratified Picacho river beds and older basin fill. Area 7c is located on the surface of the large Picacho fan remnant, approximately 800 ft (240 m) south of the radiocarbon site, at a point about 100 ft (30 m) above the Rio Grande floodplain.

Two lenticular beds of charcoal, probably associated with ancient hearths, were found in a 14-ft (4-m) section of Fillmore alluvium exposed in the south wall of the arroyo between the road and the river (Ruhe, 1967; Hawley and Kottlowski, 1969, section 6; figs. 39, 40). The upper bed, approximately 40 inches (1 m) below the surface of the small Fillmore fan remnant has been dated at about 2,850 yrs B.P. The lower bed, approximately 94 inches (2.4 m) below the surface, has been dated at about 4,900 yrs B.P. Fossil pollen and spores are locally present in this section of valley fill, but preservation is not good enough to allow for reconstruction of the middle to late Holocene plant communities in this area.

SOIL OCCURRENCE—The pattern of soils at area 7 (fig. 40) is determined by differences in soil age, landscape position, and the proportion of rock fragments. Because of high-carbonate parent materials, the argillic horizon—a common diagnostic horizon for soils in low-carbonate materials—is not present in this area. Soils of the Fillmore terrace in area 7 are dominated by Torriorthents (Dalian soils), which also occur in the colluvium of ridge sides. With facies changes to less gravelly materials, the Torrifluvents (Anthony soils) occur. The Picacho fan remnants, which are major physiographic features in this area, are occupied mainly by shallow, Typic Paleorthids, either Tencee (loamy-skeletal) or Upton (loamy). Occurrence of these Paleorthids depends largely on the con-

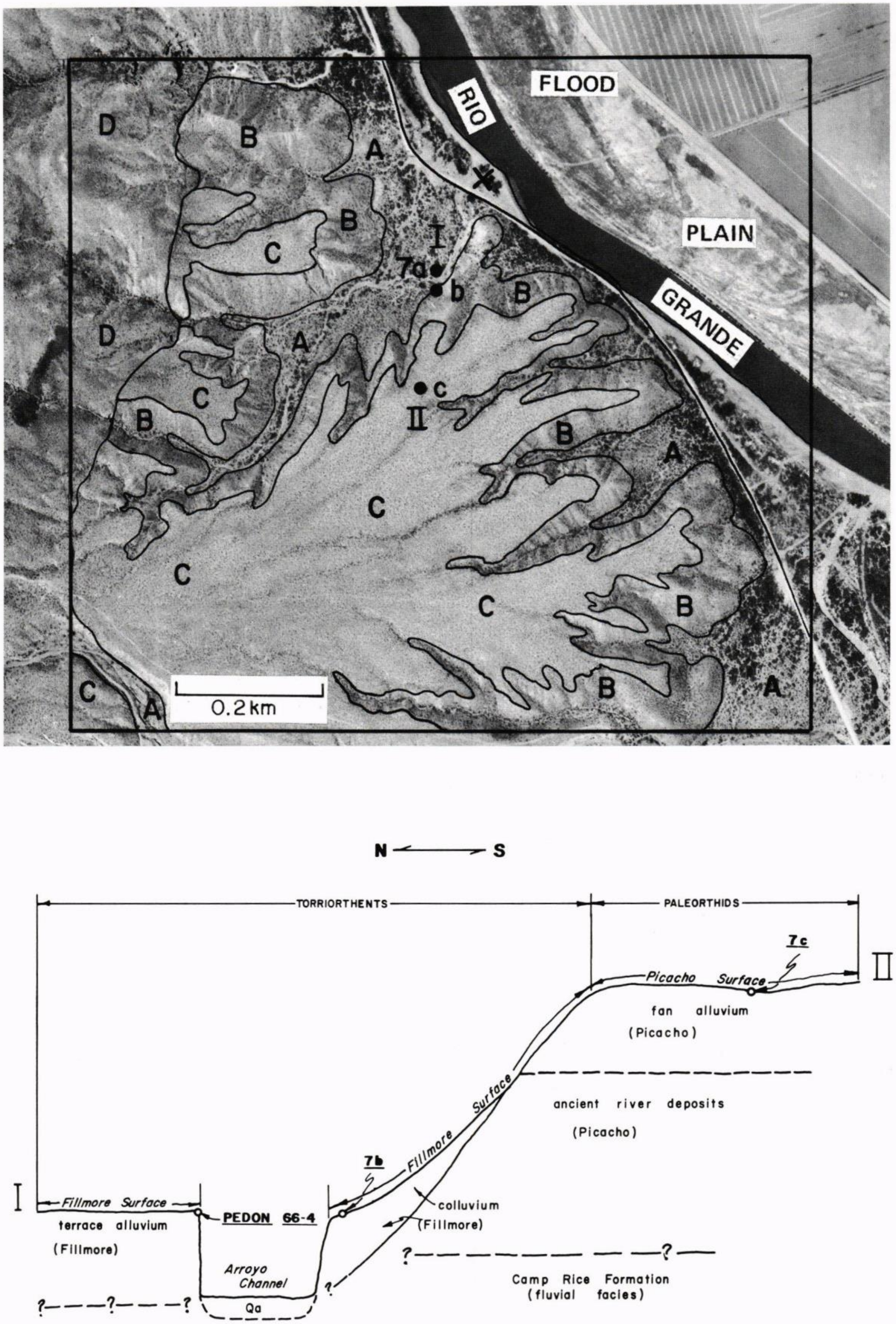


FIGURE 40—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 7. *Upper view:* map of soils in the vicinity of the Shalam Colony radiocarbon site; **A,** Dalian-Torriorthent complex (Fillmore and arroyo-channel surfaces); **B,** Dalian very gravelly sandy loam (Fillmore ridge sides); **C**, Tencee-Upton complex (Picacho surface); **D,** Torriorthent-rock outcrop (mountain slopes and summits, undifferentiated). X**,** location of dated charcoal horizons. I-II locates cross section. *Lower view:* diagrammatic section of soils, surfaces, and sediments (I-II on soil map) (from Gile, 1975, fig. 4, with permission).

tent of rock fragments in the parent materials, with carbonate-cemented fragments contributing in some cases.

Area 7a—Typic Torriorthent (Dalian 66-4) in Fillmore alluvium

This Fillmore terrace is on the north edge of the arroyo and inset below a large Picacho remnant just south (area 7c). Vegetation is mainly creosotebush, mesquite, and prickly pear. Slope is 5 percent to the east.

The uppermost of the two dated charcoal horizons was dated at 2,850 ± 120 yrs **B.P.** and was beneath the genetic horizons of a Torriorthent. Thus these horizons must be less than 2,800 yrs old. At the time of sampling the soil surface above the charcoal was disturbed. The upper deposits were traced upstream, and a pedon (fig. 41) was sampled at an undisturbed site. Laboratory data for this pedon (Dalian 66-4) are shown in table 53.

The most prominent evidence of pedogenesis consists of the stage **I** carbonate horizon with thin carbonate coatings on pebbles that is so characteristic of Holocene soils in the arid zone. Carbonate morphology is very similar to that in soils formed in low-carbonate materials and illustrates the significance of atmospheric additions of calcium to the latter soils. The carbonate horizon is too near the surface for a cambic horizon, and thus the soil is a Torriorthent. Organic carbon is quite high for valley-border soils, nearly 1 percent in the **B** horizon. The soil is strongly calcareous and contains abundant limestone fragments throughout. Moisture of the present climate has not been enough to weather the limestone fragments from upper horizons.

Area 7b—Typic Torriorthent (Dalian) in Fillmore colluvium

This soil has formed in a colluvial wedge (of Fillmore age) on the side of the Picacho remnant. The lower hillslope position (fig. 3) is typical for these colluvial wedges and, as shown in the soil map (fig. 40), they occur in a nearly continuous band around margins of the remnant. Vegetation consists of scattered creosotebush, three-awn, *Lippia wrightii,* mariola, a few mesquite, and prickly pear. The north-facing slopes here and generally in the project area have a greater variety and density of vegetation than do south-facing slopes. Slope is about 40 percent to the north.

The soil is in the Dalian series and has carbonate morphology typical of soils of Fillmore age—a stage **I** carbonate horizon with thin carbonate coatings on pebbles. The carbonate horizon is thicker and more prominent than at Dalian 66-4; soils of these colluvial wedges may represent a longer

TABLE 53—Laboratory data for a Typic Torriorthent and two Typic Paleorthids; carbonate removed for pedons 62-1 and 66-5; carbonate not removed for pedon 66-4.

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Carbonate mm <2 %	Carbonate mm <0.002 %	Organic carbon (%)
Typic Torriorthent (Dalian 66-4) on the Fillmore surface							
A	0–4	64	25	11	19	tr	0.6
Bca	4–13	68	19	12	25	2	0.9
C1ca	13–30	70	18	13	30	2	0.7
C2ca	30–53	75	14	11	30	1	0.5
C3ca	53–79	78	12	10	33	1	0.4
C4	79–109	74	13	13	34	2	0.2
C5	109–140	75	12	13	36	1	0.1
	0–79*						
Organic carbon, 3.6 kg/sq m to 109 cm							
Typic Paleorthid (Tencee 62-1) on the Picacho surface							
A	0–3	64	25	11	15†	1	0.4
B21ca	3–13	64	23	13	20†	2	0.5
B22ca	13–28	65	23	12	24†	3	0.4
K21m and K22m	28–30	47	33	20			0.2
K23m	30–51	73	16	11	40	4	0.2
K31	51–66	66	22	12	37	4	0.5
K32	66–86	56	29	15	41	4	0.3
Cca	86–107	63	23	14	38	2	0.2
K21m	28–28½	30	42	28	175		0.4
Organic carbon, 0.7 kg/sq m to 28 cm							
Typic Paleorthid (Upton 66-5) on the Picacho surface							
A	0–1	61	28	11	12		0.2
A	1–5	48	34	18	22	2	0.1
B21ca	5–8	48	36	17	27	tr	0.1
B22ca	8–20	46	36	19	24	tr	0.2
K1	20–30	47	40	14	28	2	0.5
K21m	30–34						**
K22m	34–58	52	29	19	59	8	0.2
K3	58–74	38	49	12	55	4	0.1
Cca	74–102	53	26	21	58	2	0.0
	74–102				81‡		

*45 percent coarse fragments by volume; $CaCO_3$ equivalent of 61 percent for <75 mm.
†Carbonate contents of the whole material for the A, B21ca and B22ca horizons are 41%, 36%, and 53% respectively.
**Split for analysis. The uppermost laminae contained 0.68% organic carbon; the upper and lower halves of the laminar zone contained 0.52% and 0.53% organic carbon respectively.
‡75–20 mm.

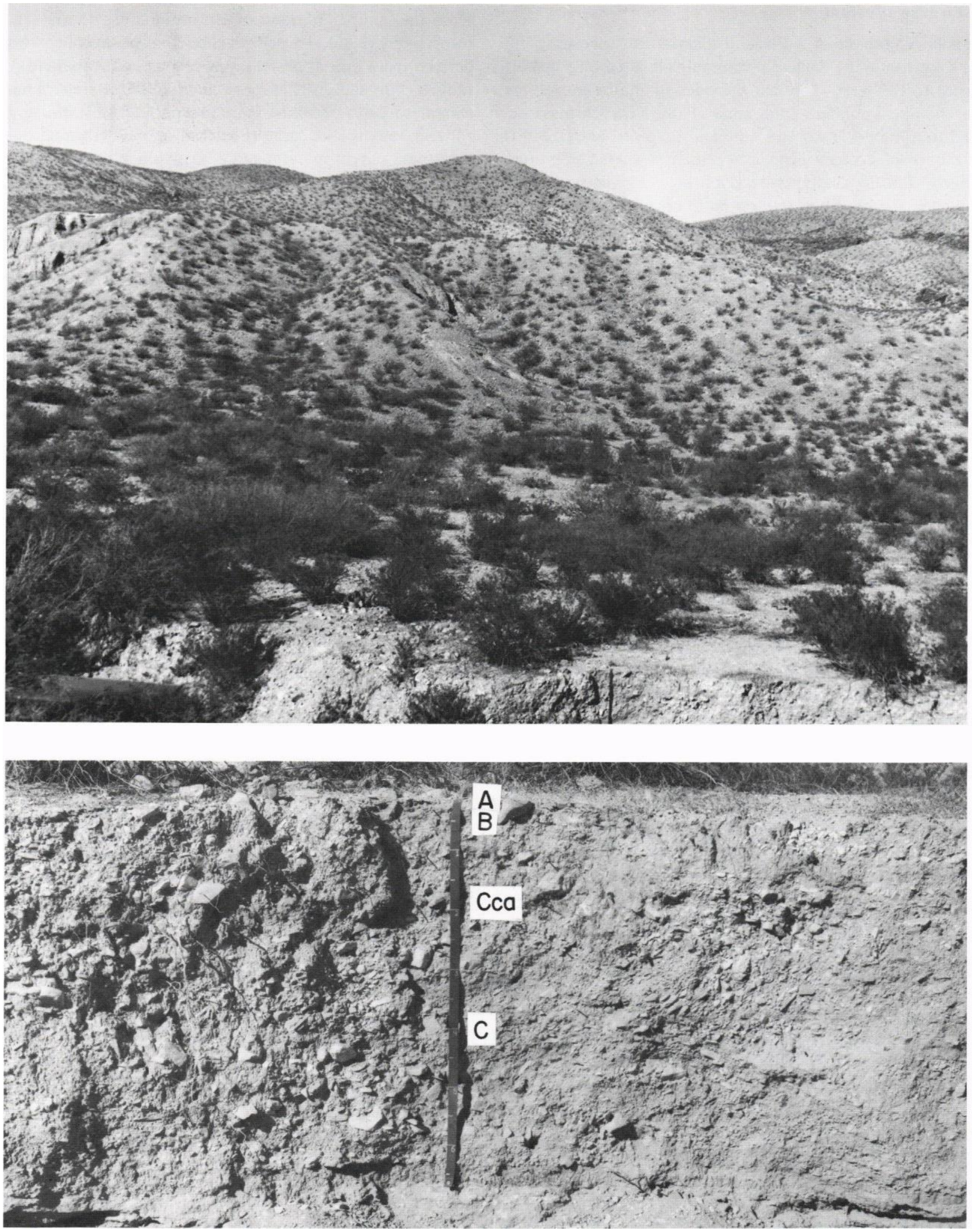


FIGURE 41—FILLMORE SURFACE AND TORRIORTHENT AT AREA *7. Upper view:* landscape of a Typic Torriorthent, Dalian 66-4, on the Fillmore surface. Foothills of the Robledo Mountains are on skyline, and the Picacho surface and associated fan alluvium is in middle ground. Vegetation is creosotebush, mesquite, and a few prickly pear. *Lower view:* Dalian 66-4, in arroyo-bank exposure of Fillmore alluvium. Scale in feet (photographed November 1966; from Gile, 1975, fig. 5, with permission).

time in the Holocene than do most Fillmore soils in a terrace position.

Area 7c—Typic Paleorthid Tencee) in Picacho alluvium

This is a remnant of a Picacho alluvial fan spreading out from a canyon in the Robledo Mountains located only a short distance to the west. The last episodes of major movement along the east boundary fault zone of this bedrock mass occurred in middle Pleistocene time and involved about 200 ft (60 m) of displacement. Slope is 4 percent. Vegetation is creosotebush, ocotillo, fluffgrass, and a few prickly pear.

Data for a similar soil (Upton 66-5) on one of the stablest sites to be found on the Picacho surface (about 1.4 mi to the south) are in table 53. A significant feature of this soil is its character with respect to evidence of silicate clay illuviation. If any evidence for an argillic horizon is to be found in these soils, which have formed in parent materials with very high carbonate content, such evidence should be found in Upton 66-5, which occurs on a very stable site. The particle-size analyses (carbonate-free basis) provide no indication of an accumulation of silicate clay despite the considerable age of this soil and its having formed partly in a Pleistocene full glacial. Also, thin-section studies of similar high-carbonate horizons indicate that not enough oriented clay would be present for an argillic horizon. These relationships have regional significance because argillic horizons have not been found in parent materials containing abundant limestone fragments, even in soils of this age. Argillic horizons have, however, formed in Pleistocene parent materials of only moderate carbonate content (Gile and Grossman, 1979).

A substantial number of limestone fragments remain in upper horizons, indicating that even the greater effective moisture of a Pleistocene full glacial could not remove all of the limestone fragments.

Carbonate translocation and accumulation have been sufficient to produce plugging and development of stage IV morphology with well-expressed laminar horizons. The K horizons of these soils tend to be more prominent than in soils formed in low-carbonate materials of the same age (Picacho; area 3). Gross thickness of the K horizons are similar. The main difference concerns the laminar horizon, which is usually discontinuous or absent in soils formed in low-carbonate materials. In contrast, many of these Tencee and Upton soils have one continuous laminar horizon and some have two, although the uppermost one has commonly been fractured. This difference in development of the laminar horizon must have been caused by the difference in carbonate source. Carbonate in soils formed in low-carbonate materials must have been almost entirely supplied from the atmosphere, and the amount must have been less than that supplied by the high-carbonate parent materials of the Tencee and Upton soils.

The radiocarbon ages of inorganic and organic carbon from the laminar horizon of Upton 66-5 are 15 and 11 kyrs respectively (3.83). These ages show that pedogenic carbonate derived from limestones millions of years old can have young radiocarbon age. Furthermore, the two dates are remarkably similar to dates obtained from morphologically similar horizons in soils of the same (Picacho) age and formed in low-carbonate parent materials (3.83), in which the calcium must have been derived almost entirely from the atmosphere.

Soil prediction

The project area is typical of large parts of the Southwest in terms of terrain, parent materials, range in age of soils, and general climatic history. Because of similarity in these important soil-forming factors, general similarities in soils and soil patterns would also be expected (Gile and Hawley, 1972). Soils similar in morphology and occurrence to those of this area have been observed in other parts of New Mexico and in desert regions of Arizona, Texas, and northern Mexico. Thus predicting the general kinds of soils to be expected in desert regions similar to the project area is possible. Soils for which occurrence may be predicted include Torripsamments, Torrifluvents, Torriorthents, Camborthids, Haplargids, Paleargids, Calciorthids, and Paleorthids.

Specific kinds of soils occur in specific situations. The soils and landscapes at study areas 1-7 show some of the soil-geomorphic relationships in the project area and some of the influences of soil age, parent materials, topography, and climate (both present and past) on soil morphology. Areas 7-22 will show other features to be considered in soil prediction. Aerial photographs (such as the one shown in fig. 40) are particularly helpful.

Last stop of today's session. Return to highway. **0.9**

37.5 Stop sign; *turn left on NM-430.* **0.2**

37.7 Bridge over Rio Grande. *Caution;* sharp curves ahead. **0.3**

38.0 Passing through Shalam Colony site (Pearce, 1965; often misspelled Shalem on maps), occupied in the late nineteenth century by a religious colony. **0.7**

38.7 Stop sign; *turn right (south) on US-85.* **0.5**

39.2 Road junction. US-85 straight ahead; Las Cruces via Valley Drive and Picacho Avenue 5 mi. NM-320 (Thorpe Road) to left; 1-25 via Doha Ana 2 mi.

End of Day 1 road log.

Day 2

Aridisols on the fan piedmont and Mollisols along the San Agustin Mountain front (low-carbonate materials); Entisols and Aridisols near the San Andres Mountains (high-carbonate materials)

The route of the second day's study tour is shown in fig. 42. Some features of soils to be seen on Day 2 are summarized in table 54.

Mile

0.0 Assembly point. New Mexico State University Agriculture Building, Espina Street and College Avenue. *Drive north on Espina Street;* prepare to turn right on University Avenue. **0.2**

0.2 Traffic light. *Turn right (east) on University Avenue* (NM-101). Leave Rio Grande floodplain and ascend fan component of Fillmore valley-border surface. **0.2**

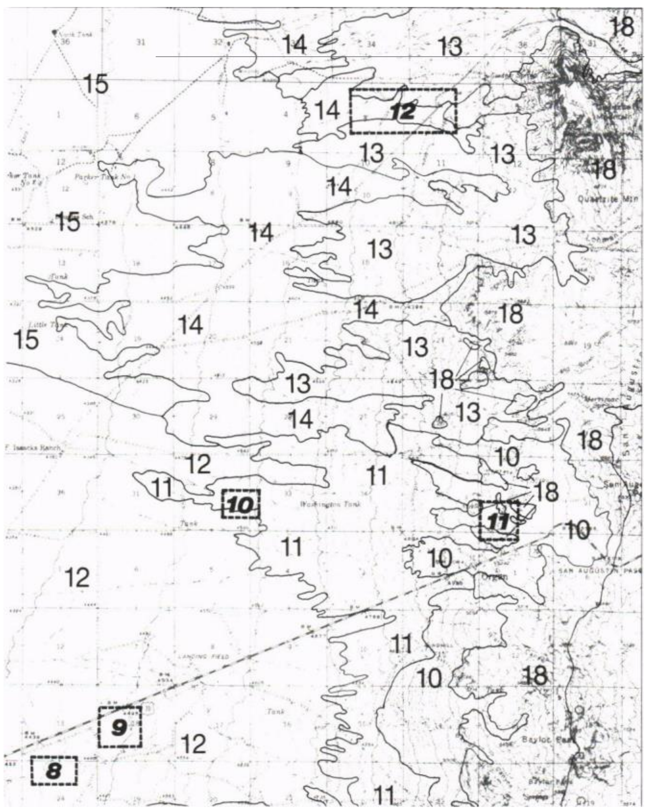


FIGURE 42—LOCATION OF STUDY AREAS 8-12, DAY 2. Explanation for this part of the general soil map (fig. 16):

10 Caralampi-Nolam-Aladdin association (Haplargid-Haplustoll association) of the Jornada and Organ surfaces.

11 Onite association (Haplargid association) of the Organ surface.

12 Berino-Bucklebar association (Haplargid association) of the Jornada **II,** Isaacks' Ranch, and Organ surfaces, and coppice dunes.

13 Conger-Monterosa, carbonatic variant complex (Paleorthid complex) of the Jornada surface.

14 Glendale-Anthony complex (Torrifluvent complex) of the Organ surface.

15 Algerita-Dona Ma-Reagan complex (Calciorthid-Haplargid complex) of the Jornada II and Organ surfaces.

18 Rock outcrop and soils of mountain slopes and summits, undifferentiated.

0.4 Traffic light at Solano Avenue. **0.4**

0.8 Traffic light at Locust Avenue. Continue east on University Avenue to 1-25 North access road. **0.3**

1.1 1-25 Interchange. Prepare to turn right after crossing overpass. **0.3**

1.4 1-25 North access loop; *bear right.* Continue north on 1-25 to US-70-US-82 East exit. This interstate segment crosses a complex of Fort Selden footslope and toe-slope surfaces (fig. 3a) with thin, sandy alluvial fills on erosion surfaces cut across Camp Rice Formation fluvial deposits. Picacho fan remnants are preserved at the mouths of three large arroyo systems (Tortugas, Las Cruces, and Alameda) heading in the Organ Mountains. Storm runoff is now regulated by large flood- and sediment-control structures located east of the highway. A line of municipal water wells supplying more than 12 million gallons per day to the City of Las Cruces is located just west of the interstate highway (King and Hawley, 1975). The wells produce from a zone of saturation in the upper Santa Fe Group 200-700 ft (60-215 m) below the surface. Individual wells produce more than 1,000 gallons per minute (63 liters per second) of good-quality water (about 500 milligrams/liter total dissolved solids). **1.9**

3.3 Lohman Avenue interchange at south edge of Las Cruces Arroyo. The water tank to left, with a mural depicting Spanish colonists of the 1598 Ofiate expedition, is on a Picacho fan remnant flanked by low Fill-more terraces along the arroyo channel. The large rock-faced dam to the right is an Army Corps of Engineers flood-control structure that extends about 2.5 mi and blocks the valleys of Las Cruces, Alameda, and intervening arroyo systems. Before closure of this structure, gauged flows of Las Cruces arroyo occasionally exceeded 2,000 cu ft/sec (56,630 liters/sec) (Water Resources Division, 1970) and caused extensive flooding in the south-central part of the city. **1.8**

5.1 Prepare to take exit for US-70 East. **0.7**

5.8 Crossing valley of Alameda Arroyo with principal spillway of the Las Cruces Flood Control Project. The channel is flanked by low Fillmore terraces and Picacho fan remnants, both inset below ridges of Camp Rice Formation basin fill that rise to the east. **0.3**

6.1 US-70-US-82 East exit; *bear right* and continue northeast on US-70. For the next mile the route ascends sideslope of the Mesilla Valley across erosion surfaces cut in sandy to gravelly, river-channel deposits of the Camp Rice Formation. **1.0**

7.1 Summit area of structural bench formed on erosion-resistant Camp Rice gravels (figs. 4b and 6). Soil-geomorphic relationships in this landscape setting will be illustrated at area 13. Roadcuts and gravel pits ahead contain excellent exposures of the mixed-rounded gravel and sand deposits of the Camp Rice

TABLE 54—FEATURES OF SOILS AND LANDSCAPES AT STUDY AREAS 8–12, DAY 2. Precipitation estimated from records at University Park, the Jornada Experimental Range, and Rope Springs; trenches are usually closed unless otherwise indicated. Symbols: s, sandy; c-l, coarse-loamy; f-l, fine-loamy; f-s, fine-silty; l-sk, loamy-skeletal; m, mixed mineralogy. All soils are thermic.

Study area	Precipi-tation (in., cm) elev. (ft)	Parent materials derived primarily from:	Geomorphic surface and age	Landform and percent slope	Nature of exposure	Classification: Subgroup	Classification: Family	Classification: Series	Diagnostic horizons	Stage of carbonate accumu-lation
8 **a,b**	9, 23 4,460	Monzonite	**a** Jornada II late Pleistocene	**a** Fan-piedmont, 1	South bank of gully	**a** Typic Haplargid	f-l, m	Berino	Argillic	III
			b Organ Holocene	**b** Narrow drainageway, 1		**b** Typic Haplargid	f-l, m	Bucklebar	Argillic	—
9 **a-c**	9, 23 4,490	Monzonite	**a-c** Isaacks' Ranch early Holocene- latest Pleistocene	**a-c** Broad drainageway in fan-piedmont, 1	North bank of gully	**a** Ustollic Haplargid **b** Typic Haplargid **c** Typic Haplargid	f-l, m f-l, m f-l, m	Berino, Ustollic variant Bucklebar Bucklebar	Argillic Argillic Argillic	II II II
10 **a,b**	10, 25 4,600	Monzonite	**a** Organ Holocene	**a,b** Slight ridge on fan-piedmont, 1	Trench	**a** Typic Camborthid	c-l, m	Pajarito	Cambic	I
			b Isaacks' Ranch early Holocene- latest Pleistocene			**b** Typic Haplargid	c-l, m	Onite	Argillic	II, III
11 **a-c**	12, 30 5,240 5,140 5,280	Monzonite	**a** Jornada piedmont late or middle Pleistocene	**a** Crest of bedrock ridge, 5	**a** Trench, open	**a** Ustollic Haplargid	l-sk, m	Coxwell, shallow variant	Argillic	I
			b,c Organ Holocene	**b** Shallow drainageway, 5	**b,c** North bank of arroyo	**b** Torriorthentic Haplustoll	s, m	Hawkeye	Mollic epipedon	—
				c Terrace		**c** Torriorthentic Haplustoll	c-l, m	Aladdin	Mollic epipedon	—
12 **a,b**	11, 28 4,760 4,675	Limestone, sandstone, granite, rhyolite, quartzite	**a,b** Organ Holocene	**a** Terrace, 2	**a** North bank of arroyo	**a** Typic Torrifluvent	c-l, m	Anthony	None	I
				b Fan, 2	**b** Trench, open	**b** Ustollic Calciorthid	f-s, m	Reagan	Calcic	I

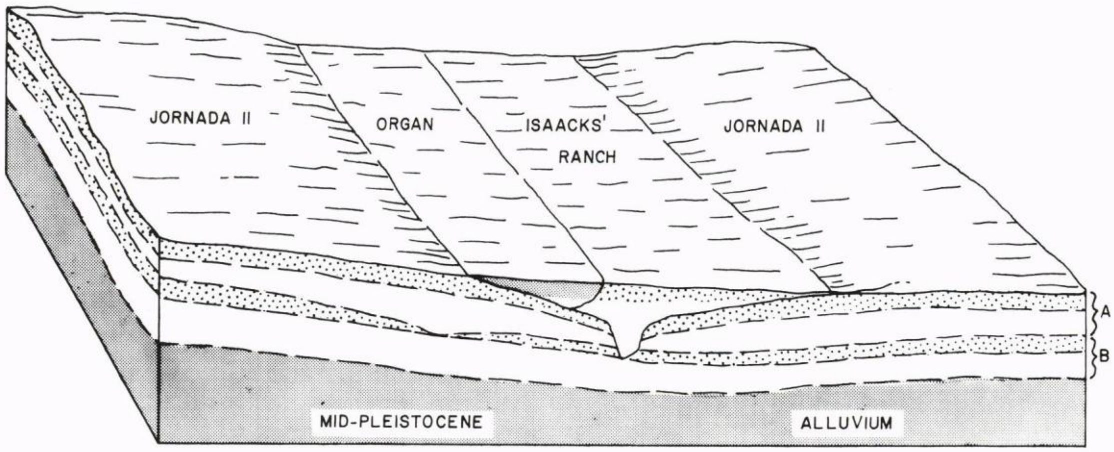


FIGURE 43—BLOCK DIAGRAM OF A FAN-PIEDMONT DRAINAGEWAY. The generalized diagram illustrates the relative age of soils of four geomorphic surfaces. **A,** Jornada II alluvium and its soil; **B,** Jornada I alluvium (Camp Rice Formation, buried) and its soil. The soils of the Jornada I surface are the oldest; soils of Jornada II, Isaacks' Ranch, and Organ are successively younger. The stipples designate Bt horizons. Horizons of carbonate accumulation occur beneath the Bt horizons (see table 51 for stage of carbonate accumulation for soils of each age). The soil morphology and occasional presence of C horizon material between the sets of genetic horizons demonstrate that the clay and carbonate horizons of Jornada I and II alluviums are those of buried soils (formed when they were at the land surface) and not the result of deep illuviation or ground-water phenomena. See area 9 for further discussion.

fluvial facies. Numerous vertebrate fossils, including mammoth, mastodon, and horse remains, have been recovered from the middle Pleistocene deposits in this immediate area (Hawley and others, 1969). **1.7**

8.8 Auto salvage yard to left. Route ascends from structural bench across outer rim (figs. 4b and 6) of the Mesilla Valley to undissected piedmont-slope area of the southern Jornada Basin. To the north the piedmont merges with the floor of the basin (La Mesa surface). *Park on south shoulder of highway* for discussion stop.

SOIL CHRONOLOGY AND BURIED SOILS ON FAN PIEDMONT

Relative ages of soils in the valley-border stepped sequence are determined by their position in the sequence (figs. 7 and 18). On the coalescent-fan piedmont, relative ages of soils of the various surfaces are determined by their position in a vertical section involving buried soils (fig. 43). The lowest buried soil shown in fig. 43 is clearly the oldest, and the soils above are successively younger. All of the buried soils shown in fig. 43 contain little or no gravel and occur at the surface in various places on the fan piedmont (areas 8, 9, 10, 14, 15, and 17).

As along the valley border, the stages of carbonate accumulation are useful as chronological and stratigraphic markers of the soils. Table 55 summarizes the stages of carbonate accumulation for soils of the fan piedmont.

The buried soils that occur in the area of this stop wedge out valleyward over the fluvial sand-gravel facies. To the north the buried soils also thin out and grade to the thick soils of the La Mesa remnant near Goat Mountain (2 mi to north), a twin-peak hill of intrusive microsyenite.

Eastward the topography grades from the dissected terrain that is tributary to the Rio Grande valley into the smooth slopes of the Jornada del Muerto Basin. Piedmont slopes, ranging to middle Pleistocene in age, gradually rise from the La Mesa remnant to the Organ Mountain front about 8 mi (13 km) to the east (fig. 6). The piedmont slope just east of this stop is essentially a relict Jornada I surface (predating river-valley incision) with discontinuous veneers of younger alluvial and eolian deposits (2.53, 2.61). The alluvial veneers thicken mountainward; and much of the piedmont slope between here and the Organ Mountains has episodically aggraded in late Quaternary time, burying the Jornada I surface and its soils by one or more increments of alluvium. These younger deposits comprise an extensive blanket of Jornada II alluvium and discontinuous bodies of Isaacks' Ranch and Organ alluviums that will be seen in areas 8 to 10. **0.7**

TABLE 55—STAGES OF CARBONATE ACCUMULATION FOR SOILS OF THE COALESCENT-FAN PIEDMONT.

Stage: Nongravelly soils	Stage: Gravelly soils	Youngest geomorphic surface on which stage of horizon occurs, and age	
I	I	Organ	100 - 7,000 yrs B.P.
II	II	Isaacks' Ranch	Early Holocene-latest Pleistocene
III	III, IV	Jornada II	Late Pleistocene
III	IV	Jornada I	Late middle Pleistocene

9.5 Jornada Experimental Range Road and study areas 14-16 (Day 3) to left. Continue east on US-70. Note the large, mesquite-covered coppice dunes. 1.2

10.7 Chevron tanks on right; prepare for right turn. Near this point the highway crosses the drainage divide between the Rio Grande and Jornada del Muerto watersheds. To the east, surface flow is to the northwest towards Isaacks Lake playa. Fig. 44 shows the geomorphic setting in areas 8 and 9 just east of this point. The ground-water table in this area is almost 350 ft (107 m) below the surface and has a northwesterly gradient towards the Rincon Valley of the Rio Grande (figs. 6 and 9). 0.7

11.4 *Turn right* onto graded subdivision road. **0.1**

11.5 Crossroad; *turn left.* Continue east across Jornada **II** surface. 0.5

12.0 Crossroad; *turn right.* Continue south and park. **0.1** 12.1 STUDY AREA 8

STUDY AREA 8

Haplargids in and adjacent to a narrow drainageway in Organ and Jornada II surfaces

SUMMARY OF PEDOGENIC FEATURES (see table 54)—Engulfment of Bt material by carbonate; smooth surfaces of peds in argillic horizon lack clay skins but sand grains in peds are coated with oriented clay; buried soil of late middle Pleistocene age, with black (Fe? Mn?) filaments and coatings; soil of late Pleistocene age adjacent to drainageway has stage III carbonate horizon; soil of the same age but in drainageway has stage I carbonate horizon and a thick noncalcareous B horizon, caused by concentration of water in drainageway and resultant deep moisture penetration.

SETTING—This study area is located on the lower part of the broad piedmont slope descending from the base of the northern Organ Mountains to the Jornada basin axis, south of Isaacks Lake playa. An Historical (age) gully, which formed along an old roadway before 1936, cuts into the surficial basin-fill deposits and exposes several stratigraphic units. The general landscape, aside from the gullied terrain and scattered coppice dunes, is part of the Jornada II geomorphic surface (2.61). This surface is underlain by deposits (here about 4-7 ft, 1.5-2 m thick) of the Jornada II morphostratigraphic unit that in turn rests disconformably on a buried Jornada **I** surface and associated Jornada I alluvium (Camp Rice Formation basin fill). Detailed studies in trenches and logging of pipeline exposures indicate that the Jornada II surface and its associated alluvium are very extensive (areas 9, 10, 12, 14, 15, 16, and 20).

The materials were laid down in a coalescent-fan depositional environment on a gentle piedmont slope. Deposits tend to be in the form of broad sheets of loamy material, but locally contain lenticular bodies of coarse gravel and sand associated with ancient channel positions. The alluvium is mainly derived from monzonite, with smaller contributions from rhyolite, limestone, intermediate volcanic, and metamorphic rocks of the Organ Mountain source area. The coarse sand originated from the disintegration of monzonite.

Jornada II deposits wedge out south and west of this area, with the Jornada **I** surface emerging as a relict piedmont slope with only discontinuous veneers of younger deposits. Locally, Jornada II alluvium extends to the distal part of the piedmont as a very thin deposit that cannot be readily distinguished from Camp Rice sediments because of textural similarity and pedogenic obliteration of stratification. The piedmont facies of the Camp Rice Formation associated with development of the Jornada I surface here represents culmination of basin-fill deposition that was immediately followed by initial river-valley incision and subsequent development of the Tortugas valley-border surface. Deposits and soils associated with the Jornada I surface can be traced about 1 mi southwest of this area to the valley-rim scarp along Alameda Arroyo. Both Tortugas and Picacho units are preserved as fills inset below the Jornada I surface in the arroyo valley. Field evidence here and near area 20 indicates that the Jornada II unit is broadly correlative with the Tortugas and Picacho morphostratigraphic units, with large areas of the Jornada II surface probably stabilizing at about the same time as the Picacho surface.

Soils in two Jornada II landscape settings will be examined here: a segment of the piedmont slope characterized by absence of discrete drainage channels and a segment crossed by a narrow drainageway. The slightly depressed channelway that crosses this particular area has probably been maintained throughout a long period of landscape development. The channel, which may have been initiated in Jornada I time, has received a small increment of Organ alluvium.

SOIL OCCURRENCE—The pattern of soils at area 8 is shown in the soil map (fig. 45) and is determined by the location of drainageways and dunes. The Haplargids, Berino soils, are dominant. Bucklebar soils, also Haplargids, occur in drainageways and in places outside of drainageways where the carbonate content is not quite enough for a calcic horizon. The Torrifluvent Pintura, thin variant, occurs in coppice dunes where depth to the buried soil (the buried analogue of Berino and Bucklebar) is 50-100 cm. Pintura soils, Torripsamments, occur in a few dunes where sandy sediments are at least 1 m thick. Some of the dunes, which are in spotted pattern on the map, have been leveled for subdivisions.

Area 8a—Typic Haplargid (Berino 60-7) in Jornada II alluvium

This soil (fig. 46) occurs near but not in a drainageway (fig. 45). Slope is 1 percent. Vegetation on dunes is mainly mesquite, with a few four-wing saltbush. Between dunes the areas are barren or have only a few snakeweed.

Berino 60-7 is on the margin of a dune (fig. 46). The upper 5 cm consists of dune sand that was not sampled. Organic carbon is very low (table 56), placing this soil well within the Typic Haplargids. The Bt horizon has a prominent maximum of silicate clay (table 56). The increase is paralleled by an increase in fine clay, supporting an illuvial origin for some of the clay. A slight maximum in extractable iron also coincides with the silicate clay maximum (table 56) and is typical.

Although peds are well developed in the B22tca horizon, thin-section studies do not show clay skins on ped surfaces. But within peds there are distinct coatings of oriented clay on sand grains and linear bodies of oriented clay, as evidence of illuviation. Clay skins in pipes, to be seen at area 9 (where the analogue of this soil has been buried throughout the Holocene), also are evidence of clay illuviation in the Pleistocene. As shown at area 3, the lower part of the argillic horizon is relict in Pleistocene Argids of the area, and its illuvial clay was emplaced largely or wholly in the Pleistocene. In Berino 60-7 evidence exists for carbonate engulfment of the lower part of a formerly thicker argillic horizon. This evidence consists of reddish-brown parts (typical of the argillic horizon) in

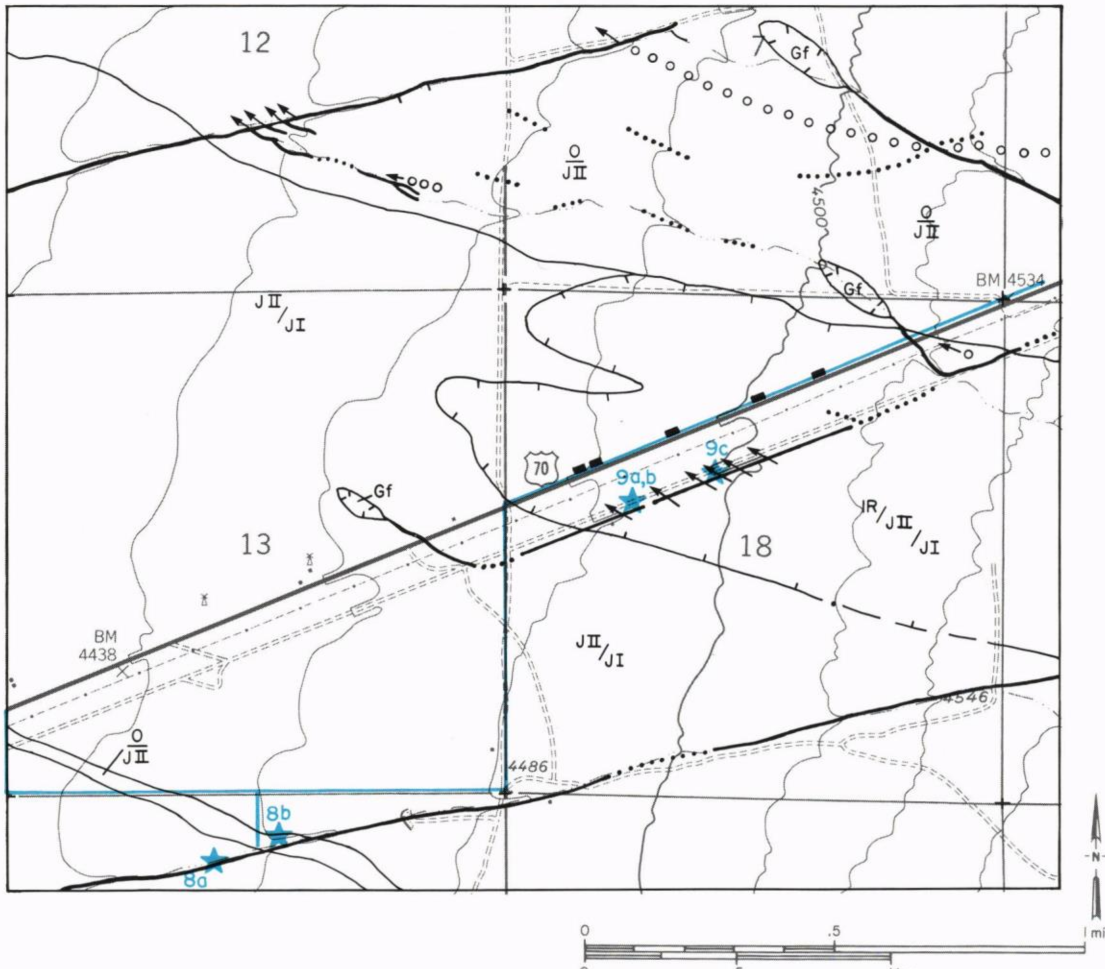


FIGURE 44—GEOMORPHIC SURFACES AND STRATIGRAPHIC UNITS, AREAS 8 AND 9.

EXPLANATION

Gf Gully-mouth fans; alluvium of Historical age.

O Organ surface (constructional phase). Fan and broad-drainageway surfaces underlain by thin, loamy to sandy alluvial deposits of the Organ morphostratigraphic unit (Holocene).

IR Isaacks' Ranch surface (constructional phase). Fan and broad-drainageway surfaces underlain by loamy to sandy alluvial deposits of the Isaacks' Ranch morphostratigraphic unit (latest Pleistocene to early Holocene); thickness up to about 7 ft (2.1 m) in local channel zones.

JII Jornada II surface (constructional phase). Coalescent-fan-piedmont surface underlain by loamy to gravelly deposits of the Jornada II morphostratigraphic unit. Contains minor inclusions of Isaacks' Ranch and Organ units.

JI Jornada I surface (constructional phase). Buried coalescent-fan-piedmont surface exposed in the Highway 70 gullies. Approximately original depositional surface of the younger piedmont facies of the Camp Rice Formation.

Hachures on contacts point towards overlapping deposits

Gullies; dotted where shallow

←oooo Organ gully-channel fills

Isaaks' Ranch gully-channel fills

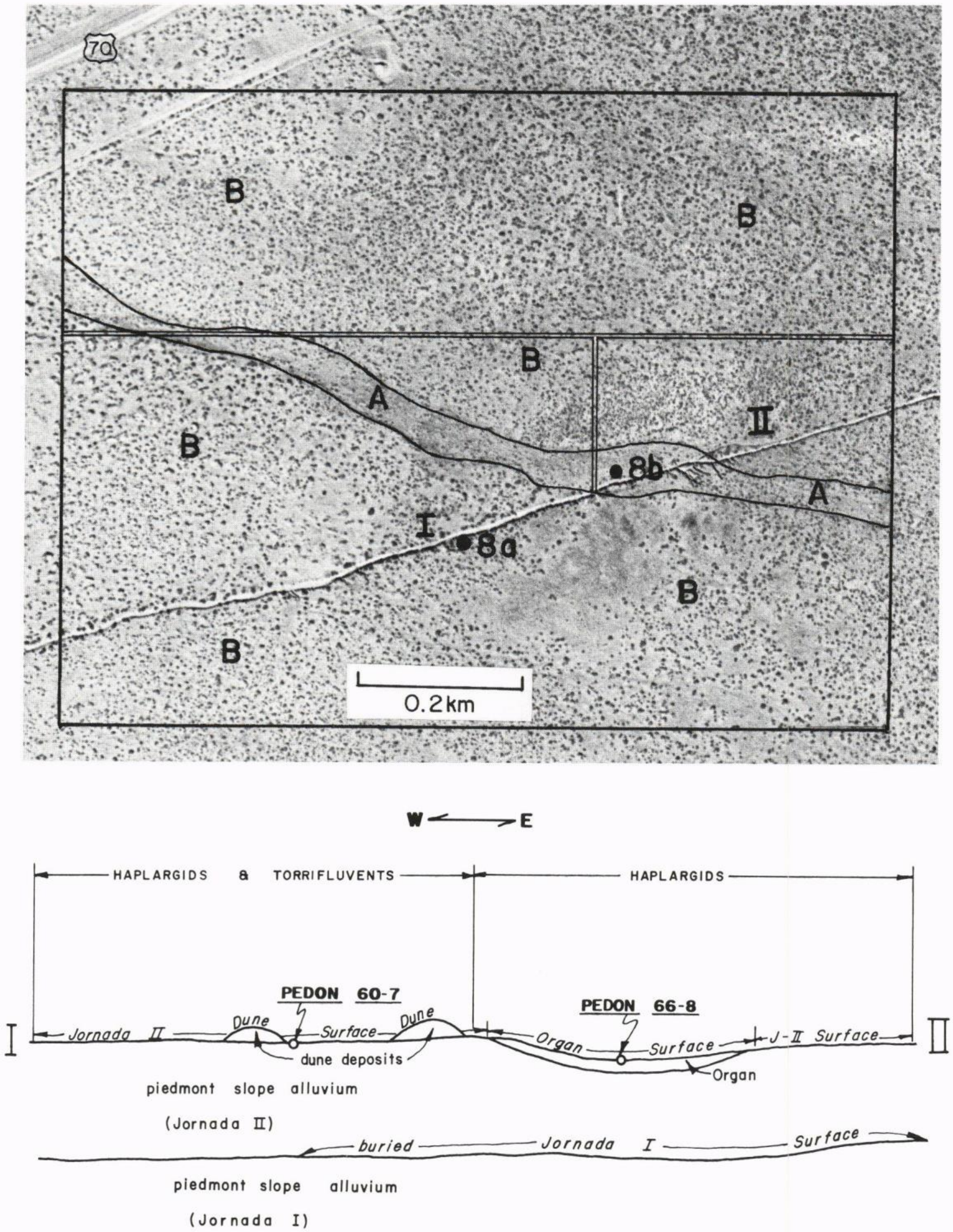
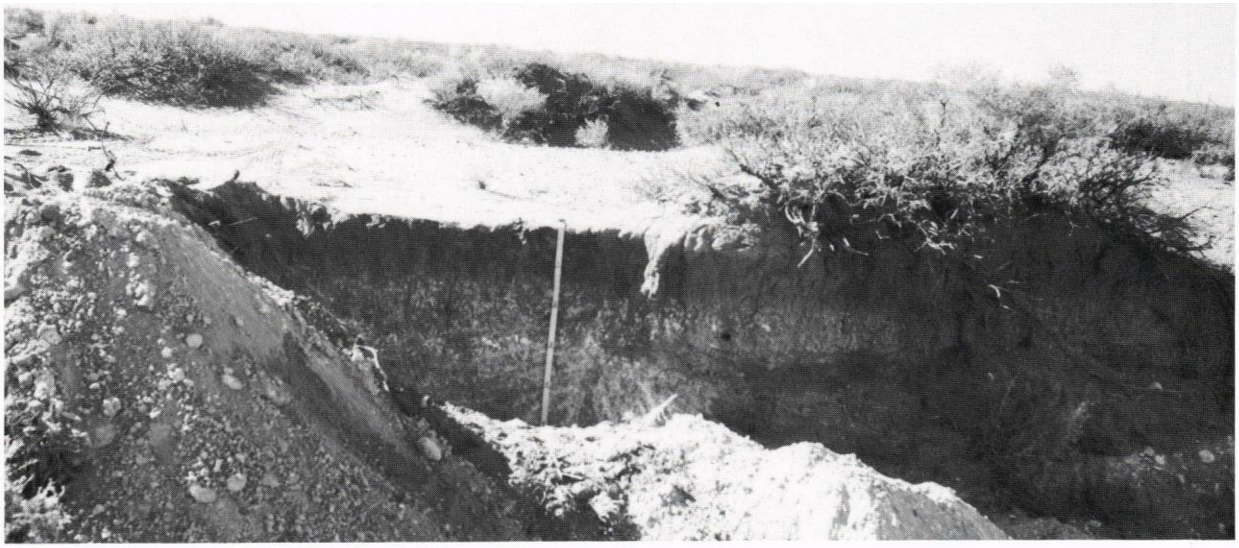


FIGURE 45—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 8. *Upper view:* map of soils; **A,** Bucklebar, overflow phase (Organ surface); **B,** Berino-Bucklebar-Pintura thin variant complex (Jornada II surface and dunes). I–II locates cross section. *Lower view:* diagrammatic section of soils, surfaces, and sediments (I–II on soil map).



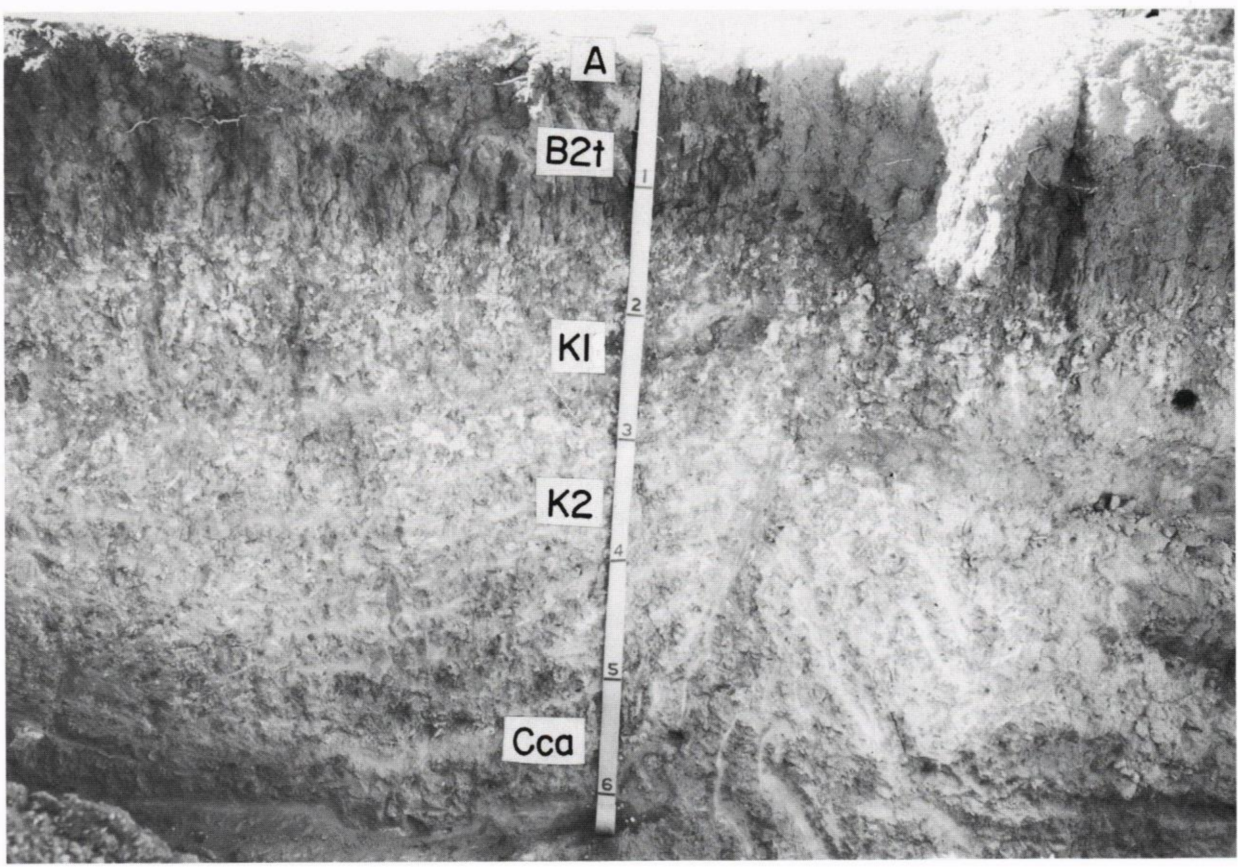


FIGURE 46—JORNADA II SURFACE AND HAPLARGID AT AREA *8a. Upper view:* landscape of a Typic Haplargid, Berino 60-7, on the Jornada II surface; vegetation on dunes is mostly mesquite, with a few four-wing saltbush; a few snakeweed occur between dunes. *Lower view:* Berino 60-7 in stage III of carbonate accumulation (soil formed in Jornada II alluvium). Scale in feet (photographed August 1965).

TABLE 56—LABORATORY DATA FOR TYPIC HAPLARGIDS IN AND WEST OF A NARROW DRAINAGEWAY; tr(s), trace $CaCO_3$ detected by qualitative procedure more sensitive than quantitative procedure used; –(s), none detected by sensitive qualitative tests (6E2; Soil Conservation Service, 1972).

Alluvium	Horizon	Depth (cm)	Sand* (%)	Clay* (%)	Fine clay (%)	Fine/total clay* (%)	Extract-able iron* (%)	Carbonate < 2 mm (%)	Carbonate < 0.002 mm (%)	Organic carbon (%)
	Bucklebar 66-8									
	C	0–8	81†	12				2		0.2
Organ	A2	8–15	67	17				tr(s)		0.3
	B21t	15–30	56	28				tr(s)		0.4
	B22t	30–51	69†	23				tr(s)		0.2
Jornada II	B21tb	51–81	56	29				tr(s)		0.2
	B22tb	81–124	53	24				tr(s)		0.2
	B31b	124–150	59	17				2		0.2
	B32b	150–198	57	19				6		0.1
	Organic carbon, 3.7 kg/sq m to 81 cm									
	Berino 60-7									
Jornada II	A1	5–13	76	14	4	0.25	0.6	tr		0.2
	B21t	13–33	60	28	12	0.44	0.8	tr		0.3
	B22tca	33–43	52	33	18	0.55	0.9	2		0.3
	K11	43–66	67	24	14	0.57	0.6	9	7	0.1
	K12	66–91	71	20	11	0.58	0.6	10	6	
	K2	91–140	70†	18	12	0.67	0.6	15	8	
	C1ca	140–157	77†	13				8		
	IIC2ca	157–165	82†	12				7		
Jornada I	3B2tcab	165–183	80	13				8		
	3K1b	183–193	76	17				34		
	3K2b	193–229	74	18				44		
	3K31b	229–246	66	20				44		
	3K32b	246–267	68	17				30		
	3K33b	267–279	67	17				17		
	3Bcab2?	279–300	69	16				15		
	Organic carbon, 1.8 kg/sq m to 66 cm									
	Dona Ana 60-6									
Jornada II	A	13–18	74	17	5	0.30		1		0.3
	A	18–28	69	20	7	0.35		2		0.5
	B21tca	28–41	64	24	10	0.43		5		0.4
	B22tca	41–51	51	32	19	0.59		8	5	0.4
	K1	51–64	59	29	18	0.62		23	17	0.3
	K21	64–86	72	16	13	0.80		22	14	0.1
	K21	86–112	74	17	13	0.76		28	16	
	K22	112–142	74	20	15	0.73		27	12	
Jornada I	K31Bb	142–175	79	14	9	0.63		25		
	K21b	175–208	78	15	10	0.71		15		
	K22b	208–244	78	13	7	0.52		19		
	C1cab	244–274	80	10	5	0.44		14		
	C2cab	274–310	81	10	4	0.36		7		
	Organic carbon, 3.5 kg/sq m to 13–112 cm									

*Carbonate-free material
†>5 percent by weight > 2 mm

the K2 horizon; extension of the silicate-clay maximum into the K2 horizon (table 56); and similar amounts of silicate clay in both carbonate nodules and internodular material of the K 1 1 horizon (table 56), indicating that the carbonate accumulated largely after the accumulation of silicate clay.

Distinct cylindroids are common in the K horizon. Some of the cylindroids are very hard and some are cemented. The latter are thought to be the oldest ones; their hardness may be due to long-continued local carbonate solution and reprecipitation and to carbonate plugging and grain separation in zones of restricted hydraulic conductivity.

Soil morphology and the low-carbonate parent materials illustrate that essentially all of the carbonate in the calcic horizons of these soils is pedogenic in origin; however, nonpedogenic as well as pedogenic carbonate is present in calcic horizons formed in high-carbonate parent materials (areas 7 and 12).

A buried soil occurs at a depth of 165 cm. Although it is on the same surface (Jornada I) as the Paleorthid at area 4, the buried soil lacks a petrocalcic horizon because of low gravel content. Distinct black filaments and coatings in the K horizon apparently consist largely of iron or manganese or both (areas 13 and 14). In the arid part of the study area the black coatings have been observed on ped surfaces and in pores of both Bt and K horizons, but only in buried soils of Pleistocene age. The black accumulations have not been seen where land-surface soils of the same age are at the surface or in Holocene soils. Black coatings on peds and pebbles do occur in argillic horizons of land-surface soils of Pleistocene age along the mountain fronts where precipitation is higher (area 21b). These factors indicate that the black coatings are features of soil development under conditions of more effective moisture than presently exist in the arid zone. In some land-surface soils of Pleistocene age the black accumulations may once have been present on peds in Bt horizons but were later covered by carbonate accumulation. Others may have been incorporated within peds as new ped surfaces formed because of wet-dry cycles and associated swelling and shrinking of the soil material. A similar explanation was proposed for the absence of clay skins (3.7).

Black, opaque bodies, commonly ranging from 0.05 to 0.5 mm in diameter, have been seen within peds in thin section. These black objects may once have been on ped surfaces, as parts of discrete filaments and coatings that now have been mixed and incorporated within peds. The black accumulations may reflect weathering of the most readily altered ferromagnesian minerals—biotite and hornblende. In buried soils, some of the black material may have been deposited from deeply penetrating water associated with deposition of sediments overlying the buried soil.

Although the buried soil is readily apparent here, westward Jornada II alluvium thins so that the carbonate horizon of its soil has formed largely in the buried argillic horizon, and the contact between the land surface and buried soils is not apparent. This lack of a distinct contact results in a very thick K horizon, as illustrated by Dona Ana 60-6 (table 56). The K horizon also contains the black filaments and coatings present in Berino 60-7.

Area 8b—Typic Haplargid (Bucklebar 66-8) in Organ and Jornada II alluvium

Bucklebar 66-8 (fig. 47) occurs in a narrow drainageway (fig. 46). Vegetation consists of a few tarbush and mesquite; there are many barren areas. Approximately 8 cm of Historical stratified sediments occur at the surface and grade into a low dune just north of the gully. A thin deposit of Organ age, very similar to Organ deposits of this texture where they are more extensive, extends from 8 to 51 cm. The Organ deposit is confined to the drainageway.

A prominent morphological change occurs in the soil of Jornada II alluvium as it extends into the drainageway. The K horizon traced from Berino 60-7 at area 9a grades into a thick, low-carbonate B horizon in the drainageway (fig. 48, table 56). Such zones with thick B horizons associated with present and/or former channels are termed subchannel zones. Water concentrated in the channels deeply leached the subchannel zones to form a soil markedly different from soils outside the channel. Soils in Jornada II alluvium outside the channel received moisture mainly by infiltration of precipitation rather than channel water, and Bt and K horizons developed instead of the thick, low-carbonate B horizon in the channel. See area 9c for further discussion and illustration of these sub-channel zones.

The deeply penetrating channel moisture also causes a change in soil classification. The soil in the channel lacks a calcic horizon within a depth of 1 m and therefore is in the Bucklebar series instead of the Berino series.

En route to study area 9. Return to east-west subdivision road; *turn right and continue east.* **0.5**

12.6 Crossroad; *turn left.* Continue north through Hacienda Acres subdivision. **0.5**

13.1 US-70. Continue northeast on highway. Prepare for right turn. **0.3**

13.4 Crossroad. *Bear to right onto right-of-way strip* between highway, shoulder, and fence. Continue about 0.3 mi and park. Cross fence and walk to gully about 500 ft south. 0.3

13.7 STUDY AREA 9

STUDY AREA 9

Land-surface and buried Haplargids of the Isaacks' Ranch, Jornada II, and Jornada I surfaces

SUMMARY OF PEDOGENIC FEATURES (table 54)—Long exposures of soils in Highway 70 gully; engulfment of Bt material by carbonate; thin Ustollic Haplargid over two buried soils; incipient calcic horizon; effect of mesquite, low dune, and soil burial on organic carbon and Ustollic Haplargids; pipes with clay skins on ped surfaces and in pores; radiocarbon ages of inorganic carbon; Typic Haplargid and low organic carbon between dunes; occasional presence of C-horizon material between sets of soil horizons that differ greatly in age and its significance; thick gully fill of early Holocene-latest Pleistocene age, with genetic horizons underlain by C-horizon material.

SETTING—The "Highway 70 Gully" (Gile and Hawley, 1966) is incised in Isaacks' Ranch, Jornada II, and uppermost Camp Rice (piedmont-facies) deposits (2.61, fig. 44). These sediments are derived mainly from monzonite, with minor amounts of rhyolite, intermediate volcanic, and sedimentary rocks. The gully is cut transverse to the old drainage trend. Its walls provide an excellent cross-section view of relict and buried surfaces (2.14) and associated deposits and soils.

Fig. 43 shows general soil-geomorphic relationships. The figure also illustrates the episodic nature of sedimentation and surface stability that has characterized evolution of this middle piedmont-slope landscape during at least the latter part of the Quaternary. Four distinct soils indicate intervals of surface stability subsequent to each of four major episodes of landscape instability and sediment deposition. The youngest deposit, the Organ unit of Holocene age, is exposed only in a small area near the east end of the gully. There the Organ unit fills channels cut in Jornada II sediments and Camp Rice basin fill. Downslope it spreads out as a thin and discontinuous veneer of alluvium on older units, mainly Jornada II. Isaacks' Ranch alluvium (early Holocene-latest Pleistocene) is mainly confined to a broad drainageway position inherited from the Jornada surface complex.

The Isaacks' Ranch unit fills channels cut into Jornada II deposits and spreads out laterally and downslope to form a sheet of alluvium on the drainageway floor that buries the Jornada II surface. Marginal to the drainageway the Jornada II unit emerges as an extensive relict component of the piedmont landscape, part of which was observed at area 8.

SOIL OCCURRENCE—Soil distribution is shown in the soil map (fig. 48). The pattern of soils is determined by differences in soil age, texture, organic carbon, and thickness of deposit. Nearly all the soils in broad drainageways have argillic horizons and are Haplargids. Most are of Isaacks' Ranch age. Usually these soils to not have enough carbonate for a calcic horizon and therefore Bucklebar soils, which lack calcic horizons, are dominant. Small areas of Berino, Ustollic variant, occur in and beneath low dunes where an incipient calcic horizon is present and where organic carbon is higher than between dunes. Onite soils, coarse-loamy, occur instead of the fine-loamy Bucklebar soils where texture of Isaacks' Ranch alluvium is coarser; these areas are slight ridges (fig. 48).

Area 9a—Ustollic Haplargid (Berino variant 59-6) in Isaacks' Ranch alluvium; buried Haplargids in Jornada I and II alluviums

Slope is 1 percent to the west. Vegetation on dunes consists mainly of mesquite, with some four-wing saltbush. A few tarbush, snakeweed, and desert thorn occur between the dunes.

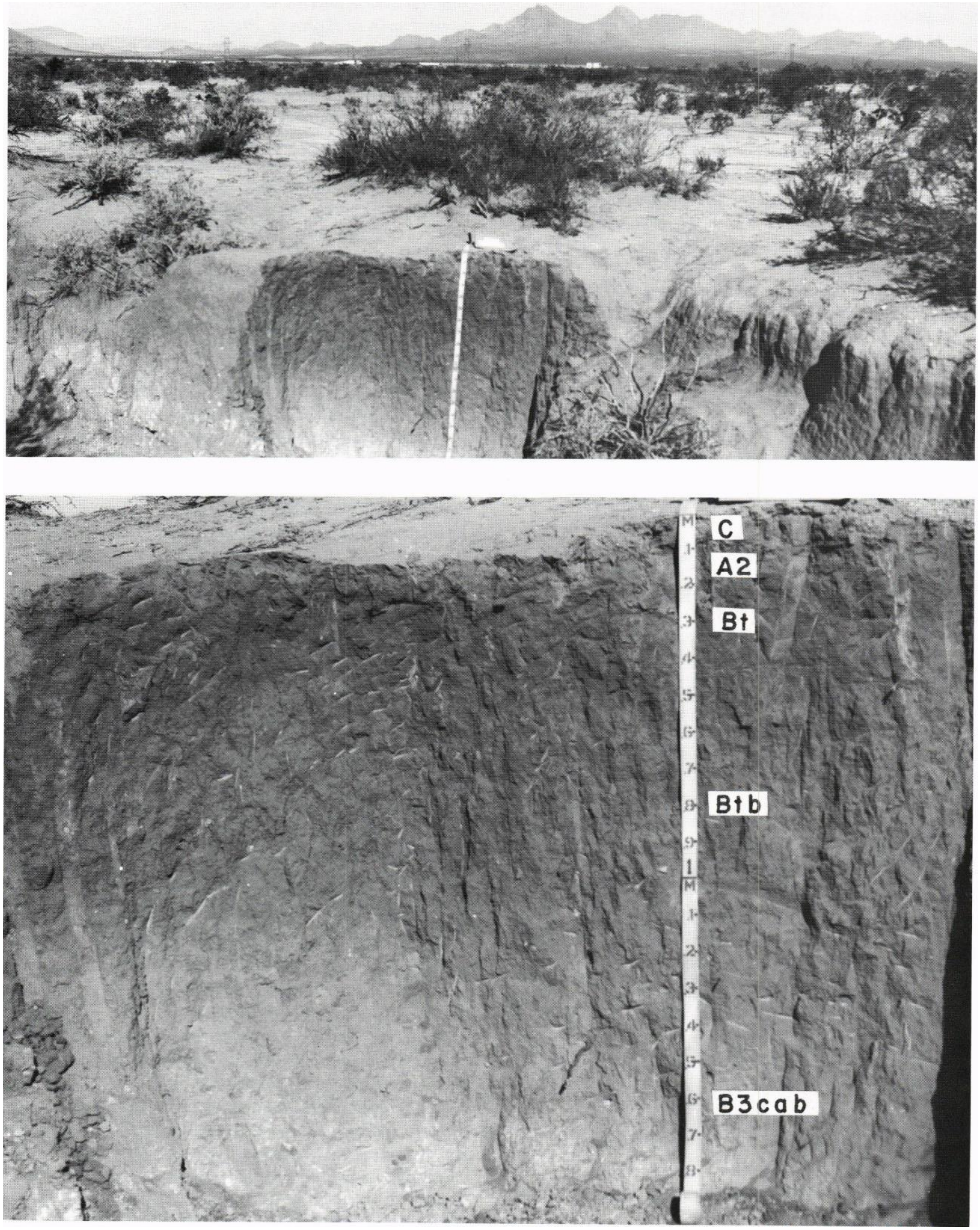


FIGURE 47—ORGAN DRAINAGEWAY AND HAPLARGID AT AREA 8b. *Upper view:* landscape of the Typic Hapiargid, Bucklebar 66-8, in a narrow drainageway on the Organ surface; vegetation consists of a few tarbush and mesquite; Doila Ana Mountains on skyline (center and right). *Lower view:* Bucklebar 66-8 in stage I of carbonate accumulation; soil formed in Jornada II unit, with veneer of Organ alluvium. Scale in meters (photographed October 1971).

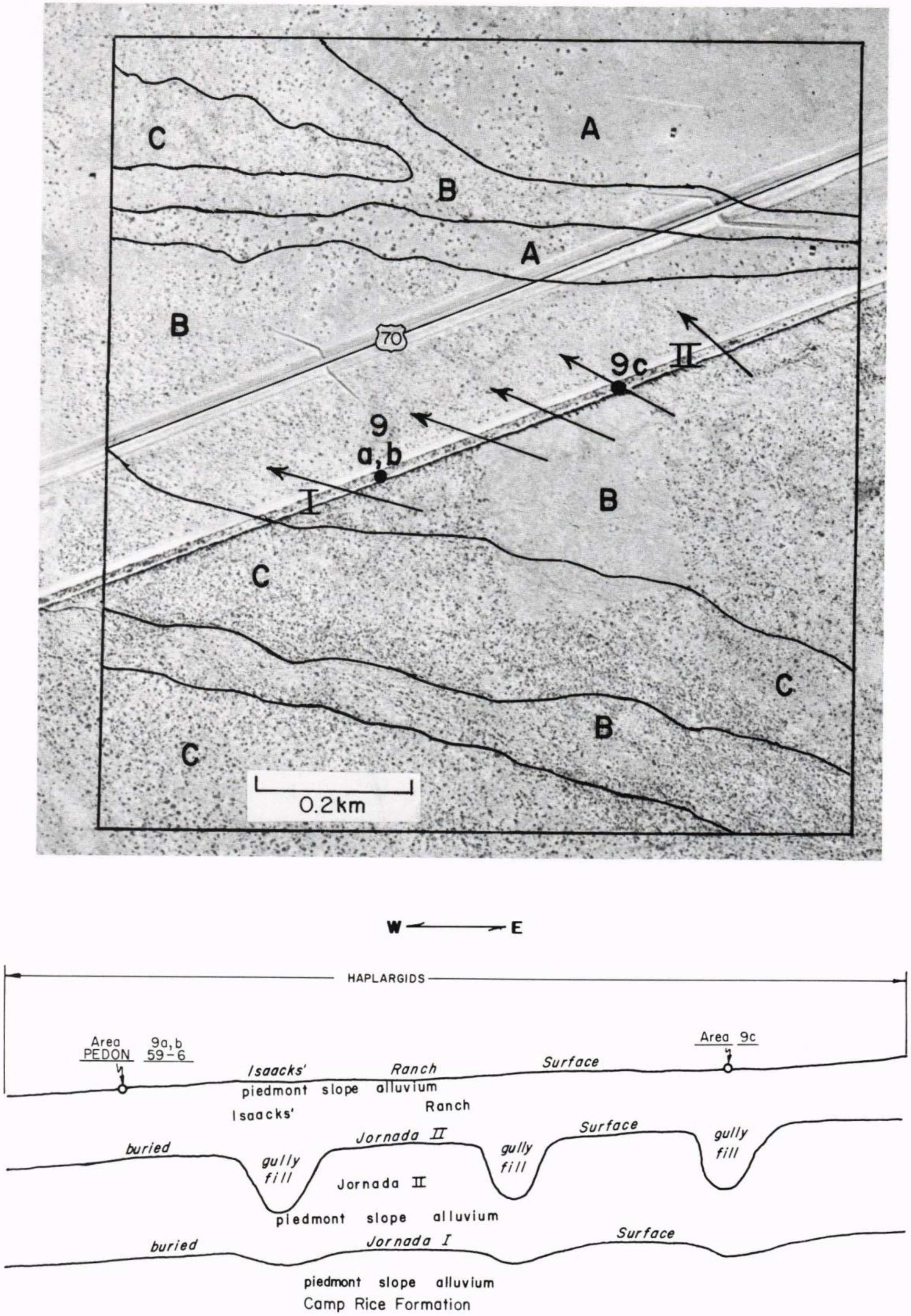


FIGURE 48—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 9. *Upper view:* map of soils; **A**, Onite sandy loam (Isaacks' Ranch surface); **B**, Bucklebar sandy loam, overflow phase (Isaacks' Ranch surface); **C**, Berino sandy loam (Jornada II surface). Arrows show location and direction of Isaacks' Ranch channel fills. I–II locates cross section. *Lower view:* diagrammatic section of soils, surfaces, and sediments (I–II on soil map).

FIGURE 49—ALLUVIUMS AND SOILS AT AREAS 9a, b. Morphostratigraphic units in north wall of Highway 70 gully: a) Jornada I alluvium and buried Haplargid in stage III of carbonate accumulation; b) Jornada II alluvium and buried Haplargid in stage III of carbonate accumulation; c) Isaacks' Ranch alluvium and land-surface Haplargid in stage II of carbonate accumulation. Pipes outlined at left and right. Pedon 59-6 (area 9a) is about I m (3 ft) to right of tape; the Haplargid at area 9b just left of tape. Scale in feet (photographed March 1965).

Berino variant 59-6 (fig. 49) has an A horizon, a Bt horizon, and a nodular, stage II carbonate horizon. The sampled horizons (table 57) occur below 20 cm of dune sediments, in which mesquite occurs. The dune sediments are shallow enough that roots of the mesquite and four-wing saltbush extend into upper horizons of the underlying buried soil. Between dunes and where dunes are absent, the A horizon has been eroded in many places; organic carbon is lower and the soils are Typic Haplargids (area 9b and Bucklebar 59-7, table 57).

The stage II carbonate is typical o f Isaacks' Ranch alluvium all along the gully. In the project area, this nodular, stage II carbonate does not occur in soils less than 6,000 yrs old, as indicated by radiocarbon ages of buried charcoal (area 12). The B22tca horizon barely qualifies as a calcic horizon (table 57); a minimum of 15 percent $CaCO_3$ is needed for these soils. This carbonate content is higher than is common for soils of Isaacks' Ranch age and may be a reflection of the shallow depth to the clayey B2tb horizon, which would be expected to slow downward movement of water. Thus carbonate may have precipitated over a more restricted depth range than in thicker deposits of Isaacks' Ranch alluvium, leading to higher carbonate values. Also there is a certain amount of expected lateral variation in the percentages of carbonate, by analysis, in the carbonate horizon. Thus, in most places the carbonate horizon in Isaacks' Ranch alluvium contains too little carbonate (less than 15 percent) to qualify as a calcic horizon, but in a few places there is barely enough to qualify. Such variation is to be expected and is suggested by carbonate morphology, the nodules being somewhat more numerous in some places than in others. This variation is illustrated by comparison of area 9a with area 9b, which has less macroscopic carbonate in Isaacks' Ranch alluvium than does area 9a.

That the two buried soils of Berino variant 59-6 were formed at the land surface is strongly suggested by morphology of their Bt and K horizons, which are very similar to those of land-surface soils. Conclusive evidence that they were formed at the land surface is provided by the occasional presence of underlying C-horizon material that contains little or no evidence of clay or carbonate accumulation (area 9c, and exposures between areas 9a and 9c). In addition, Jornada **II** alluvium emerges at the land surface on either side of the broad drainageway. Thus the Bt and K horizons of the two buried soils may be traced as buried horizons where C-horizon material is absent.

Although the upper buried soil is near the land surface, it does not affect soil classification, which is based on the argillic horizon of the land-surface soil. However, buried soils at such shallow depth may be recognized at the phase level where significant to land use.

Area 9b—Typic Haplargid (Bucklebar) in Isaacks' Ranch alluvium

This soil (fig. 49) occurs about 1.5 m west of pedon 59-6. Organic carbon is lower in these barren areas between dunes. At area 9b, four composited samples to a depth of 38 cm contained 0.43 percent organic carbon, and these soils are Typic Haplargids (see also Bucklebar 59-7, table 57).

Section 3.6 presented radiocarbon ages of various morphological forms in several horizons of a very gravelly pedon of late Pleistocene age. Radiocarbon studies of Bucklebar 59-7 and the pedon at area 9b (table 58) include soils of various ages but formed in low-gravel material. In Bucklebar 59-7, of Isaacks' Ranch age, both the fine-earth carbonate and sand-size carbonate in carbonate nodules have C-14 ages of 8 kyrs (table 58). These ages are reasonable relative to ages of other alluviums because Isaacks' Ranch alluvium is known to be older than 6,400 yrs, the age of charcoal in the lower part of Organ alluvium (area 12).

Relative ages of fine-earth carbonate in the Klb and K2b horizons (table 58) also seem reasonable. Carbonate in the K 1 b horizon has a C-14 age of 12 kyrs and has engulfed the lower part of a formerly thicker argillic horizon, as indicated by morphology and date (table 57). Carbonate in the K2b horizon has a C-14 age of 26 kyrs, would have been emplaced

TABLE 57—LABORATORY DATA FOR A TYPIC HAPLARGID AND AN USTOLLIC HAPLARGID; sand, silt, clay, and fine/total clay on carbonate-free basis.

Alluvium	Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Fine clay (%)	Fine/total clay (%)	Extractable iron (%)	Carbonate <2 mm (%)	Carbonate <0.002 mm (%)	Organic carbon (%)
	Ustollic Haplargid (Berino variant 59-6) at Area 9a										
Isaacks' Ranch	A1	0–13	62	21	17			0.8	tr	tr	
	B21tca	13–30	55	16	28	11	0.38	0.8	8	6	0.7
	B22tca	30–51	53	20	26	8	0.31	0.8	15	11	0.6
Jornada II	B1b	51–71	64	18	18	9	0.48	0.8	5	3	0.4
	B2tb	71–91	51	12	38	20	0.52	0.9	5	1	0.1
	K1b	91–117	65	14	21	9	0.44	0.7	12	8	0.2
	K2b	117–168	71	14	15	9	0.58	0.6	18	10	0.1
Jornada I	B2tb2	168–201	36*	39	25	10	0.41	1.0	15	12	
	K21b2	201–231	70	9	21	10	0.48	0.7	32	21	
	K22b2	231–262	67	14	19			0.7	34	19	
	Organic carbon, 4.8 kg/sq m to 91 cm										
	Typic Haplargid (Bucklebar 59-7) east of Area 9										
Isaacks' Ranch	A	0–15	63	23	14	5	0.38	0.8	1		0.4
	B21t	15–38	62*	17	22	11	0.48	0.8	tr		0.4
	B22tca	38–58	49*	20	23	11	0.47	0.8	3		0.3
	C1ca	58–97	71*	10	19	7	0.38	0.7	8		0.2
	C2ca	97–127	35	38	27	9	0.34	1.0	6		0.1
Jornada II	Bbca	127–147	57*	21	23	6	0.27	1.1	8		
	Organic carbon, 3.7 kg/sq m to 97 cm										

* >5 percent by weight >2 mm

TABLE 58—RADIOCARBON AGES OF INORGANIC CARBON IN LAND-SURFACE AND BURIED HAPLARGIDS.

Horizon	Depth cm	Carbonate dated	C-14 age kyrs
Typic Haplargid (Bucklebar 59-7) in Isaacks' Ranch alluvium			
Cca	66-91	Fine-earth carbonate in nodules	8
		Sand-size carbonate in nodules	8
Buried Haplargids (at area 9b) in Jornada II and I alluviums			
K1b	81-96	Fine-earth carbonate	12
K2b	142-168	Fine-earth carbonate	26
		Sand-size carbonate	30
K22b2	231-262	Fine-earth carbonate	27

below the argillic horizon during its early development, and should be older than carbonate in the Klb horizon.

Fine-earth carbonate in the K22b2 horizon dates at only 27 kyrs (table 58). This horizon is in a soil of Jornada I age (late middle Pleistocene) and is overlain by Jornada II alluvium and its soil, which must have formed partly during the last full glacial. Thus carbonate in the K22b2 horizon is thought to have been considerably youthened by deeply penetrating moisture of the full glacial (table 29, section 3.83).

Reddish-brown pipes are shown at areas 9a and 9b (fig. 49). The pipes shown have now been eroded away, but other pipes are exposed along the gully. Such pipes contain the only clay skins on ped surfaces and in pores to be found in this desert area. Because the pipes are buried by Isaacks' Ranch alluvium, they must have formed in the Pleistocene. They show that clay skins did form in places in the Pleistocene and are evidence of clay illuviation in the Pleistocene.

Walk east along the gully to area 9c. Exposures of pipes and C-horizon material may be seen at various places along the gully. Thick C-horizon material of Isaacks' Ranch age will be seen at area 9c.

Area 9c—Typic Haplargid (Bucklebar) in Isaacks' Ranch alluvium

Former channels cut deeply into Jornada II alluvium in places and are now filled with Isaacks' Ranch alluvium (figs. 44, 48, 50). Fig. 50 is a photograph and diagram of such a channel at area 9c. Bucklebar soils, Typic Haplargids, occur in the Isaacks' Ranch gully fill.

Between the 5- and 16-m stations (fig. 50), part of Jornada II alluvium dips, truncates the basal sand and gravel, and fills a channel that deeply cuts the K horizon of the soil in Jornada I. Overlying Isaacks' Ranch alluvium similarly dips and truncates Jornada II alluvium. Similar relationships were observed in other places along the gullies, showing that certain channel positions are inherited and remain about the same throughout major periods of sedimentation and soil formation.

As shown in fig. 50, the lower K horizon of Jornada II grades laterally into reddish, B-like zones beneath the channel fill. As noted at area 8b, these B-like zones are termed sub-channel zones. They are common beneath former channels along the gully exposures and were formed by deeply penetrating channel water prior to their filling with Isaacks' Ranch alluvium.

Accumulations of reddish, high-chroma silicate clay are prominent in some gravels and sands of basal Jornada II alluvium. At first glance these clay accumulations might suggest a buried B horizon, but their occurrence coincides with the contact of pervious coarse-textured materials on the finer-textured soil of Jornada I. The clay tends to "hang" in these coarse-textured sediments (water movement into the underlying, compact soil of Jornada I would be much slower), especially where they rest on the K horizon of the truncated soil. Such reduced penetration is reflected by the discontinuous nature of the reddish coatings on peds of the upper K horizon. This clay was deposited by water that moved downward from former zones of greater water movement, such as subchannel zones or pipes.

Further details on the sediments and soils along the gully may be found in Gile and Hawley (1966).

En route to study area 10. *Proceed northeast on US-70; prepare for left turn in 2 mi.* To the east a coalescent-alluvial-fan surface rises towards an undulating surface composed of individual fans along the mountain front. Geomorphic-surface components of the piedmont slope range from middle Pleistocene to Holocene in age, with large areas (Jornada II) having stabilized in late Pleistocene time before onset of the late Wisconsinan pluvial. **0.9**

14.6 Hangar Lake subdivision on left. *Take left lane* and prepare for left turn. **1.0**

15.6 Road to Butterfield Park on right. *Turn sharp left* on graded road to Moongate subdivision. Continue north across Jornada II surface. **0.7**

16.3 Cattle guard. To the north the Jornada II surface is buried by small fans and drainageway fills of Isaacks' Ranch and Organ units. Fig. 51 shows the geomorphic setting of area 10, ahead. **1.5**

17.8 Dip; gully crossing. *Turn around ahead; park facing south* along road just north of gully. **0.1**

17.9 STUDY AREA **10**

STUDY AREA 10

Camborthids of the Organ surface; Haplargids of the Isaacks' Ranch surface; the Isaacks' radiocarbon site

SUMMARY OF PEDOGENIC FEATURES (see table 54)—Charcoal dated at 4,200 yrs B.P. beneath a noncalcareous, reddish-brown cambic horizon and stage I carbonate horizon; incipient argillic horizon occurs laterally in some soils of the same age, illustrating initial development of the argillic horizon; distinct argillic horizon occurs continuously in soils more than 4,000 yrs old.

SETTING—This general area has been termed the Isaacks' radiocarbon site (Gile, 1975). Two charcoal horizons have been dated here; both are about 4,000 yrs old (table 10). The piedmont slope in this area has been the site of at least three major episodes of late Quaternary sedimentation (fig. 51). To the north a large body of Organ alluvium buries or is inset below older basin-fill deposits. Elsewhere a discontinuous veneer of Organ alluvium is locally present in low-lying areas. Smaller bodies of Isaacks' Ranch alluvium form low ridges south of the main Organ deposit. A sheet of Jornada II alluvium appears to be present almost everywhere beneath the younger materials. The Historical episode of manmade landscape instability is partly represented by the gully at this site and by arroyo-mouth fans to the east.

Vegetation consists of scattered clumps of black grama, fluffgrass, a few Mormon tea, *Yucca elata*, and mesquite. Slope is 2 percent to the west.

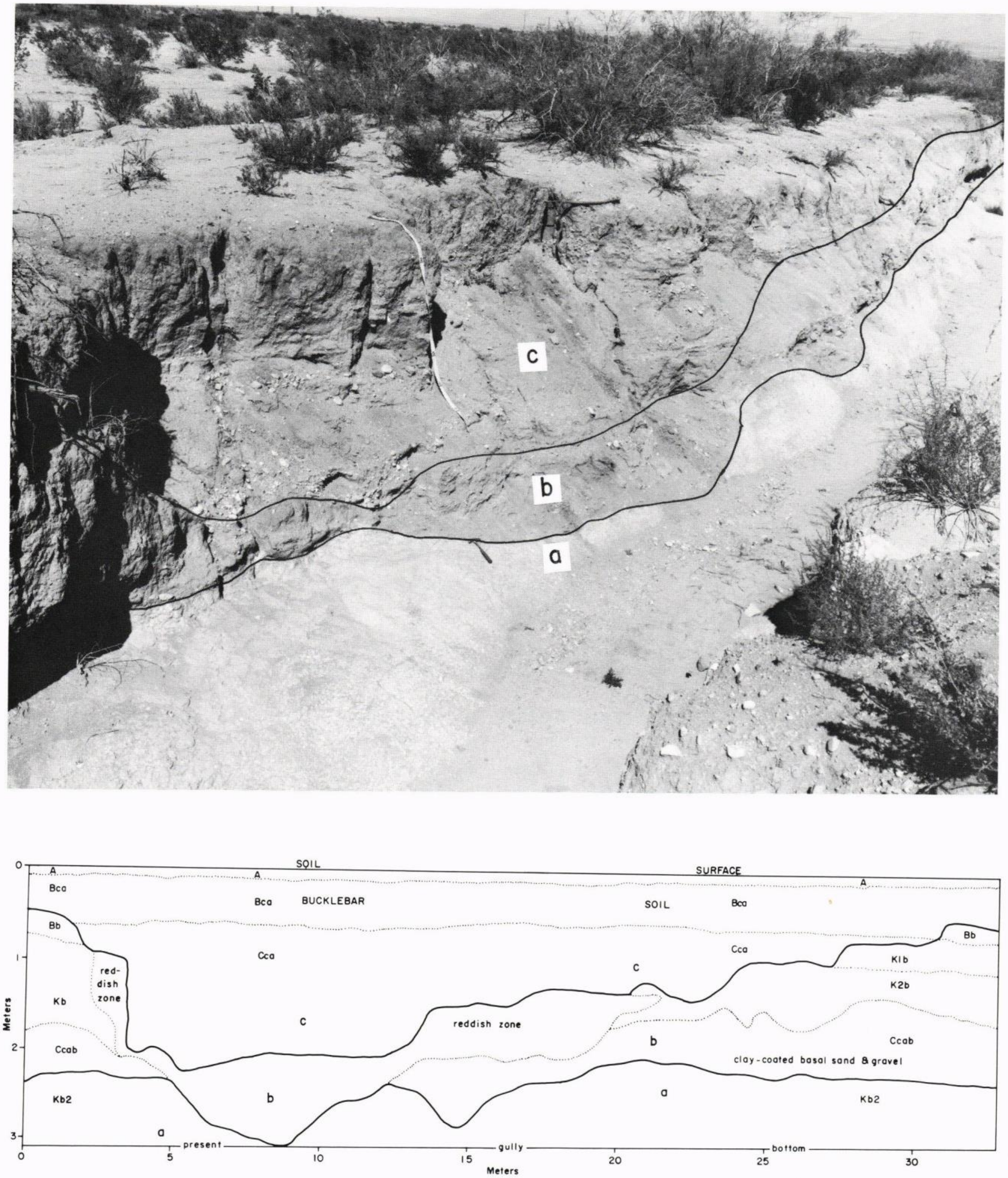


FIGURE 50—ISAACKS' RANCH CHANNEL FILL AT AREA 9c. *Upper view:* photograph of gully-channel facies of Isaacks' Ranch alluvium (taken March 1965); a) Jornada I (Camp Rice) alluvium and buried soils; b) Jornada II alluvium and buried soils; and c) Isaacks' Ranch alluvium and soils. Scale in feet. *Lower view:* cross-section diagram of gully fill shown above. Scale in meters.

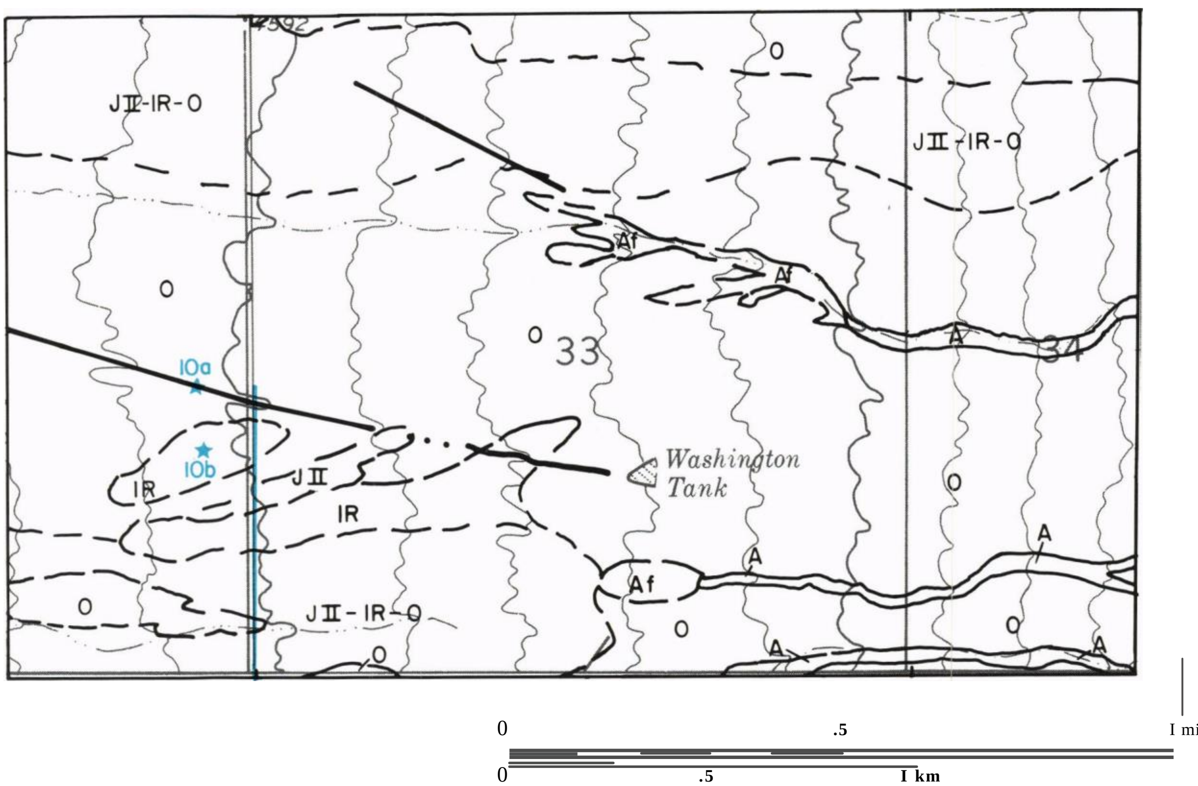


FIGURE 51—GEOMORPHIC **SURFACES AND STRATIGRAPHIC UNITS, AREA 10.**

EXPLANATION

Af	Arroyo-mouth fans; alluvium of Historical age.
A	Arroyo surfaces (major channel areas). Associated sandy to gravelly sediments of Historical age partly fill channels cut into older units. In areas 10-12 this mapping unit contains common inclusions of younger Organ fill-terrace surfaces.
0	Organ surface (constructional phase). Fan and drainageway surfaces underlain by sandy, gravelly and loamy alluvial deposits of the Organ morphostratigraphic unit; thickness up to about 7 ft (2.1 m).
IR	Isaacks' Ranch surface (constructional phase). Fan and drainageway surfaces underlain by loamy to sandy alluvial deposits of the Isaacks' Ranch morphostratigraphic unit; thickness up to about 7 ft (2.1 m).
JII	Jornada II surface (constructional phase). Coalescent-fan-piedmont surface underlain by deposits of the Jornada II morphostratigraphic unit (5-8 ft, 1.5-2.5 m thick). Contains minor inclusions of Isaacks' Ranch and Organ units and is disconformable on Camp Rice alluvium and buried soils of the Jornada I surface.
JII-IR-O	Jornada II surface with thin, discontinuous cover of Isaacks' Ranch and Organ units.
	Gullies—Historical.

SOIL OCCURRENCE—The pattern of soils at area 10 (fig. 52) is due to differences in soil age, soil texture, and landscape position. Typic Haplargids (Onite soils) and Typic Camborthids (Pajarito soils) are dominant on the slight ridges and intervening, slightly lower areas in the vicinity of the radiocarbon site. The soils are of Organ age and in this area the argillic horizon is in its incipient stages, occurring in some places but not in others. Bucklebar soils, fine-loamy Haplargids, occur in some of the narrow drainageways between the ridges. The argillic horizon is continuous in soils of the Isaacks' Ranch surface, as on the ridge just south of the radiocarbon site.

Area 10a—Typic Camborthid (Pajarito 67-3) in Organ alluvium

Charcoal in the C horizon of Pajarito 67-3 (fig. 53) has been dated at 4,200± 105 yrs **B.P.** A noncalcareous, reddish-brown cambic horizon and a stage **I** carbonate horizon occur above the charcoal and therefore must be less than about 4,200 yrs old. Relations at the Gardner Spring radiocarbon site indicate that this soil is probably at least 2,200 yrs old, and it may be nearly 4,000 yrs old if the sediments above the charcoal were deposited soon after the fire. This soil must have formed under a climate very similar to the present one. The morphology and dated charcoal indicate that all of the genetic horizons are developing now; none are relict, although some horizons of older soils are. The Bt horizon is thinner than in soils of late Pleistocene age (areas 8 and 9).

Reddish-brown coatings of oriented clay on sand grains in the cambic horizon indicate some illuviation of silicate clay. However, the minimum requirement of 3 percent increase in clay for an argillic horizon is not met (table 59), and the Bt horizon is a cambic horizon instead of an argillic horizon.

Organic and inorganic carbon dates were obtained from pedon 67-1, 70 m upslope. This pedon occurred along the south edge of the gully, and upper horizons had been truncated.

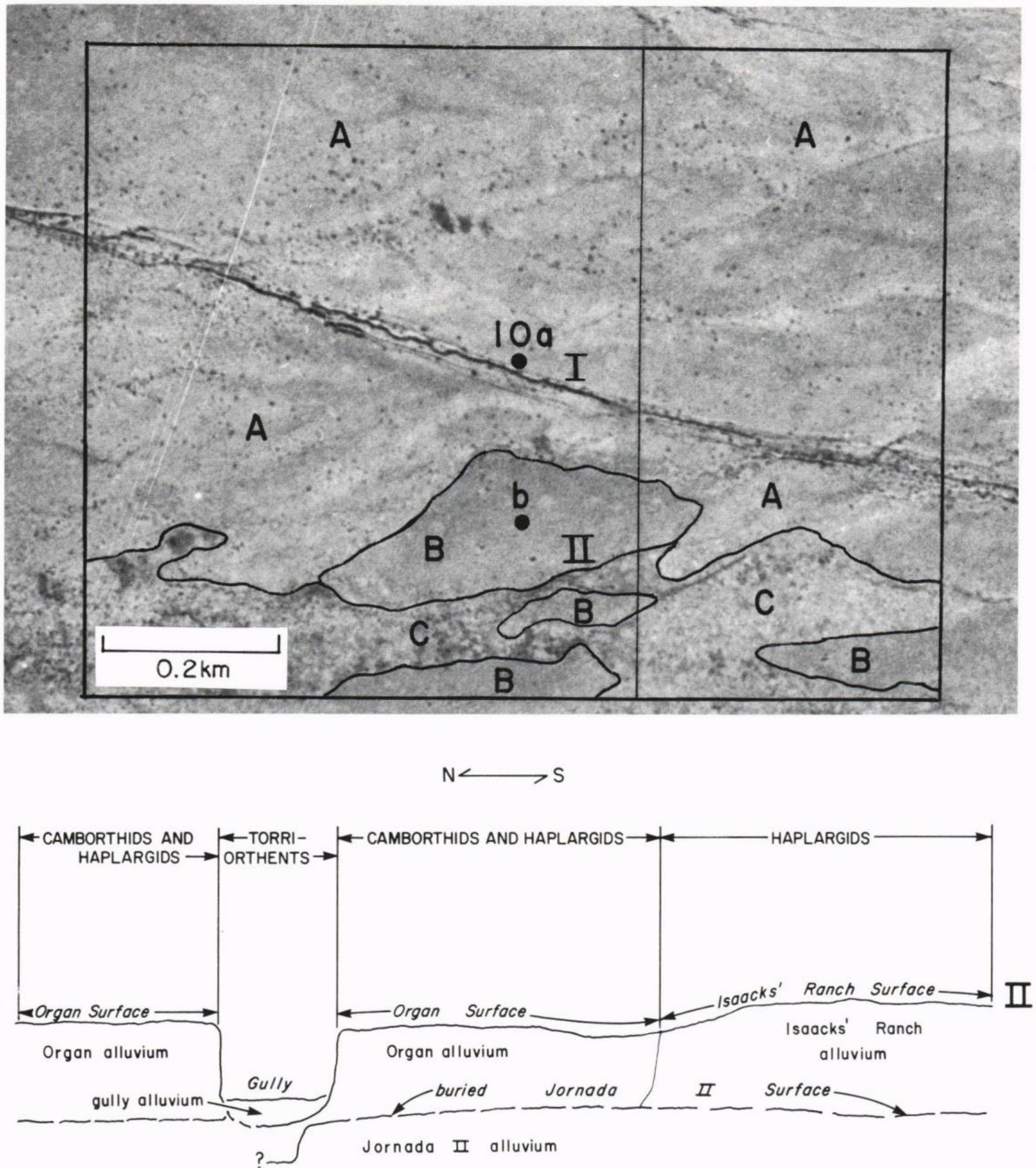


FIGURE 52—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 10. *Upper view:* map of soils in vicinity of the Isaacks' radiocarbon site; **A**, Onite-Pajarito complex (Organ surface); **B**, Onite sandy loam (Isaacks' Ranch and Organ surfaces); **C**, Bucklebar, overflow phase (Organ and Isaacks' Ranch surfaces). I–II locates cross section. *Lower view:* diagrammatic section of soils, surfaces, and sediments (I–II on soil map); from Gile, 1975, fig. 17, with permission.

TABLE 59—LABORATORY DATA FOR TYPIC CAMBORTHID (PAJARITO 67-3); sand, silt, and clay on carbonate-free basis.

Horizon	Depth	Sand	Silt	Clay	>2 mm vol.	Carbonate	Organic carbon
	%	%	%	%	%	%	%
A	0-3	78	15	7	10		0.18
A	3-10	73	18	9	5		0.30
B21t	10-20	75	16	9	5		0.26
B22t	20-28	74	18	9	10		0.22
C1ca	28-58	74	18	8	15	2	0.19
C2ca	58-91	74	17	9	10	3	0.13
C3	91-127	91	5	4	20	1	0.04

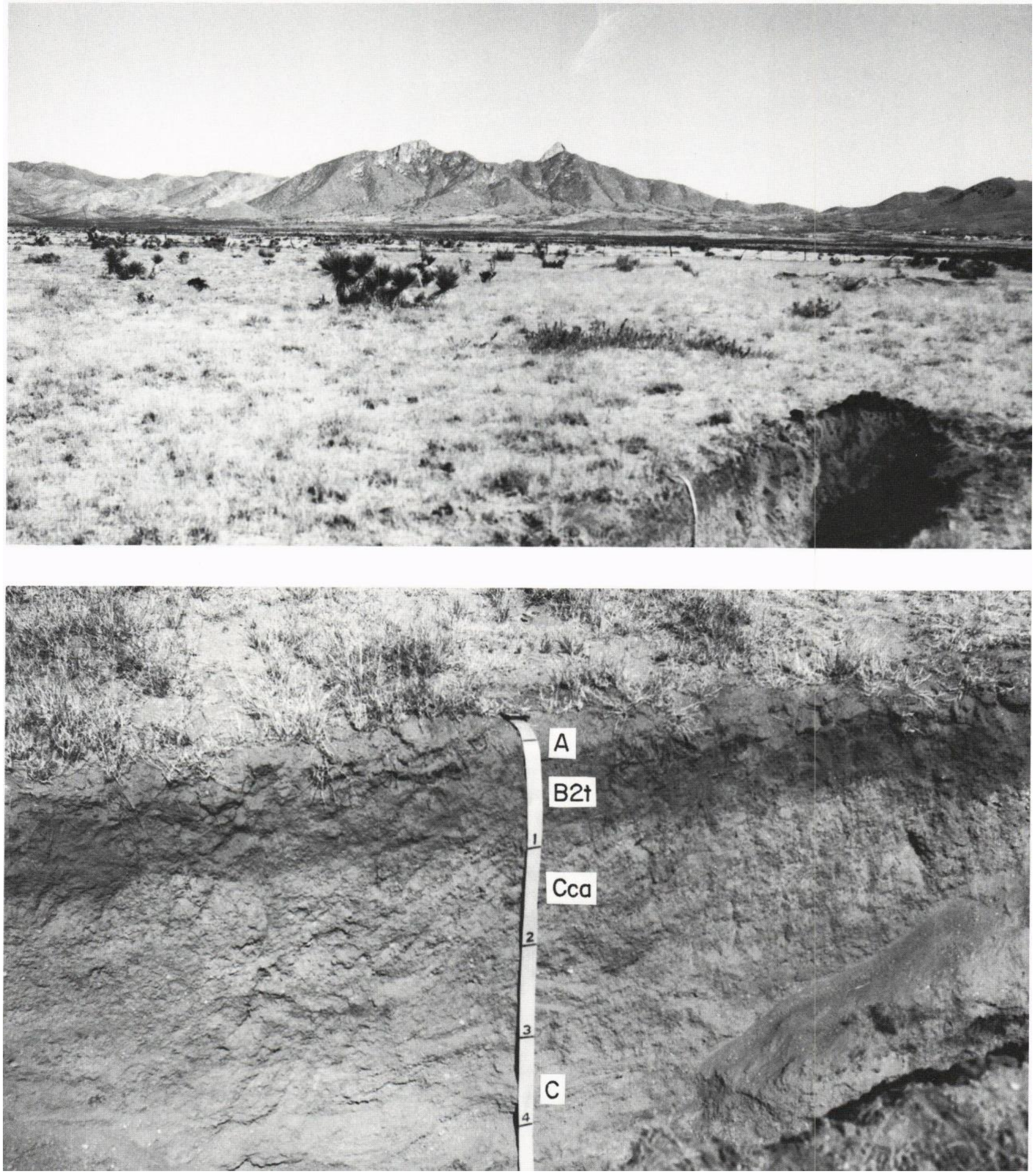


FIGURE 53—ORGAN SURFACE AND CAMBORTHID AT AREA 10a. *Upper view:* landscape of a Typic Camborthid on an Organ ridge at the Isaacks' radiocarbon site; San Agustin Mountains in the center of skyline; San Andres Mountains at left; Organ Mountains at right are south of San Agustin Pass, the low point in the skyline. Vegetation consists mainly of black grama and *Yucca elata. Lower view:* Pajarito 67-3. The Bt horizon is a cambic horizon. Charcoal in Organ alluvium may be seen in lower right-hand corner of the profile. Scale in feet (photographed October 1967; from Gile, 1975, fig. 18, with permission).

Charcoal from 43- to 53-cm depth in the Cca horizon dated at approximately 4,000 yrs B.P. Two dates were obtained from carbonate that must be younger than 4,000 yrs because it was above the charcoal: 1) carbonate adhering to pebbles dated at approximately 4,400 yrs B.P. and 2) carbonate in the 0.02-0.002 fraction dated at about 1,600 yrs B.P. The older date for the pebble coatings would be expected because such coatings represent the first carbonate to be precipitated (3.6). But the date is older than it could be according to the underlying dated charcoal. The general relation of older dates for inorganic rather than for associated organic carbon dates also holds for much older samples (3.83).

In places a buried soil with a thin, reddish-brown B horizon has been observed beneath the Camborthid. The buried soil may represent a stable period in earlier Organ time and may have formed during an interval analogous to the hiatus (5,800-7,100 yrs B.P.) mentioned by Haynes (1968a).

Walk south to the pit in Isaacks' Ranch alluvium. The site forms the local topographic high and is slightly higher than area 10a. Organ deposits in the vicinity of area 10a are inset against this ridge.

Area 10b—Typic Haplargid Onite) in Isaacks' Ranch alluvium

This soil has a sandy loam Bt horizon and a late stage II horizon of carbonate accumulation. In contrast to the soil in Organ alluvium at area 10a, the silicate clay maximum here is distinct and this soil falls well within the Argids. Another contrast is that all soils on this ridge have argillic horizons; there is no gradation to the cambic horizon as in soils of the Organ surface.

The carbonate horizon is more prominent than usual in soils of Isaacks' Ranch age, and this soil may have been developing since earliest Isaacks' Ranch time or slightly before this. Chronologically and morphologically this soil is between soils of the Organ surface and soils of the Jornada II surface. The relationships suggest a time of greater penetration of moisture for the soils of Isaacks' Ranch age than for the soils of Organ age, but somewhat less than for the soils of Jornada II. Such conditions could have existed shortly after the last full glacial (1.22 and 2.73).

Parent materials, slope, vegetation, and landscape of this soil are similar to those of the Camborthid at area 10a. The considerable increase in size of both the silicate clay and carbonate maxima must be due to greater soil age. Larger amounts of silicate clay and carbonate—both of which must be largely of atmospheric origin—have accumulated in this soil over a much longer period of time.

En route to study area 11. *Return to US-70.* **2.2**

20.1 US-70. *Turn left* and continue northeast on highway to Organ. **1.3**

THE ARID TO SEMIARID TRANSITION ZONE

Study area 11 is in the semiarid zone that comprises the mountains and uppermost piedmont slopes. A number of changes in soils are related to increase in elevation and precipitation towards the mountains. At stable sites, upper horizons become darker and organic carbon increases mountainward. Nearly all of the soils in the semiarid part of the project area are Mollisols or Ustollic intergrades. The Mollisols are mainly of Holocene age and are on stable sites. The Aridisol-Mollisol transition is of two types. In one, Holocene Aridisols gradually change to Holocene Mollisols at an elevation of about 5,000 ft (1,524 m). In the other, the transition is abrupt and occurs because soils of Pleistocene age have been truncated and adjacent Holocene soils have not. Such truncation is indicated by drainageways and has resulted in chromas or values too high for a mollic epipedon. This MollisolAridisol transition is abrupt instead of gradual because the Holocene Mollisols commonly occur on low terraces inset against the older, higher Aridisols (area 21).

Depth of leaching gradually increases towards the mountains. In soils with low-carbonate parent materials, a surficial noncalcareous zone gradually thickens mountainward. At the same time, Bt horizons thicken and the top of the carbonate horizon deepens.

In many places physiography of the upper piedmont slope is dominated by large Pleistocene fans. The fans shown in fig. 54 are south of Organ and US-70 and can readily be seen en route to area 11 (large fans are not present at area 11, which is dominated by pediments, small bedrock outliers, and low deposits of Holocene age). The fans represent several stages of development, mostly during late to middle Pleistocene time, with only minor areas of Holocene age. A coalescent-fan piedmont of Holocene age is downslope from the individual Pleistocene fans (fig. 54). The Holocene fan piedmont is almost wholly of Organ age, buries Isaacks' Ranch sediments and soils in many places, and is part of an almost continous belt of Organ deposits along the mountain front. Soils of Isaacks' Ranch and Jornada II age emerge at the surface still further downslope (areas 9 and 10). Fig. 42 shows the dominant soils.

21.4 Opposite east edge of Butterfield Park. The top of the zone of saturation in thick basin-fill deposits is about 600 ft (200 m) below the surface. Within a mile to the east the water table rises abruptly as impermeable rocks of the Organ Mountain mass are encountered at increasingly shallow depths (figs. 6 and 9). Piedmont-slope gradient to the east increases to more than 3 per-

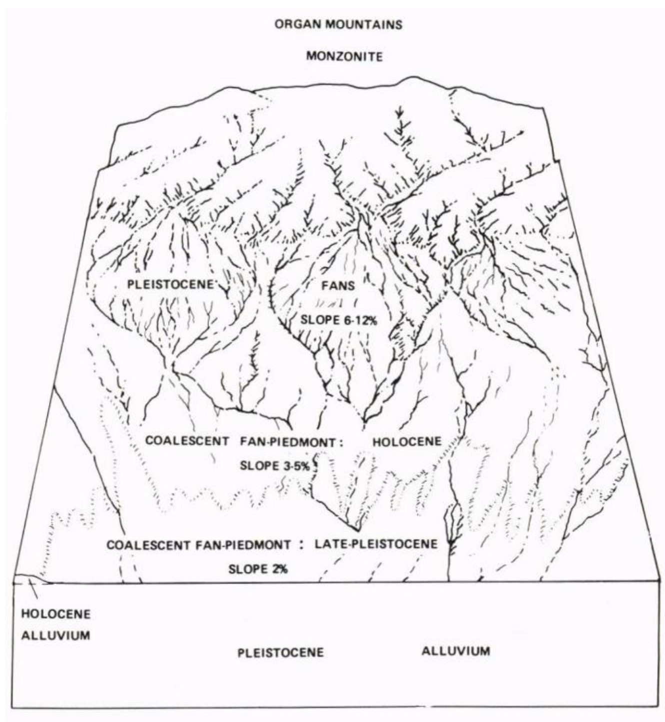


FIGURE 54—BLOCK DIAGRAM OF THE ORGAN MOUNTAIN PIEDMONT, showing mountain front and piedmont slope south of Organ (fig. 42), with downslope individual fans and coalescent alluvial-fan piedmont.

cent. Large areas of the Jornada II surface are buried by monzonite-derived alluvium of the Organ unit. Creosotebush dominates the dissected areas where Organ alluvium is thin or absent, and carbonate horizons of pre-Organ soils occur at shallow depths. 1.0

22.4 Apollo Highway junction. NASA Manned Spacecraft Test Site and Gardner Spring radiocarbon site (study area 12) are located 7 mi north. **0.7**

23.1 Enter village of Organ, once a thriving mining community (Dunham, 1935). *Take left lane* and prepare for left turn. **0.5**

23.6 East edge of Organ, just past service station; *turn left through cattle guard onto graded road.* Proceed north across piedmont area with bedrock outlier hills and many abandoned mine workings. **0.4**

24.0 Cattle guard. The route continues over a complex of Organ and Jornada surfaces. Fig. 55 illustrates the geomorphic setting of study areas 1 la-c, ahead. Thin arroyo-terrace and fan deposits of late Quaternary age discontinuously bury a gently undulating erosion surface cut on bedrock, here quartz-bearing monzonite and Paleozoic metasedimentary rocks. The low hills are formed by resistant masses of silicified sedimentary rocks. These rocks were altered during intervals of orogenic activity and mineralization associated with emplacement of the Organ Mountain (monzonite) batholith about 32 m.y. ago and with somewhat earlier igneous activity (Dunham, 1935; Seager, 1981). **0.5**

24.5 *Turn vehicles around and park on west edge of road.* **0.1**

24.6 STUDY AREA 11

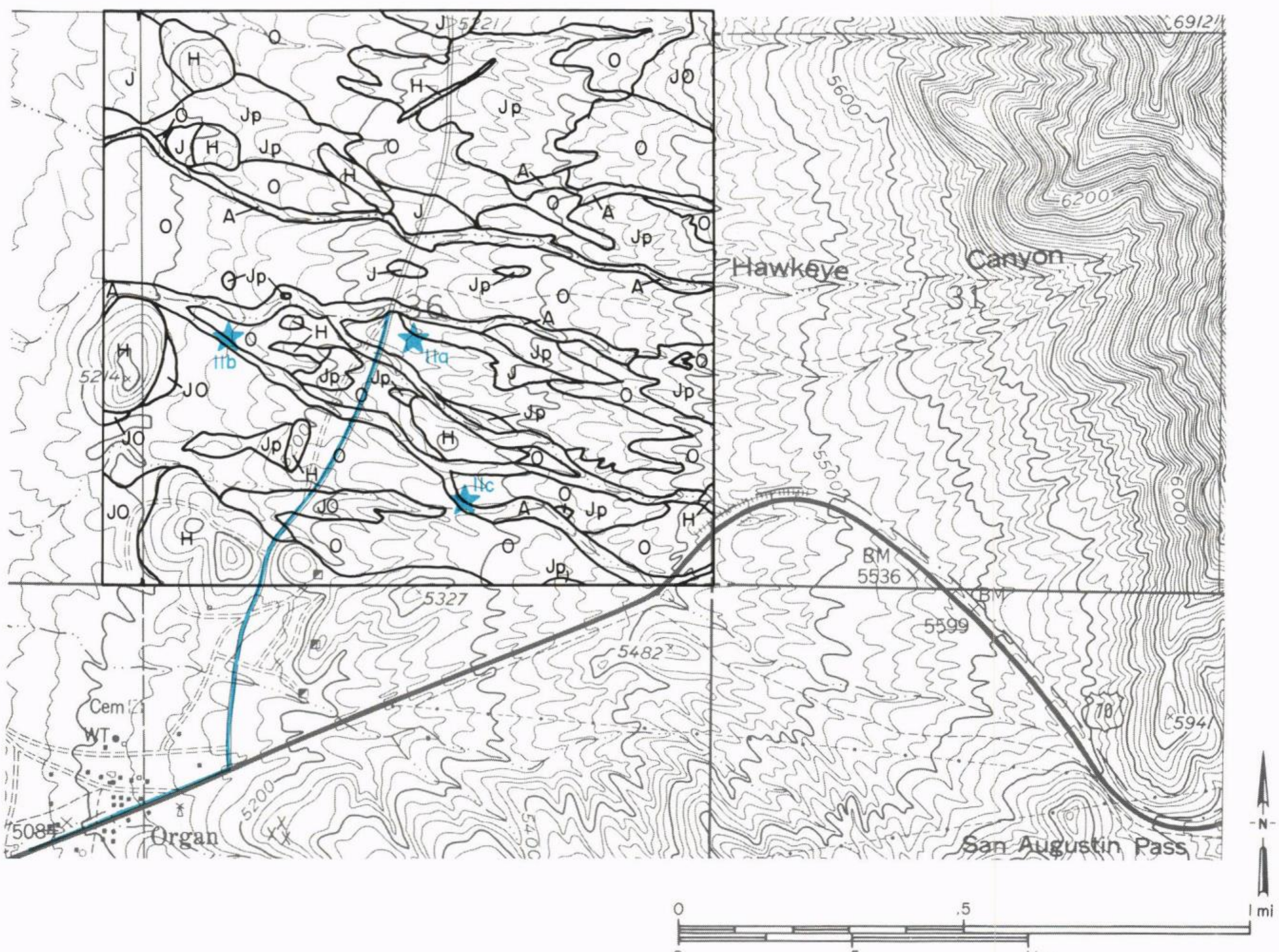


FIGURE 55—GEOMORPHIC SURFACES AND STRATIGRAPHIC UNITS, AREA 11.

EXPLANATION

A Arroyo surfaces (major channel areas). Associated sandy to gravelly sediments of Historical age partly fill channels cut into older units. In areas 10–12 this mapping unit contains common inclusions of younger Organ fill-terrace surfaces.

O Organ surface (constructional phase). Fan and drainageway surfaces underlain by sandy, gravelly, and loamy alluvial deposits of the Organ morphostratigraphic unit; thickness up to about 10 ft (3 m) thick.

J Jornada I and II. Undifferentiated, constructional piedmont-slope surfaces and associated deposits in areas 16 to 18. Alluvium is generally thin (5 ft, 1.5 m thick) and rests on Jp surfaces. Contains minor inclusions of Organ and Isaacks' Ranch units.

Jp Jornada I and II rock-pediment complex. Erosion surfaces cut on bedrock of the Organ–San Agustin Mountain block; dominantly monzonite in east 2/3 of section 36 and dominantly metasediments and volcanics in west 1/3 of section. Pediment complex is locally dissected by arroyo channels and discontinuously veneered with alluvial deposits ranging from Camp Rice (piedmont facies) to Organ.

JO Jornada, Isaacks' Ranch (fig. 51), and Organ units—undifferentiated; thin alluvial and colluvial deposits on bedrock.

H Hills and ridges; rock uplands projecting above Jp surfaces.

STUDY AREA 11

Haplargids of a pediment in monzonite; Haplustolls of the Organ surface

SUMMARY OF PEDOGENIC FEATURES (table 54)—Precipitation (approximately 30 cm annually) is greater than in the arid zone downslope; Mollisols occur at stable sites that are level transversely; Aridisols occur in less stable areas such as narrow ridges; atmospheric additions of calcium in the semiarid zone; Ustollic Haplargid in monzonite pediment has clay and carbonate coatings on rock fragments in fractured bedrock; Torriorthentic Haplustoll has thick, dark A horizon and lacks a carbonate horizon, but sensitive analyses reveal the presence of very small amounts of carbonate.

SETTING—The Jornada surface in this area has both erosional and constructional footslope elements (fig. 55). The former comprises a rock pediment (2.21) with local thin veneers of transported alluvium, which grades downslope to alluvial piedmont-slope surfaces. Jornada I and Jornada II subdivisions have not been mapped out, but rather the surface is regarded as a complex of several geomorphic units ranging from middle to late Pleistocene age. The transverse profile of the Jornada surface near areas I la and I lc is gently undulating with topographic lows being partly filled with Holocene sediments of the Organ morphostratigraphic unit. Downslope the Organ valley fills coalesce to form a thin apron of alluvial-fan deposits that bury constructional parts of the Jornada surface. East of the road, slopes on the Jornada pediment and Organ surfaces range from 5 to 10 percent. To the west, the surface slopes gradually decrease. Information from test drilling and geophysical surveys (American Metals Climax, Bear Creek, and Kerr-McGee mining companies, personal communications) indicate that the longitudinal slope of the rock surface continues for several miles at a gradient of 5-7 percent, with the thickness of alluvial cover gradually increasing. This buried pediment or suballuvial-bench surface (2.21) is terminated in a zone located about 2-2.5 mi to the west, where depths to bedrock abruptly increase from about 300 ft (92 m) to more than 2,500 ft (765 m) (fig. 6). The bulk of the fill above the buried pediment appears to be middle Pleistocene or older in age.

A greater variety of vegetation and somewhat greater density of vegetation are characteristic of the mountain fronts because of increased precipitation, which probably is about 30 cm annually here. Most vegetative types in this area also occur at lower elevations. Blue grama and beargrass, however, do not.

SOIL OCCURRENCE—The pattern of soils at area 11 (fig. 56) is determined by parent-material differences (bedrock versus alluvium and high-carbonate versus low-carbonate material) and differences in soil age. Both Mollisols and Aridisols are present; and, because of extensive Organ deposits, this area well illustrates the character of the Mollisol-Aridisol transition in the semiarid zone. Nearly all of the Mollisols are of Holocene age because, in most places, the Organ surface is quite stable and level transversely; and the mollic epipedon is still preserved. In and near area 11, many soils of Pleistocene age have dark surface horizons with fairly high organic carbon but lack a mollic epipedon because a Bt horizon, with chroma too high for a mollic epipedon, occurs at shallow depths. This feature is thought to be largely due to soil truncation because these areas have drainageways and the mollic epipedon occurs only at stablest sites. Similarly, Holocene soils on narrow ridges also lack mollic epipedons.

The soils formed in bedrock show the effects of differences in carbonate content of the bedrock on soil development; the soils (mostly Ustollic Haplargids) in monzonite bedrock have reddish, largely noncalcareous Bt horizons whereas the soils (Torriorthents and Calciorthids) in calcareous rocks lack these horizons and are strongly calcareous throughout. The linear contact between these soils (fig. 56) marks a fault between sedimentary rocks (limestone and shale) and quartz monzonite (Dunham, 1935; Seager, 1981).

The soils of Organ age are mainly Torriorthentic Haplustolls. Aladdin soils occur where textures of the control section average coarse-loamy and are most common in the topographic highs of the Organ surface. Hawkeye soils occur where control--section textures average sandy. These textures are in the younger, lower portions of the Organ landscape and in areas where textures of Organ alluvium are particularly coarse. The Haplustolls commonly overlie bedrock at variable depths and in places are inset against bedrock highs. Typic Haplargids are found in areas of strong truncation.

Area lla—Ustollic Haplargid (Coxwell variant 70-1) in monzonite bedrock of Jornada pediment surface

The pedon (fig. 57) occurs in the center of a slight bedrock ridge sloping 5 percent. Age of the pediment is unknown but it is older than Organ and is probably at least Jornada I in part. Absence of steep slopes or strong dissection, presence of bedrock at quite uniform depths, and lateral continuity of the soil suggest relative stability for a long period of time. Laboratory data are in table 60.

The pedon has thin A and Bt horizons over bedrock **(R**

TABLE 60—LABORATORY DATA FOR AN USTOLLIC HAPLARGID (COXWELL VARIANT 70-1) DEVELOPED IN MONZONITIC BEDROCK; tr(s), trace $CaCO_3$ detected by qualitative procedure more sensitive than quantitative procedure used; -(s), none detected by sensitive qualitative tests (6E2; Soil Conservation Service, 1972).

Horizon	Depth	Sand	Silt	Clay	>2 mm vol.	Carbonate	Organic carbon
	CM						
A2	0-5	72	18	10	20	-(s)	0.4
B1t	5-11	67	17	15	20	-(s)	0.5
B2t	11-21	62	15	24	45	tr(s)	0.6
B 3tca	21-52						0.2

Organic carbon, 2.0 kg/sq m to 52 cm

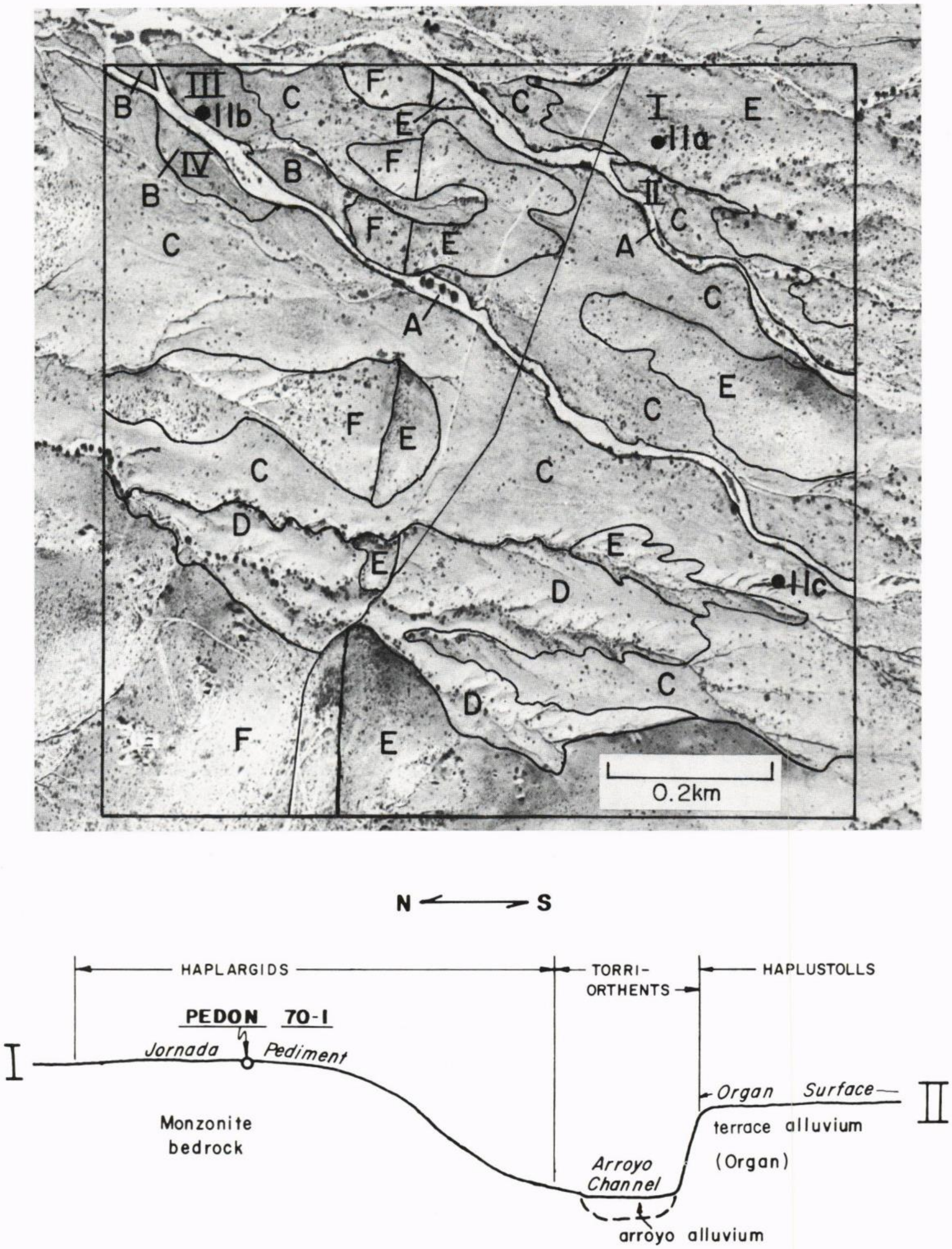


FIGURE 56—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 11. *Upper view:* map of soils; **A**, Torriorthents (arroyo-channel surface); **B**, Hawkeye sandy loam (Organ surface); **C**, Aladdin sandy loam (Organ surface); **D**, Sonoita sandy loam (Organ surface); **E**, Haplargids and rock outcrop (Jornada pediment surfaces and mountain slopes and summits, undifferentiated); **F**, Torriorthents and Calciorthids (Jornada pediment surfaces and mountain slopes and summits, undifferentiated). I–II and III–IV (fig. 58) locate cross sections (from Gile, 1977, fig. 12, with permission). *Lower view:* diagrammatic section of soils, surfaces, and sediments (I–II on soil map).

FIGURE 57—JORNADA PEDIMENT AND HAPLARGID AT AREA 11a. *Upper view:* landscape of an Ustollic Haplargid, Coxwell variant 70-1, on Jornada pediment. Vegetation is snakeweed, *Yucca baccata,* prickly pear, fluffgrass, blue grama, cholla, and beargrass. Slope is 5 percent. San Agustin Mountains in background; San Agustin Peak at right. *Lower view:* Coxwell variant 70-1, developed in monzonite bedrock. Scale in meters (photographed October 1971).

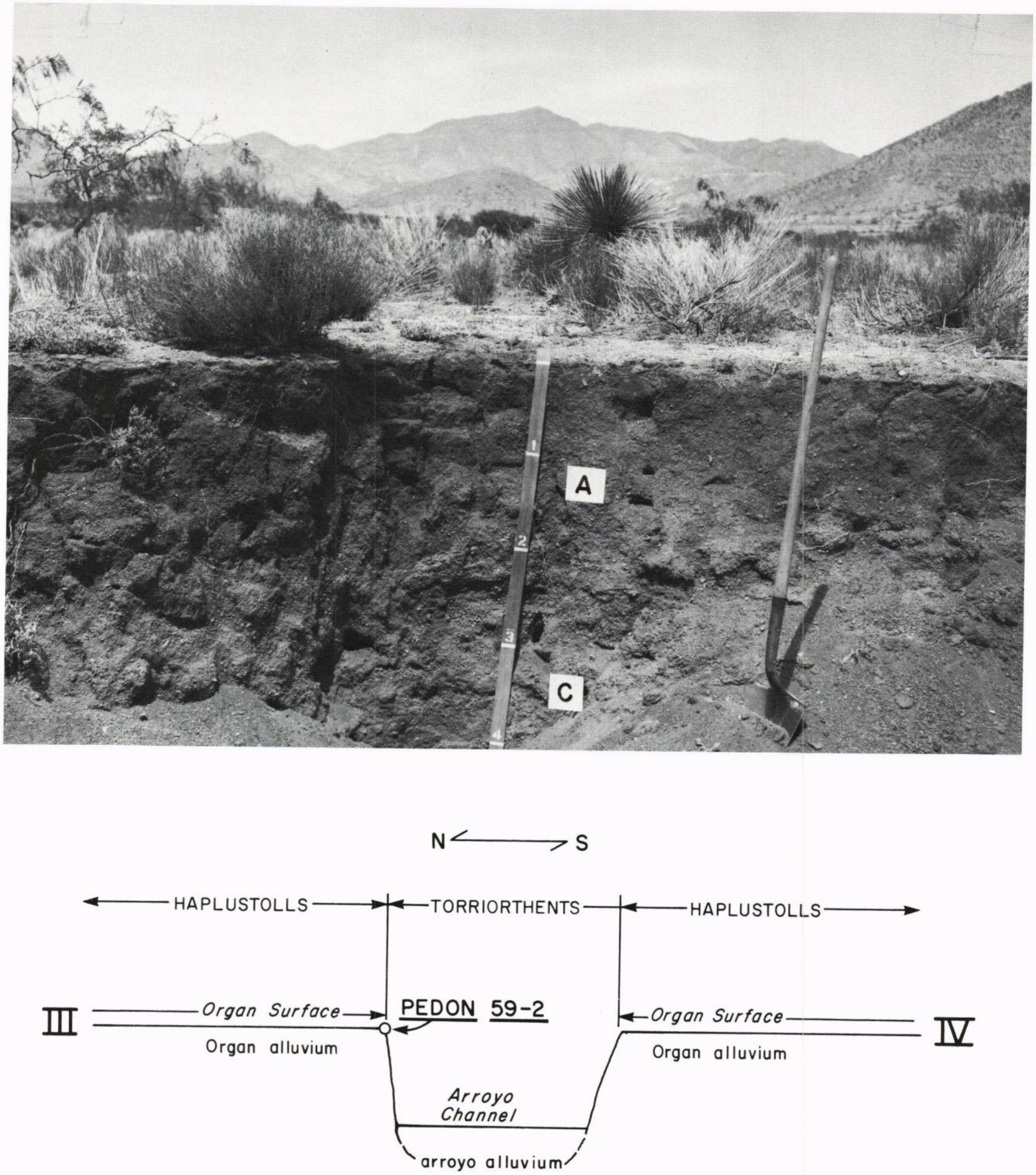


FIGURE 58—Organ surface and Haplustoll at area 11b. *Upper view:* photograph of a Torriorthentic Haplustoll, Hawkeye 59-2, in Organ alluvium. Vegetation consists of snakeweed, *Yucca elata,* mesquite, Mormon tea, fluffgrass, and cholla. Slope is 5 percent. San Andres Mountains are in background. Scale in feet (photographed 1960). *Lower view:* diagrammatic cross section of soils, surfaces, and sediments, showing location of Hawkeye 59-2 (III–IV on soil map, fig. 56).

TABLE 61—CLAY MINERALOGY FOR AN USTOLLIC HAPLARGID (COXWELL VARIANT 70-1) DEVELOPED IN MONZONITIC BEDROCK; xxx—abundant, xx—moderate, x—small, tr—trace. In R2t horizon, mica flakes were handpicked from crushed rock fragments of the horizon. Mica and quartz were identified by x-ray diffraction. The mica flakes were then heated in an H_2O_2 solution and the flakes decanted. The mineral expands partially upon solvation with glycerol. A broad 24-angstroms peak is present, indicating regularly alternating 14- and 10-angstrom minerals (mica and chlorite, vermiculite or montmorillonite).

Horizon	Clay mineral				
	Montmorillonite	Mica	Kaolinite	Vermiculite	Montmorillonite-chlorite intergrade
A2	x	x	x		
B1t	x	x	x		
B2t	x	xx	x		
B3tca	xx	x	x		
R1tca	xx-xxx	x	x	x	
R2t	xx	xx	x	xx	x

horizon) at 52 cm. A weak horizon of carbonate accumulation begins at 21 cm. Clay and carbonate, probably derived largely from atmospheric sources, have moved into the bedrock, forming horizons of clay and carbonate accumulation. Thin sections show that preferred orientation of clay in the B2t horizon is weak. Strongly expressed clay films are present in the B3t and in the Rt horizons. These clay films are reddish brown and show only weak evidence of internal orientation. The clay mineralogy is summarized in table 61.

Sands in the B2t horizon are rich in weatherable minerals, including small amounts of hornblende and mica. Most of the mica shows very pale yellow interference color. The hornblende looks rather fresh in thin section. Most of the books of mica in the B2t horizon appear fairly altered but the overall optical properties of biotite are retained. X-ray observations on mica flakes from the Rtca horizon are in table 61. Although this soil must have formed partly during at least one pluvial and would have been moistened even more frequently than now, mineral alteration has not been rigorous.

En route to study area 11b. Walk down the piedmont slope, crossing a complex of erosion surfaces on Tertiary monzonite and Paleozoic sedimentary rocks and several ages of constructional surfaces associated with thin deposits of middle to late Quaternary age on bedrock units. The route crosses the intrusive monzonite/sedimentary rock contact zone. Numerous mine shafts and prospect pits are located in this area.

Area llb—Torriorthentic Haplustoll (Hawkeye 59-2) in Organ alluvium

The Organ constructional surface at this site is formed by the coalescence of fills of several shallow drainageways. The bedrock in the sediment source areas (phase **III,** quartz-bearing monzonite of Dunham, 1935) readily breaks down into primary crystal constituents (dominantly oligoclase and perthite with accessory biotite, quartz, and mafic minerals) yielding fragments varying in size from coarse sand to fine pebbles. Biotite occurs in the sediments. Slope is 5 percent. Vegetation consists largely of snakeweed, *Yucca elata,* mesquite, Mormon tea, fluffgrass, and cholla.

Hawkeye 59-2 is in the north bank of the arroyo (fig. 58). The A horizon is thick and dark (fig. 58). This thickness may be due largely to periods of sedimentation separated by intervals of stability during which an A horizon formed. This area is directly downslope from steep slopes of the San Agustin Mountains and is in the path of main drainage lines from these mountains. The area is therefore in a position favoring accumulation of sediment.

Other factors may favor development of these thick A horizons. Mixing by rodents may contribute; krotovinas have been observed in some areas. The appreciable percentage of coarse fragments (table 62) and the apparent low-bulk density would lower water retention. The soils are highly pervious and have relatively low water retention at field capacity (volume proportion retained at 0.1 bar of 0.10 to 0.15). A given increment of precipitation should cause relatively deep wetting, which may contribute to the thickness of the zone strongly exploited by roots.

Extractable iron contents are higher for this soil than for sandy soils of the valley border (area 19; 3.85). The sand in pedon 59-2 contains approximately 4 percent (by volume) biotite. This biotite comes from monzonite that crops out a short distance to the east.

Effects of climate on soils of the same age are illustrated by these soils and by the texturally similar Bluepoint soils (area 19) along the valley border, where precipitation is approximately 20 cm annually. Organic carbon content is substantially greater in the Haplustolls and is attributed to greater effective moisture along the mountain fronts. These soils are noncalcareous throughout and lack a horizon of carbonate accumulation. This feature is a reflection of greater precipitation here; in deposits of the same age to the west, the soils have horizons of carbonate accumulation at depths of 0.5 m or less (area 10). However, very slight amounts of carbonate are found when a sensitive qualitative method is used (tables 11, 62). Calcium from the atmosphere probably is currently being added to this soil. Because of higher precipitation here, however, the carbonate is more diffuse than at lower elevations, and some of it has probably moved to greater depths than in soils at lower elevations.

Walk eastward along arroyo to area 11c. Note the occasional bedrock outcrops along the arroyo. Organ alluvium is the dominant basin-fill unit in this area.

Area llc—Torriorthentic Haplustoll (Aladdin) in Organ alluvium

This area is located in a small valley between two low monzonite ridges and several pediments. These deposits of coarse sandy to fine gravelly Organ alluvium form the fill over much of the valley floor; however, bedrock and pre-Organ piedmont-slope deposits are exposed at some localities. Slope is 5 percent. Vegetation is black grama, fluffgrass, mesquite, snakeweed, Apache plume, and Mormon tea.

This soil is similar to the one seen at area 11b except that textures in the control section average coarse-loamy. Refer to laboratory data for Aladdin 59-1 (table 62). Note the increase in silicate clay with depth. Clay illuviation may be partly responsible, but the distinct 5YR or 7.5YR hues typical of Bt horizons in this area are absent. Because of higher clay content, the horizons concerned tend to be harder than analogous horizons in Hawkeye soils.

Aridisols (Haplargids) instead of Mollisols do occur on narrow ridges nearby, in alluvium of similar age, composition and texture. Sonoita 60-8 (table 58) is an example; it has a Bt horizon and lacks the thick dark A horizons of the Haplustolls. Organic carbon is substantially less than in the Haplustolls (table 62). A possible reason for absence of a

TABLE 62—LABORATORY DATA FOR MOLLISOLS AND AN ARIDISOL IN THE SEMIARID ZONE; tr(s), trace $CaCO_3$ detected only by qualitative procedure more sensitive than quantitative procedure used; –(s), none detected by sensitive qualitative test (6E2; Soil Conservation Service, 1972).

Horizon	Depth	Sand	Silt	Clay	>2 mm vol.	Extractable iron	Carbonate	Organic carbon
	cm	%	%	%	%	%	%	%
Torriorthentic Haplustoll (Aladdin 59-1), elevation 5,500 ft (1,676 m)								
A11	0-5	71	22	7	15	0.6	-(s)	0.8
A12	5-36	66	23	11	15	0.7	-(s)	0.6
A13	36-53	70	19	11	15	0.7	-(s)	0.5
A14	53-89	69	20	11	20	0.7		0.4
A15	89-117	74	17	9	20	0.6		0.3
AC	117-147	69	20	11	15	0.7	tr(s)	0.2
C1	147-173	76	15	9	20	0.7	-(s)	0.1
C2	173-218	78	14	8	15	0.7		0.1
Organic carbon, 4.7 kg/sq m to 89 cm								
Torriorthentic Haplustoll (Hawkeye 59-2), elevation 5,125 ft (1,562 m)								
A11	0-8	72	20	8	5	0.8	tr(s)	1.0
A12	3-20	82	12	6	15	0.9	tr(s)	0.7
A13	20-41	81	13	6	15	1.0	tr(s)	0.5
A14	41-71	80	13	7	15	0.9	tr(s)	0.3
C1	71-99	74	18	8	15	0.9	tr(s)	0.3
C2	99-132	72	19	9	15	0.8	0.1	0.2
C3	132-173	78	15	7	20	1.0	0.6	0.2
Organic carbon, 4.6 kg/sq m to 99 cm								
Typic Haplargid (Sonoita 60-8), elevation 5,000 ft (1,524 m)								
A	0-8	82	12	6	10		tr	0.2
B21t	8-23	75	13	12	15	1.0	-	0.2
B22t	23-48	75	13	12	30	1.3	tr	0.2
B3	48-81	83	11	7	20		tr(s)	0.1
2Cca	81-102	81	13	6	25		1	
Organic carbon, 1.7 kg/sq m to 102 cm								

thick, dark A horizon in Sonoita is its location on a slight ridge that could not have been accessible to sedimentation for some time. The evidence suggests that, while Bt horizons were forming in Sonoita soils, sediments were still accumulating at the surface of Aladdin and Hawkeye soils. In addition, some surficial materials may have been truncated at Sonoita 60-8.

En route to study area 12; *return to Apollo Highway junction* on US-70 west of Organ. 2.1

26.7 Apollo Highway access road; *bear right* and continue north towards NASA Manned Spacecraft Center—Apollo Test Facility. The route parallels the San Agustin-San Andres Mountain front for the next 6 mi, crossing broadly undulating topography characteristic of the upper piedmont slopes at the base of the range. 2.3

FANS AND INTERFAN VALLEYS WEST OF SAN AGUSTIN-SAN ANDRES MOUNTAINS

The upper piedmont landscape along the western front of the San Agustin-San Andres Mountains is characterized by alternating fans and interfan valleys (fig. 59; 2.21). Large Pleistocene fans at the mouths of major canyons form the topographic highs; intervening broad interfan valleys, commonly with surfaces of Holocene age, form the lows. The large fans extend approximately 3 mi (5 km) out from the mountain front where they coalesce to form a nearly smooth fan-piedmont surface that slopes toward the Jornada Basin axis 5 mi (8 km) further west (study areas 14–18). The fan

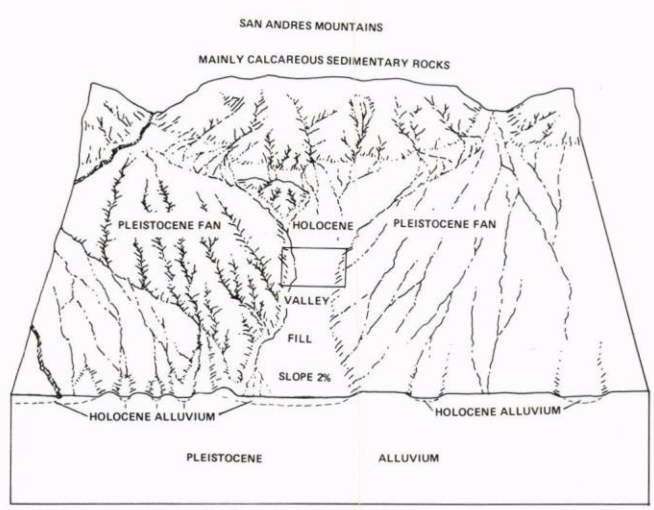


FIGURE 59—BLOCK DIAGRAM OF SAN ANDRES MOUNTAIN PIEDMONT, showing mountain front and piedmont slope in vicinity of Gardner Spring radiocarbon site. Bear Canyon fan at left and Lohman Canyon fan at right. Radiocarbon site (area 12a) is in Holocene fill of interfan valley at center of diagram.

heads are locally deeply trenched, and much runoff from mountain slopes is either channeled down or diverted into the interfan valleys. The creosotebush-covered fans are darker and greener than the light-colored grass that is typical of the larger interfan valleys. The difference in color is visible many miles from the mountain front.

29.0 Cross narrow transition zone between low carbonate, monzonite-derived, and high-carbonate, sedimentaryrock-derived alluvium. 2.0

31.0 Cattle guard; crossing south slope of Lohman Canyon fan. The fan area is approximately 6 sq mi (15.5 sq km). Its source drainage basin is in Paleozoic carbonate and clastic rocks with some Precambrian igneous and metamorphic rocks and Tertiary intrusive rhyolite. Basin area is approximately 4 sq mi (10 sq km) with a relief ratio of 0.12 (total basin relief/basin length). 2.1

33.1 Apollo Project security gate. Sign in and proceed to study area 12 with NASA escort. 0.6

33.7 STUDY AREA 12

STUDY AREA 12

Torrifluvents and Calciorthids of the Organ surface; the Gardner Spring radiocarbon site

SUMMARY OF PEDOGENIC FEATURES (table 54)—Charcoal dated at 2,100 and 2,200 yrs B.P. beneath a stage I carbonate horizon; buried soil at least 2,200 but not more than 4,600 yrs old; soils formed in high-carbonate parent materials; lack of reddish-brown B horizons found in low-carbonate materials; incipient calcic horizon in a soil 2,200 to 4,600 yrs old; effect of Wisconsinan full glacial in development of a reddish-brown argillic horizon that has not formed at any time in the Holocene; a chronology of Holocene pedogenesis in the project area.

SETTING—This general area has been termed the Gardner Spring radiocarbon site (Gile and Hawley, 1968). Eight charcoal horizons in Organ alluvium have been dated here (table 63, fig. 60). Figs. 60 and 61 are maps of geomorphic surfaces and soils in the area. The site is in an interfan valley between Bear and Lohman Canyon fans. Bear Canyon fan has an area of approximately 8 sq mi (20 sq km). Its source drainage basin

TABLE 63—RADIOCARBON AGES OF BURIED CHARCOAL AT THE GARDNER SPRING RADIOCARBON SITE.

Charcoal horizon no. (see fig. 60)	Alluvium and radiocarbon age, yrs B.P.
	Lower part of Organ III
3	1130 ± 90
	Base of Organ II
1	2120 ± 110
7	2220 ± 95
	Lower part of Organ I
2	4640 ± 180
5	4700 ± 120
6	4570 ± 120
4	4960 ± 130
8	6400 ± 110

is in Paleozoic and Cretaceous carbonate and clastic rocks, Precambrian igneous and metamorphic rocks (acid to basic), and Tertiary intrusive rhyolite. The basin area is approximately 7 sq mi (18 sq km) with a relief ratio of 0.09. Ridge summit remnants of the older, partly dissected fans north and south of the interfan valley are the general age equivalents of Jornada I surfaces seen in areas 4, 8, and 9.

Incision of major fan-head trenches and cutting of broad valleys in interfan lowlands occurred in late Pleistocene time, probably much earlier than the Holocene interval of aggradation. The Organ deposits covering the trench and valley floors commonly rest on well-developed buried soils, associated with an extensive buried Jornada II surface. The buried soils emerge as partly relict soils on ridge sideslopes and merge with still-stronger soils of Jornada I fan-surface remnants. The buried Jornada II surface slopes towards the Jornada Basin axis at a gradient gentler than the adjacent fan remnants. Younger and older fan profiles intersect 2-3 mi (3-5 km) out from the mountain front; and a Jornada II valley fill, only partly buried by Organ deposits, spreads out and in turn buries distal slopes of Jornada I fans (sheet 2).

The valley at the Gardner Spring radiocarbon site is between dissected remnants of two large Jornada I fans. It constitutes a broad drainageway underlain by Organ deposits that

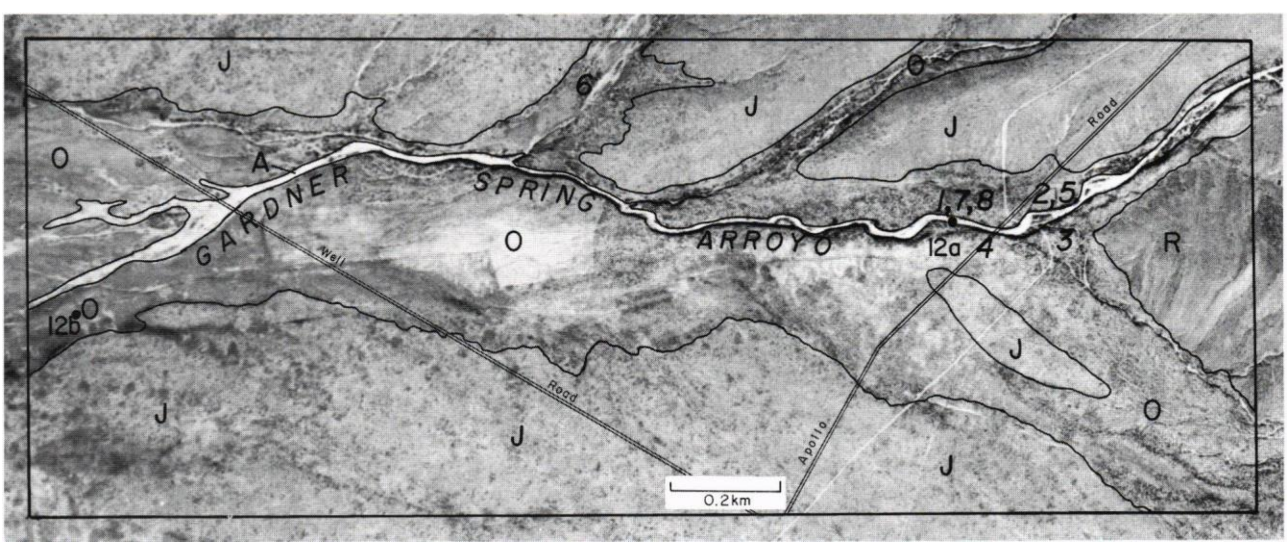


FIGURE 60—GEOMORPHIC SURFACES AT AREA 12, showing location of charcoal-dated Organ sediments (sites 1-8) at Gardner Spring radiocarbon site (tables 10 and 63); **A,** arroyo channel; **0,** Organ surface; **J,** Jornada surface-undivided; **R,** bedrock-carbonate sedimentary.

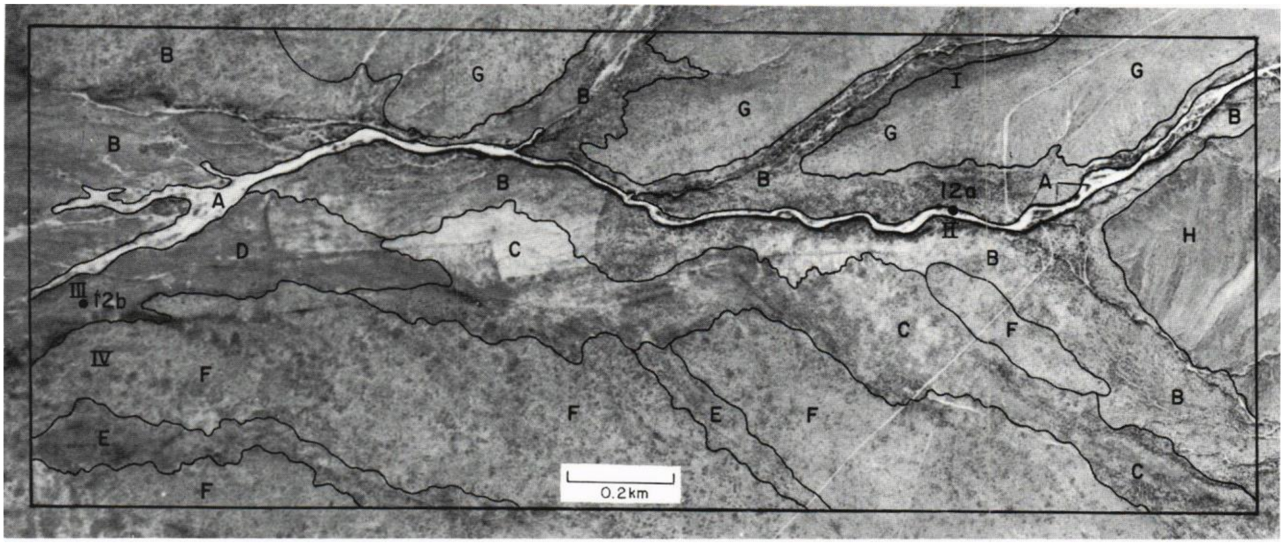


FIGURE 61—MAP OF SOILS IN VICINITY OF AREA 12, Gardner Spring radiocarbon site; **A,** Torriorthents (arroyo channels); **B,** Anthony complex (Organ surface); C, Reagan complex (Organ surface); **D,** Reagan clay loam (Organ surface); **E,** Conger complex, overflow phase (Jornada surface); **F,** Conger-Monterosa, carbonatic variant complex (Jornada surface); **G,** Monterosa, carbonatic variant (Jornada surface); **H,** sedimentary rock land (mountain slopes and summits, undifferentiated). I-II and III-IV locate cross sections (fig. 63).

have been cut by Gardner Spring arroyo (fig. 60). The arroyo banks provide excellent exposures of silty to gravelly valley-fill alluvium associated with several ages of the Organ surface. Buried soils associated with the Jornada II surface can be observed at several places below Organ alluvium. This older surface forms the floor and sideslopes of the interfan valley.

A number of lenticular beds of charcoal, possibly associated with buried hearths, have been found in sections of Organ alluvium exposed along this arroyo and two tributaries. Radiocarbon dates obtained from charcoal collected from eight beds and physical evidence of several distinct breaks in sedimentation indicate that at least two major, and one minor, episodes of alluviation occurred during development of the Organ surface in Holocene time (fig. 62). The first episode (characterized by the deposition of as much as 10 ft [3 m] of silty to loamy sediments) was initiated prior to about 6,000 yrs B.P. and ceased after 4,500 yrs B.P., but before 2,200 yrs B.P. These low-gravel sediments are designated Organ I alluvium. A second episode of alluviation, characterized by the deposition of more gravelly sediments, buries large areas of the Organ I surface. Charcoal beds sampled at the base of the gravelly overlay at two localities yield dates of about 2,100 and 2,200 yrs B.P. This younger sediment is designated Organ II alluvium. Charcoal was also recovered from the fill of a channel cut into both Organ I and II deposits. The C-14 date of this charcoal (about 1,100 yrs B.P.) is evidence of a still later cycle (Organ III) of erosion and deposition. The alluvial chronology at Gardner Spring is in close agreement with Haynes' (1968a) alluvial chronology of the southwest United States. Organ I alluvium corresponds to Haynes' Deposition C2; Organ II to Deposition D, and Organ III to Deposition E. The start of Organ alluviation may approximately coincide with the beginning of the altithermal (or about 7,500 yrs B.P.) according to Antevs (1955).

Vegetation is creosotebush and tarbush on the surface of the terrace. Slope is 2 percent to the west.

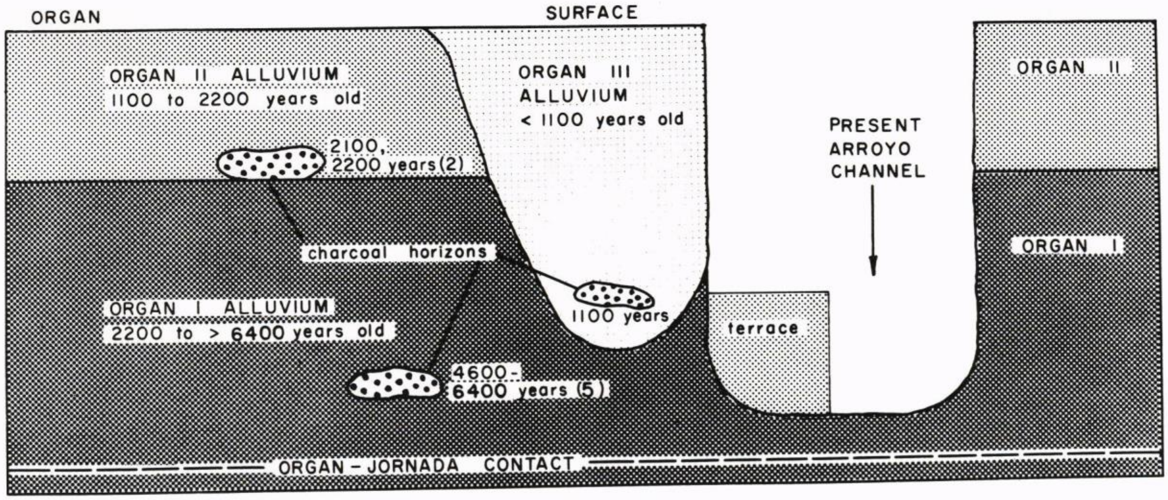
SOIL OCCURRENCE—The pattern of soils at area 12 (fig. 63) is determined by differences in soil age and particle size of the parent materials. Soil occurrence in this area may be related to two prominent parts of the landscape—the high fans (Jornada I and II surfaces) west of the mountain canyons and the interfan valleys (Organ surface) occupying the topographic lows between these fans. Soils of the fans are primarily the Ustollic Paleorthids Conger and Monterosa, carbonatic variant. In general more organic carbon is present in these soils than at lower elevations, and the Ustollic subgroups are common. In some areas, however, depth to the petrocalcic horizon is less than 18 cm and the Paleorthids are Typic. Soils of the topographic lows (Organ surface) between the fans are dominated by Torrifluvents (Anthony, its loamy-skeletal variant, and Glendale) and by weak Calciorthids (Reagan soils) that have formed in some areas of earliest Organ. Torriorthents dominate the arroyo channels; in places, the exhumed petrocalcic horizon of Jornada II age is exposed.

Area 12a—Typic Torrifluvent (Anthony 65-2) in Organ alluvium

Anthony 65-2 (figs. 62, 63) occurs on the north bank of Gardner Spring Arroyo (fig. 62). Distinct strata at the base of Organ II alluvium mark the boundary between Organ II and the buried soil of Organ I alluvium. The dated charcoal (fig. 62) and stratigraphic relationships show that the soil of Organ II must be at least 1,100 yrs old but that it cannot be older than 2,100 yrs.

The most prominent feature of pedogenesis in the soil of Organ II is the stage I carbonate horizon (the Cca horizon, fig. 62), in which pebbles are thinly coated with carbonate. Analyses (table 64) show a slight maximum of clay-size carbonate but no maximum on a less than 2 mm basis, and hence the soil is not a Calciorthid. This soil qualifies as a Fluvent on two counts: it has more than 0.2 percent organic carbon at a depth of 1.25 m, and organic carbon decreases irregularly with depth (3.1).

A radiocarbon age of 2,700 yrs B.P. was obtained from coatings of pedogenic carbonate on pebbles in the 2C2ca horizon (table 64; 3.83). As at area 7c, the date shows that low radiocarbon ages can be obtained on pedogenic carbonate even though it must have been partly derived from ancient limestone. However, the radiocarbon age is older than it



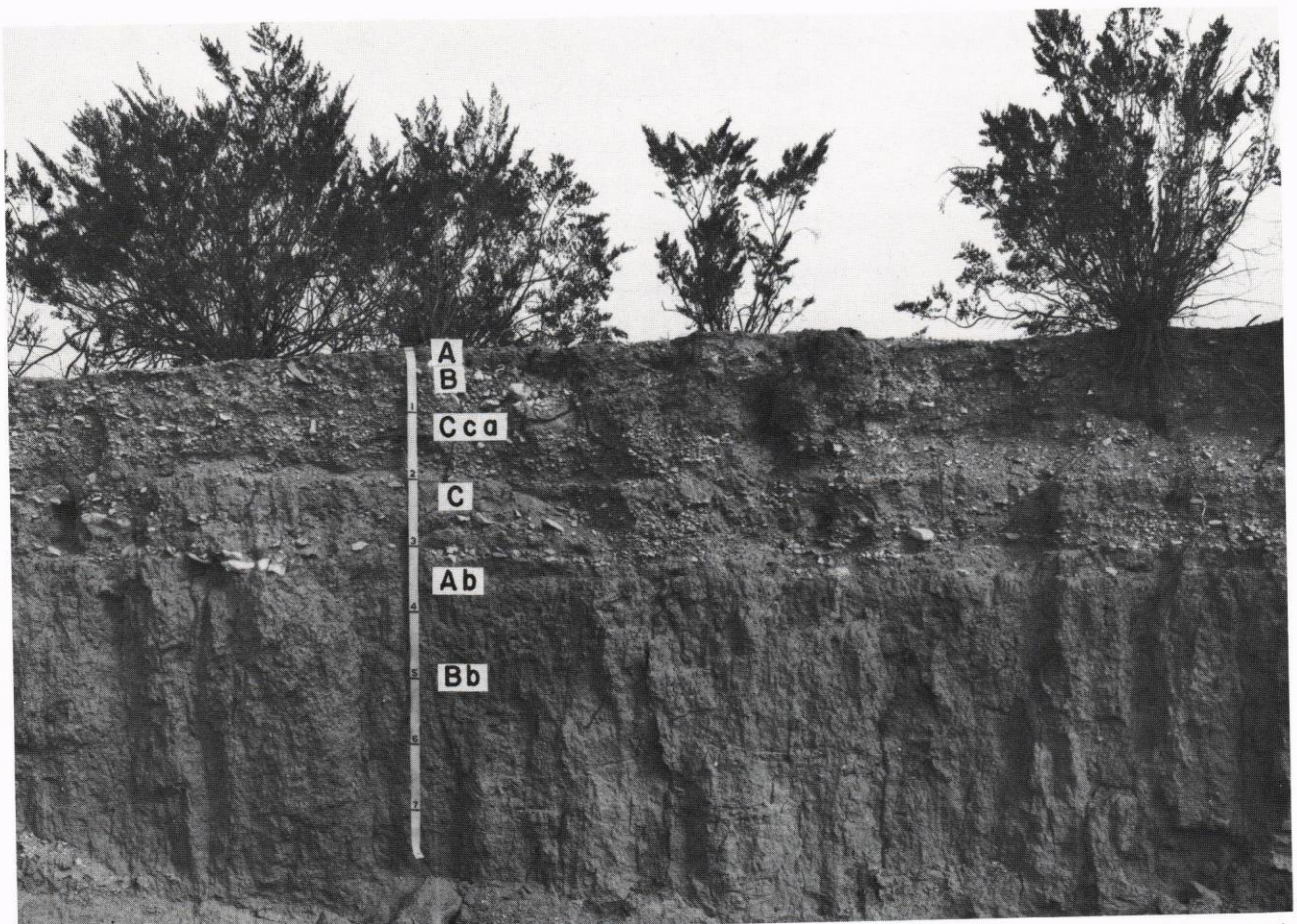


FIGURE 62—STRATIGRAPHIC RELATIONSHIPS AND TORRIFLUVENT IN ORGAN ALLUVIUM, AREA 12a. *Upper view:* diagram of chronostratigraphic relationships and charcoal horizons at the Gardner Spring radiocarbon site. *Lower view:* profile of a Typic Torrifluvent, Anthony 65-2. The base of the gravelly material (at about 3½ ft depth) marks the boundary between Organ II, above, and Organ I, below. Scale in feet (photographed October 1965).

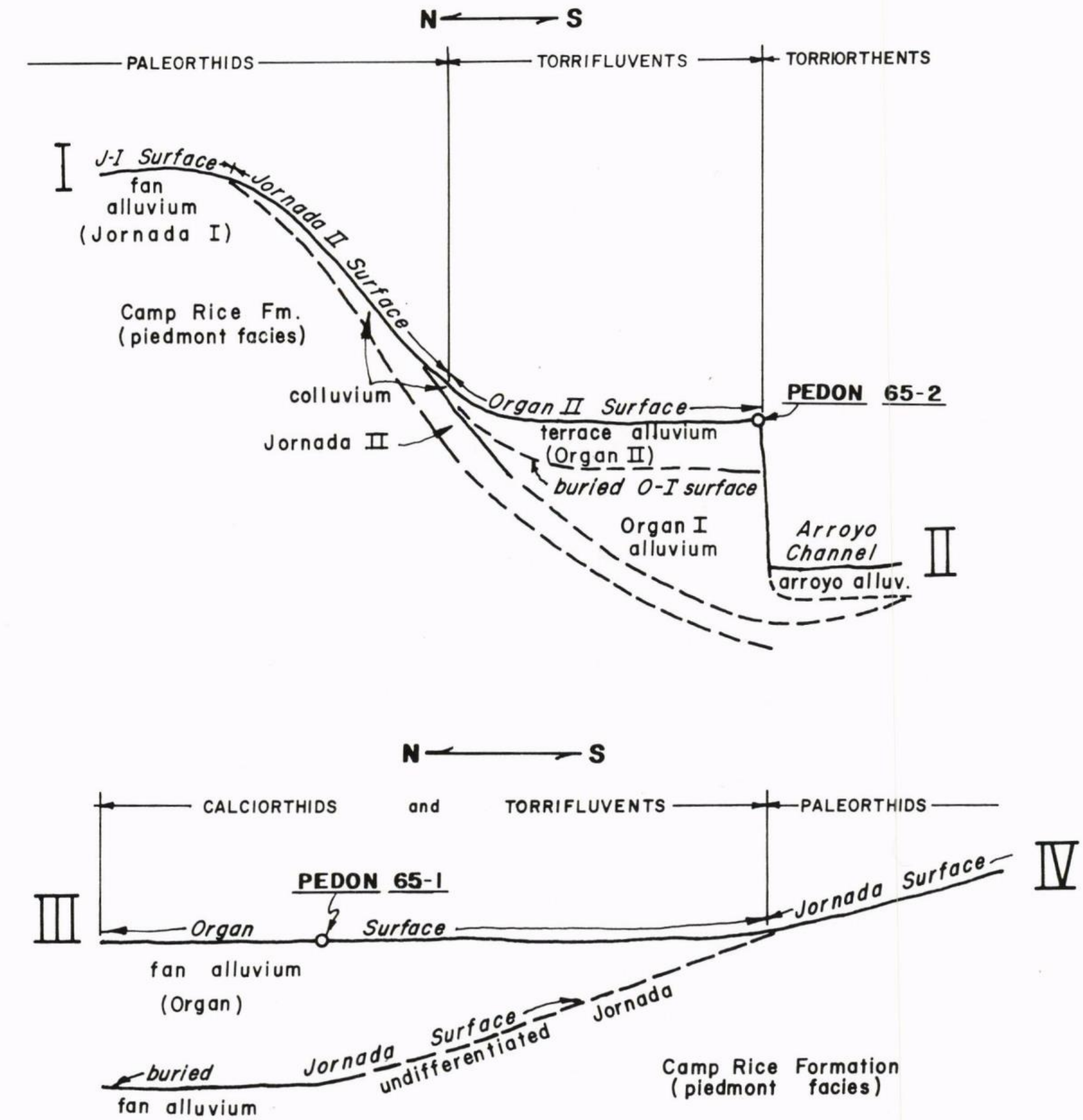


FIGURE 63—CROSS SECTIONS OF SOILS, SURFACES, AND SEDIMENTS, AREA 12. *Upper view:* diagrammatic section at area 12a (I–II on soil map, fig. 61). *Lower view:* diagrammatic section at area 12b (III–IV on soil map, fig. 61).

could be by C-14 dating of organic carbon, because charcoal beneath the 2C2ca horizon was dated at 2,200 yrs B.P. (area 10 and 3.83).

The radiocarbon ages of buried charcoal show that the soil in Organ I alluvium has been buried about 2,100 yrs; evidence exists for weak soil development prior to burial. Bulk density of the Ab horizon is relatively low, as would be expected in an A horizon, and increases in the Bb horizon (table 64). The buried soil has a structural B horizon with weak prismatic and subangular blocky structure. Very few carbonate filaments occur on ped faces, but there is essentially no carbonate maximum (table 60).

En route to study area 12b. Return to Apollo Project Headquarters area; *prepare for right turn.* **0.4**

34.1 Crossroad. *Turn right on graded road leading to water-well field.* Road junction is located near the northeastern edge of Lohman Canyon fan. The piedmont slope here consists of a complex of Jornada **I** and II surfaces. **0.5**

34.6 South margin of interfan valley floor. Organ alluvium wedges out near this point against the Jornada surface. The valley floor is underlain by Organ I alluvium that locally extends to depths of as much as 7 ft (1.8 m). It rests disconformably on the Jornada II surface and is discontinuously overlain by arroyo-channel and fan deposits. **0.4**

35.0 *Park vehicles and walk west across valley floor (about 2,000 ft) to area 12b.*

Area 12b—Ustollic Calciorthid (Reagan 65-1) in Organ alluvium

This area is located near the south edge of the interfan valley between Bear Canyon and Lohman Canyon fans. The bounding Jornada I fan remnants are buried a short distance to the west by younger fans associated with the Jornada II and Organ I surfaces. Approximately 1.2 m of Organ alluvium rests disconformably on older Jornada II(?) interfan valley fill with a well-developed soil. Slope is 2 percent to the west.

TABLE 64—LABORATORY DATA FOR A TORRIFLUVENT AND A CALCIORTHID AT THE GARDNER SPRING RADIOCARBON SITE; sand, silt, and clay on carbonate-free basis.

Alluvium	Horizon	Depth	Sand	Silt	Clay	>2 mm vol.	Carbonate <2 mm	Carbonate <0.002 mm	Organic Carbon	Bulk Density
		cm	%	%	%	%	%	%	%	%
	Anthony 65-2. Soil in Organ II alluvium is 1,100 to 2,100 yrs old.									
Organ II	Aca	0-3	70	20	10	20	8	tr	0.57	
	Bca	3-8	68	21	11	20	9	1	0.57	
	2C1ca	8-28	67	20	13	50	15	4	0.79	
	2C2ca	28-41	75	15	10	50	16	1	0.41	
	2C3	41-64	85	8	7	45	16	1	0.33	
	3C4	64-89	69	18	13	15	17	3	0.25	
	4C5	89-97	80	11	9	30	16	tr	0.16	
	VC6	97-107	59	25	16	4	15	1	0.28	
	(Buried soil, below, has been buried 2,100 yrs and is from 2,200 to 4,600 yrs old.)									
Organ I	5Ab	107-117	46	36	18	1	18	2	0.35	1.25
	5B1b	117-130	42	38	20	tr	16	2	0.36	1.27
	5B21cab	130-150	41	38	21	tr	15	3	0.47	1.39
	5B22cab	150-180	43	36	21	1	16	4	0.44	1.46
	5B3b	180-216	45	34	21	2	17	3	0.34	1.32
	5C1b	216-259	43	34	23	1	17	4	0.34	1.26
	5C2b	259-287	49	32	19	tr	17	3	0.28	1.31
	Reagan 65-1. Soil in Organ I alluvium is 2,200 to 4,600 yrs old.									
Organ I	A†	0-5	41	44	15	tr	12	tr	0.83	
	A†	5-13	31	47	22	tr	13	tr	1.09	1.25
	B1	13-23	38	40	22	tr	13	2	0.67	1.34
	B21ca	23-38	30	43	27	tr	15	2	0.70	1.39
	B22ca	38-66	25	42	33	tr	17	5	0.58	1.40
	B23ca	66-94	28	39	33	tr	16	4	0.45	1.33
	B3ca	94-114	40	32	28	2	12	4	0.29	1.43
	C	114-132	50	25	25	2	8	2		
	(Buried soil, below, has been buried at least 6,500 yrs and is of late Pleistocene age.)									
Jornada II	Btcab	132-150	62	19	19	3	5	2		
	2K2b	150-173	67	15	18	3	43	13		
	2K31b	173-190	66	17	17	75	41	14		
	2K32b	190-216	69	16	15	60	41	15		
	2K32b	216-241	74	14	12	60	37	11		

* Carbonate - containing basis.
† Discontinuous occurrence of fine strata in the A horizon, and a stone line at its base indicate that the A is much younger than the underlying horizons.

Vegetation is mainly burrograss; there are a few creosotebush and tarbush.

Fig. 64 shows Reagan 65-1. Organ **I** alluvium, buried by Organ II alluvium at area 12a, is at the surface here. Comparison of the buried and land-surface soils in Organ I alluvium therefore allows an appraisal of pedogenesis in these parent materials over the past 2,200 yrs. Differences are apparent; one is the development of an incipient calcic horizon. Very little pedogenic carbonate is apparent in the buried analogue of this soil at area 12a. Thus a calcic horizon can form in these highly calcareous parent materials in approximately 2,500 yrs (some time would be required for the obliteration of sedimentary strata and development of soil structure as at area 12a). The carbonate maximum, both by morphology (carbonate filaments) and laboratory analysis, occurs in the B22ca horizon (table 64), which qualifies as a calcic horizon; and the soil is therefore a Calciorthid (see area 16 for a Reagan pedon of late Pleistocene age).

These relationships illustrate the importance of high-carbonate parent materials on the classification of soils of Holocene age. Freshly deposited, high-carbonate parent materials already contain more than 15 percent $CaCO_3$ equivalent, one of the requirements of the calcic horizon in these soils. All that is needed is an accumulation of authigenic carbonate in a horizon that is more than 15 cm thick and that has at least 5 percent more $CaCO_3$ equivalent than the C horizon.

This relatively short time required for the development of the calcic horizon—about 2,500 yrs—contrasts greatly with the time required for low-carbonate parent materials. As suggested by the soils of Isaacks' Ranch and Jornada II, the time required for the development of a calcic horizon may be about 15,000 or 20,000 yrs where calcium for the carbonate must be derived entirely from the atmosphere.

The calcic horizon in this vicinity is in its incipient stages, occurring in some places but not in others. The lateral shift from a horizon that qualifies as calcic to one that does not is marked morphologically by a change from common carbonate filaments on ped faces (as in the calcic horizon of Reagan 65-1) to very few or no carbonate filaments on ped faces. The latter soils are Torrifluvents, where textures are relatively fine (silt loam; silty clay loam; clay loam) because analyses indicate that organic carbon values would be 0.2 percent or more to a depth of 125 cm. Such a soil is illustrated by Glendale 60-15 (Gile and Grossman, 1979), which lacks a calcic horizon both by morphology and analyses.

The relations above show the character of development of carbonate horizons and the effect on soil classification in high-carbonate parent materials of the area. Soils illustrating the transition from the Entisols to the Aridisols do not pass

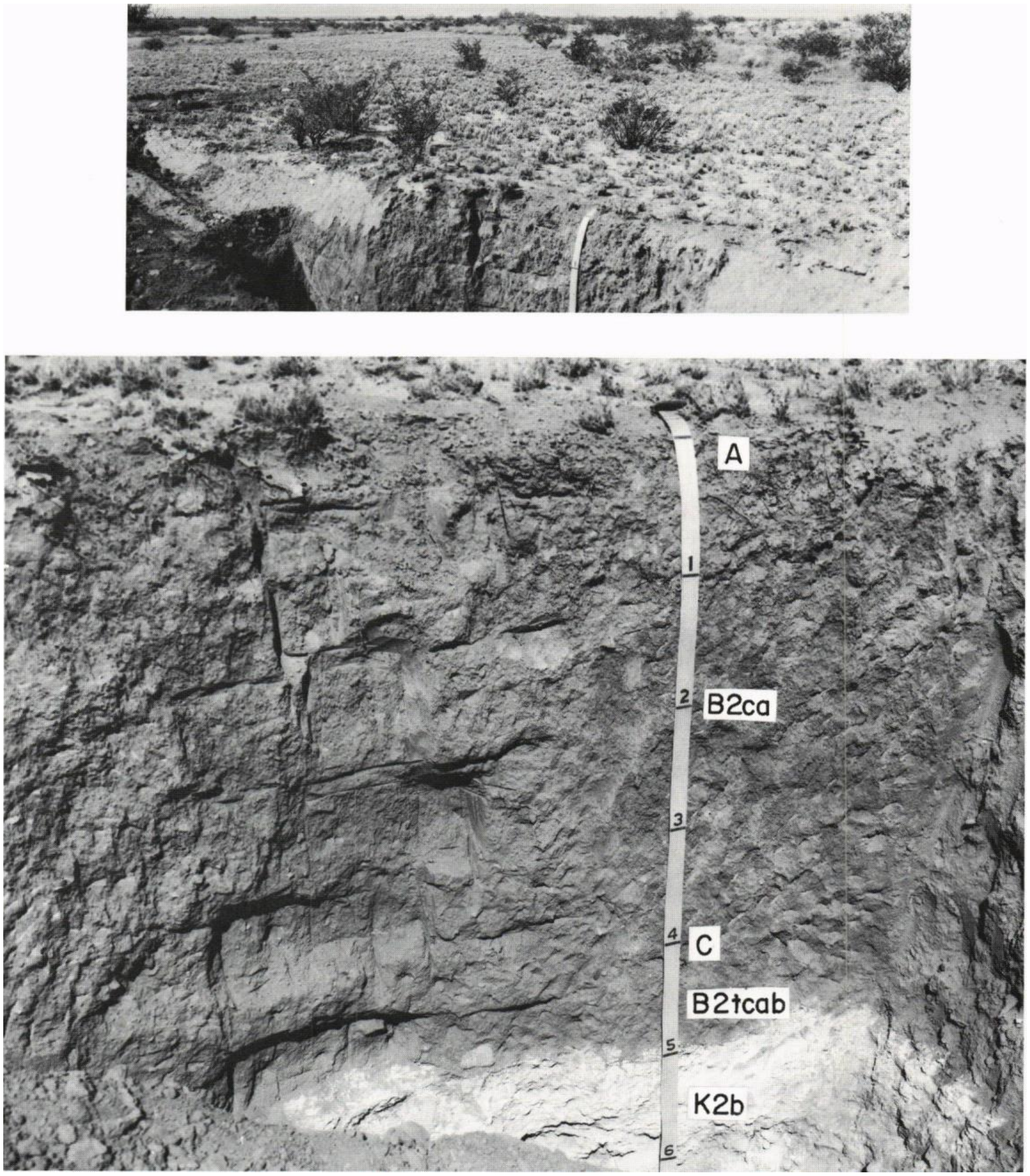


FIGURE 64—ORGAN **SURFACE AND CALCIORTHID AT AREA** 12b. *Upper view:* landscape of an Ustollic Calciorthid, Reagan 65-1, on the Organ surface. *Lower view:* Reagan 65-1; this pedon illustrates initial development of calcic horizon (the B2ca horizon, above; table 64) in high-carbonate parent materials. The Btb and K2b symbols designate a buried Haplargid. The Calciorthid is in Organ I alluvium, and the buried Haplargid is in Jornada II alluvium. Scale in feet (photographed September, 1965).

through the Camborthids (as is the case in low-carbonate parent materials) because of soil morphology and the interrelations of the definitions of the cambic and the calcic horizons. If carbonates are present in the parent materials, the cambic horizon must be underlain by a horizon with much larger amounts of carbonate (Soil Survey Staff, 1975). Such a carbonate horizon in these high-carbonate parent materials would contain enough carbonate for a calcic horizon, and the soils would be Calciorthids.

The buried Haplargid beneath Organ I alluvium (fig. 64) must have formed before about 6,500 yrs ago, primarily or wholly during the Pleistocene. Judging from exposures elsewhere, the argillic horizon must once have been carbonate-free. In contrast, after at least 2,000 yrs of soil development in the Holocene, abundant carbonate still remains in Organ I alluvium, and no morphological evidence of an argillic horizon has been found. These relationships indicate that a full-glacial period of the Pleistocene must have been required for the development of the argillic horizon in these parent materials. More effective moisture would be available for leaching during such times. The underlying, prominent horizon of carbonate accumulation is additional evidence that considerable leaching did take place during the Pleistocene.

However, the parent materials in this area have been considerably diluted with low-carbonate rocks, such as rhyolite and quartzite from Quartzite Mountain and granite in the Bear Canyon watershed. Thus the parent materials contain less carbonate than at area 7, where no evidence of an argillic horizon (present or former) has been found in soils of about the same age.

TABLE 65—THE CHRONOLOGY OF HOLOCENE PEDOGENESIS IN THE PROJECT AREA; summarized for all major sediments except sandy ones. Illustrative soils are on stable sites of the Organ surface except for those designated Fillmore. Cited expression of pedogenesis usually occurs within the upper 0.5 to 0.8 m of the deposit. Only major morphological features are listed here. Sandy sediments were excluded to simplify the table. Soils of coppice dunes are less than 100 yrs old and consist of C-horizon material. Most other sandy soils occur along the valley border. At stablest sites these soils have noncalcareous brown B horizons and weak Cca horizons. In low-gravel sediments the soils are Torripsamments; in high-gravel sediments they are Torriorthents. At unstable sites where the soils have been truncated, the B horizons may be calcareous throughout or may have been truncated.

Soil age, years B.P.	High-carbonate parent materials		Low-carbonate parent materials	
	Low-gravel materials	High-gravel materials	Low-gravel materials	High-gravel materials
0 (fresh alluvium in arroyo channels)	calcareous		mostly calcareous	
<100(?)	Thin gray A horizon that is vesicular in places; slight accumulation of organic carbon. Torrifluvents, Torriorthents			
100(?) to 1,100	Slight carbonate accumulation in the form of a few filaments and patchy coatings on some of the scattered pebbles. Torrifluvents, Torriorthents	Similar to low-gravel materials except that the carbonate maximum is slightly more apparent, with filaments and discontinuous coatings on pebbles. Torrifluvents, Torriorthents	Chronological control not available for this interval. Observations suggest features similar to high-carbonate materials except for development of noncalcareous upper horizons in places. Torriorthents	
1,100 to 2,100	A very few faint, discontinuous filaments and grain coatings. Where a few pebbles occur they tend to have complete carbonate coatings. Torrifluvents, Torriorthents	Thin Bca† horizon with little or no macroscopic carbonate, underlain by Cca horizon with thin, continuous carbonate coatings on pebbles. Torrifluvents, Torriorthents	(Fillmore) Noncalcareous, brown or reddish brown B horizon underlain by horizon with few faint, discontinuous carbonate filaments and grain coatings. Cambic horizon* Camborthids	(Fillmore) Noncalcareous, reddish brown B horizon underlain by Cca horizon with thin, continuous carbonate coatings on pebbles. Cambic horizon* Camborthids Argillic horizon* Haplargids
4,000? (2,200 to 4,600)	Texture clay loam, silty clay loam, silt loam; development of compound prismatic and subangular blocky structure; carbonate filaments common in places. Torrifluvents Calcic horizon* Calciorthids	Similar to above except that the pebble coatings are thicker. Torrifluvents Torriorthents Calcic horizon* Calciorthids	Noncalcareous, brown or reddish brown B horizon underlain by Cca horizon with carbonate coatings on sand grains. Camborthids Argillic horizon* Haplargids	Noncalcareous, reddish brown B horizon underlain by Cca horizon with carbonate coatings on pebbles. Haplargids
7,000?			Noncalcareous, reddish brown B horizon underlain by Cca horizon with carbonate coatings on sand grains. Haplargids	

*Marks initial development of named diagnostic horizon under stated conditions.
†Horizon between the A horizon and the carbonate maximum. Does not extend deep enough for a cambic horizon.

CHRONOLOGY OF HOLOCENE PEDOGENESIS IN PROJECT AREA

Radiocarbon ages of buried charcoal beneath Holocene soils at the Gardner Spring and other radiocarbon sites (table 10; 2.6) and land survey notes have provided chronological control of Holocene soils along both the arid valley border and piedmont slopes and the semiarid mountains. Tracing soils and geomorphic surfaces from the dated sites indicates a chronology of pedogenesis for the entire project area (table 65). The time encompassed dates from about 7,500 yrs B.P. to the present. Soils of Leasburg and Isaacks' Ranch age are not included in this discussion. Some surfaces of Leasburg and Isaacks' Ranch age may date from early Holocene (10,0007,500 yrs B.P.), but most of these deposits were probably emplaced during the first major period of drying that followed the full glacial—from about 13,000 to 11,000 yrs B.P. (2.73). This is the Monahans interval of Wendorf and Hester (1975).

Holocene soils record the beginning of various soil horizons (table 65). Those horizons that developed in the Holocene include the diagnostic cambic, argillic, and calcic horizons in Soil Survey Staff (1975; 3.1).

Carbonate content of the parent materials is a major factor in determining the direction of soil development in the Holocene (table 65). With increasing age in high-carbonate materials, the progression of soil development is marked by the development of an A horizon, destruction of thin sedimentary strata, development of structure in materials of sufficiently fine texture, slight accumulation of carbonate, and finally the development of an incipient calcic horizon in some areas. As indicated in table 65, reddish-brown, noncalcareous B horizons have not formed in high-carbonate parent materials at any time in the Holocene.

Soils in coppice dunes occur extensively in low-carbonate, sandy sediments deposited since 1850. No B horizons have formed in these materials. Noncalcareous, reddish-brown B horizons start their development quite early in low-carbonate parent materials (table 65). In soils of the Fillmore surface, incipient development of the argillic horizon and the Haplargids is shown only at stablest, oldest sites, in very gravelly materials that range from about 1,000 to 2,000 yrs old. Facies changes to low-gravel materials are accompanied by a concomitant shift to a cambic horizon and the Camborthids because the increase in silicate clay required for the argillic horizon is not met in low-gravel materials of this age. Camborthids and incipient Haplargids that may be as old as 4,000 yrs occur in low-gravel materials of the Organ surface. Haplargids occur continuously in the same kind of materials that may date from about 7,500 yrs ago. Thus the soils formed in low-carbonate parent materials illustrate the development of both incipient and (in oldest soils) fairly distinct argillic horizons in the Holocene.

Carbonate horizons are the best and most common pedogenic indicators of soil age. Stage I carbonate horizons are a major feature of pedogenesis in the Holocene. Because of atmospheric additions of calcium, the carbonate horizons are morphologically similar whether they have developed in low-or high-carbonate parent materials.

End of field study tour for Day 2. Return to Las Cruces via Apollo Highway and US-70.

Day 3

Aridisols of a structural bench and adjacent exhumed Haplargids; Vertisols of a playa and Aridisols on adjacent fan piedmont (low-carbonate materials); Aridisols in basin floor (low- and high-carbonate materials)

The route of the third day's study tour is shown in fig. 65. Classification and diagnostic features of soils to be seen on Day 3 are summarized in table 66.

Mile

0.0 Assembly point. New Mexico State University Agriculture Building. Route to mile 3.3 (via Espina Street, University Avenue, and 1-25 North) is the same as Day 2. Prepare to leave interstate at Lohman Avenue (NM-320). 3.3

3.3 Lohman Avenue exit; *bear right.* Follow signs to city sanitary-landfill site. 0.3

3.6 Stop sign; *turn right (east) on Lohman Avenue. 0.1* 3.7 *Turn right onto Telshor Avenue.* 0.2

3.9 Intersection; *turn left (east) on Foothill Road.* Roadcut to right is in fluvial sand and gravel of the Camp Rice Formation. 0.3

4.2 South abutment and emergency spillway of Corps of Engineers flood-control dam to left. Route to east ascends ridge capped by mixed-rounded (fluvial) gravel facies of the Camp Rice. Valley-border slopes here are mainly erosional and of late Quaternary age. Fort Selden alluvium and colluvium form a discontinuous veneer on sandy Camp Rice deposits. 0.7

4.9 Crossroad; route rises to summit of broad gravel-capped ridge that forms an extensive structural bench along upper slopes of the valley border. 0.5

5.4 Sand-and-gravel pit to left. Upper palate and teeth of

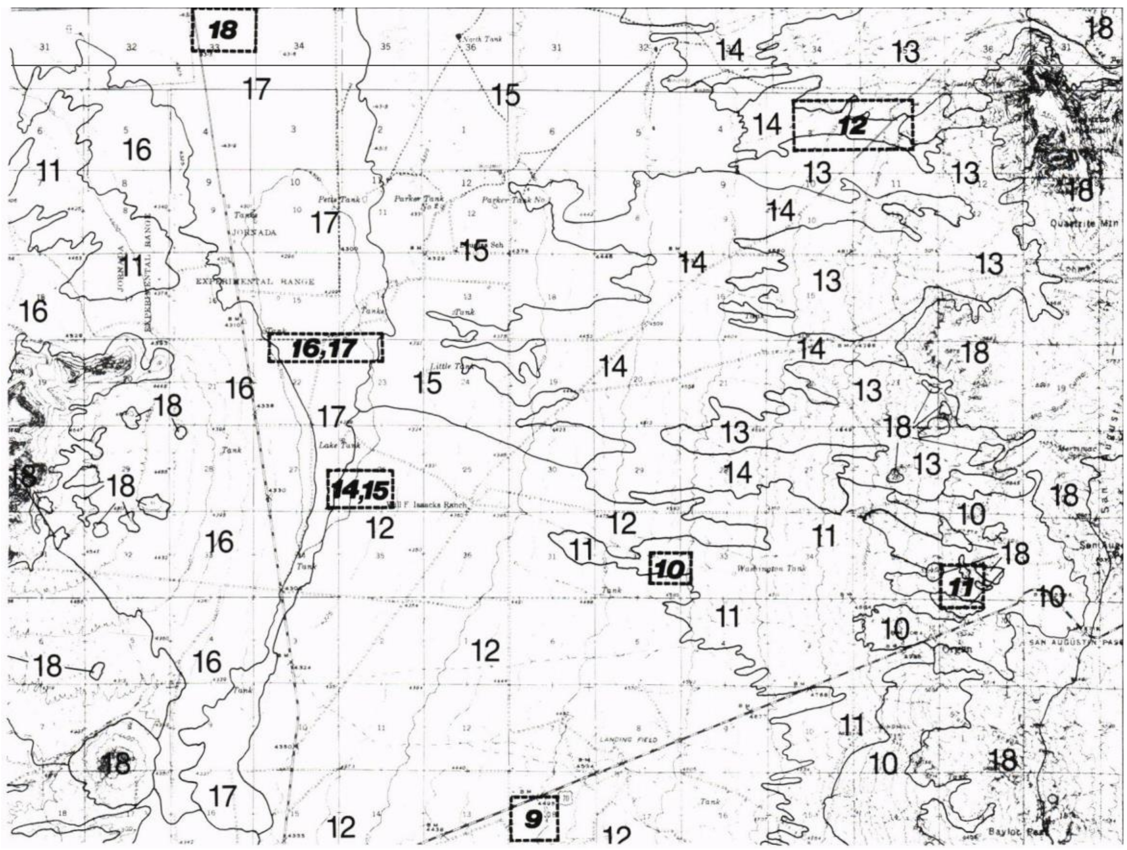


FIGURE 65—LOCATION OF STUDY AREAS 14-18, DAY 3. Area 13, not shown, is on the valley border east of Las Cruces (fig. 17). Explanation for this part of the general soil map (fig. 16):

10 Caralampi-Nolam-Aladdin association (Haplargid-Haplustoll association) of the Jornada and Organ surfaces.
11 Onite association (Haplargid association) of the Organ surface.
12 Berino-Bucklebar association (Haplargid association) of the Jornada **II,** Isaacks' Ranch, and Organ surfaces, and coppice dunes.
13 Conger-Monterosa carbonatic variant complex (Paleorthid complex) of the Jornada surface.
14 Glendale-Anthony complex (Torrifluvent complex) of the Organ surface.
15 Algerita-Dona Ana-Reagan complex (Calciorthid-Haplargid complex) of the Jornada II and Organ surfaces.
16 Dona Ana-Onite-Anthony association (Haplargid-Torrifluvent association) of the Jornada II and Organ surfaces.
17 Stellar-Reagan-Algerita association (Haplargid-Calciorthid association) of the Jornada **I,** Petts Tank, Lake Tank, and La Mesa surfaces.
18 Rock outcrop and soils of mountain slopes and summits, undifferentiated.

TABLE 66—FEATURES OF SOILS AND LANDSCAPES AT STUDY AREAS 13–18, DAY 3. Precipitation estimated from records at University Park and the Jornada Experimental Range. Trenches usually closed unless otherwise indicated. Symbols: s, sandy; c-l, coarse-loamy; f-l, fine-loamy; f-s, fine-silty; f, fine; vf, very fine; m, mixed mineralogy; t.s. var., thin solum variant; s.s. var., sandy subsoil variant; c.s. var., clayey subsoil variant. All soils are thermic.

Study area	Precipitation (in., cm) elev. (ft)	Parent materials derived primarily from:	Geomorphic surface and age	Landform and percent slope	Nature of exposure	Classification: Subgroup	Family	Series	Diagnostic horizons	Stage of carbonate accumulation
13 a,b	8 4,300	Noncalcareous gravel and sand	**a** Post-Tortugas late Pleistocene	**a** Structural bench, nearly level	**a,b** Open trench	**a** Typic Calciorthid	s, m	Caliza, sandy variant	Calcic	III
			b Dissected Jornada Holocene	**b** Ridge side, 30		**b** Typic Haplargid (exhumed)	f-l, m	Dona Ana	Argillic	II
14 a-c	9 4,285- 4,295	Monzonite, rhyolite, andesite, limestone, sandstone, shale	**a** Lake Tank Holocene–late Pleistocene	**a** Playa, level	**a-c** Trenches	**a** Typic Torrert	vf, m	Dalby taxadjunct	None	—
		Monzonite	**b,c** Organ Holocene	**b** Edge of playa, 1		**b** Typic Haplargid	f-l, m	Bucklebar	Argillic	I
				c Slight ridge, 1		**c** Typic Haplargid	c-l, m	Onite	Argillic	I
15 a-f	9 4,320	Monzonite	**a** Jornada II late Pleistocene	**a** Fan piedmont, 1	**a-f** Trenches	**a** Typic Haplargid	f-l, m	Berino	Argillic, calcic	III
			b-f Organ Holocene	**b** Margin of slight ridge, 1		**b** Typic Haplargid	c-l, m	Onite, t.s. var.	Argillic	I
				c Crest of slight ridge, 1		**c** Typic Haplargid	s, m	Onite, s.s. var.	Argillic	I
				d Side of slight ridge, 1		**d** Typic Camborthid	c-l, m	Pajarito	Cambic	I
				e Margin between ridge and drainageway, 1		**e** Typic Haplargid	f-l, m	Bucklebar	Argillic	I
				f Drainageway, 1		**f** Ustollic Haplargid	f, m	Headquarters, c.s. var.	Argillic	I
16 a,b	9 4,300	Limestone, sandstone, granite, rhyolite	**a** Organ Holocene	**a** Fan piedmont, 1	**a** Open trench	**a** Ustollic Calciorthid	f-l, m	Reagan, light subsoil variant	Calcic	I
		Limestone, sandstone, granite, rhyolite	**b** Petts Tank late Pleistocene	**b** Basin floor, nearly level	**b** Trench	**b** Ustollic Calciorthid	f-s, m	Reagan	Calcic	III
17	9 4,295	Rhyolite, andesite, monzonite	Jornada I middle Pleistocene	Basin floor, level	Trench	Ustollic Haplargid	f, m	Stellar	Argillic	III
18	9 4,310	Noncalcareous sand	Jornada I middle Pleistocene	Crest of slight ridge, nearly level	Trench	Typic Calciorthid	c-l, m	Algerita	Calcic	III

a middle Pleistocene Mastodon *(Cuvieronius)* were recovered from this pit (Hawley and others, 1969). **0.2**

5.6 STUDY AREA 13

STUDY AREA 13

Calciorthids of a structural bench; exhumed Haplargids

SUMMARY OF PEDOGENIC FEATURES (see table 66)— Pedogenesis in exhumed gravel deposited by the ancestral Rio Grande; structural bench contrasted to a constructional surface; exhumed, once-buried Haplargids above the river gravel; fossil vertebrates of the Camp Rice Formation and their significance as chronologic markers; analogues of exhumed Haplargids have oldest (dead) C-14 dates found in the project area.

SETTING—The structural benches (2.22, fig. 3b) forming nearly level to undulating summits of ridges in the western part of this study area are part of an extensive erosion-surface complex cut on resistant gravelly sediments (Camp Rice fluvial facies) deposited by the ancestral Rio Grande (figs. 6 and 7). To the east a thickening wedge of younger Camp Rice alluvium, derived from the central Organ Mountains, overlaps the fluvial deposits. Remnants of the Jornada I surface, marking the culmination of middle Pleistocene piedmont-slope aggradation and the top of the Camp Rice Formation, are preserved a short distance to the east near the power line. A low, sinuous scarp ascending to post-Jornada I ridge remnants (fig. 66) marks the present limit of erosional stripping of loamy, low- gravel piedmont-toeslope deposits from the more resistant gravelly beds of the fluvial facies as well as from the outer rim of the Rio Grande valley.

In contrast to materials seen in fans and fan piedmonts, where rock types in coarser-size fractions were traceable directly to their local mountainward sources, the fluvial facies of the Camp Rice Formation contains a wide variety of rock types, some derived from upriver sources far to the north. As much as 40 ft (12 m) of the formation is exposed in gravel pits in this area and along US-70 several miles north. The unit consists of crossbedded pebble gravel and sand, with scattered fine cobbles. Large-scale sets of crossbeds fill channels cut in underlying sets. Armored mudballs with reddish to greenish clay centers are minor constituents of the sediments, as are thin clay to loam stringers. A percent count of rock types in pebble gravel samples from the upper part of one gravel pit is: rhyolite, 33; andesite and latite, 20; granite-gneiss, 14; quartz, 8; chert, 7; sandstone and siltstone, 6; monzonite, 5; basalt, 4; and quartzite, 3. In the sample from this pit the andesitelatite, quartz, quartzite, basalt, and monzonite pebbles were rounded to well rounded. The rhyolite, chert, granite-gneiss, and sandstone-siltstone pebbles were angular or subangular to well rounded. A few rounded pebbles of obsidian and coarser clasts of rhyolite pumice have also been collected from the mixed-rounded gravels in this region. The deposits are resistant to erosion because of their high gravel content and permeability.

These ridges illustrate class 5 dissection (fig. 22). In some areas, stablest parts of a few ridge crests may date from Tortugas time; however, all parts of the landscape in this area appear to be younger than Tortugas. Exhumation of these gravelly sediments must have started shortly after initiation of valley entrenchment in middle Pleistocene time and is continuing today. In addition, the sediments have been variably dissected and eroded since their exhumation. This means that the time of exposure at the land surface and hence the time available for soil development must range widely for these sediments. Thus, structural benches contrast markedly with stable areas of constructional geomorphic surfaces such as the Picacho surface.

SOIL OCCURRENCE—The pattern of soils at area 13 (fig. 68) is determined by differences in soil age, gravel volume, degree of dissection, and the materials being exhumed by dissection. Calciorthids, mainly Caliza soils and their sandy variant, are dominant on most of the ridge crests of the structural bench. Paleorthids occur in high-gravel materials on a few of the stablest ridge crests. Torriorthents (Arizo soils) are dominant on upper sides of ridges. Downslope they usually grade to less gravelly Torriorthents (Yturbide soils), which average 15-35 percent gravel in their control sections, and Torripsamments (Bluepoint soils), which average less than 15 percent gravel in their control sections. Arizo soils are dominant in terraces adjacent to the channels.

In the dissected materials east of the scarp, much of the considerable morphological variation at the land surface is caused by textural differences within soils as various horizons are beveled on the slopes. Because of this very wide range in morphology, the soils are grouped within a single mapping unit, dissected Haplargids (fig. 66). On ridge sides the buried soils are mantled by a thin, discontinuous layer of gravelly colluvium.

Area 13a—Typic Calciorthid (Caliza, sandy variant) of a structural bench on Camp Rice gravels

This soil occurs on the nearly level ridge crest of a structural bench. Vegetation consists of creosotebush, ratany, and a few clumps of fluffgrass.

Caliza, sandy variant, has a thin A horizon and a calcic horizon. The upper boundary of the carbonate maximum is very near the surface. This upper boundary and the narrow ridge crest indicate soil truncation since soil development started. Partly because of truncation, the 25-100-cm control section averages sandy over most of the exposure. On the east side of the exposure, however, the control section is finer and averages coarse-loamy (Whitlock soils).

Walk east to area 13b, the western edge of a broad belt of dissected soils (partly buried-partly exhumed) developed in the younger piedmont toeslope facies of Camp Rice sediments that overlap the river gravel.

Area 13b—Typic Haplargid (Dona Ana) in exhumed beveled Camp Rice deposits

This soil occurs on a ridge side sloping 30 percent to the east. Vegetation is creosotebush, ratany, and fluffgrass.

On ridge sides the colluvial mantle is usually thin or absent so that classification at any one spot depends on the character of the soil at that spot. Here the exhumed soil is a fine-loamy Haplargid that falls within the range of the Dona Ana series. The reddish-brown Bt horizon and the carbonate horizon are similar to these horizons in soils presently at the land surface.

The buried and exhumed soils have loamy textures and have formed in a sequence of low-gravel Camp Rice deposits. The buried soils do not slump readily, and a discontinuous scarp marks the area of their outcrop and contact on the underlying river gravel. These soils crop out over a large area that extends along the east rim of the Mesilla Valley from the Goat Mountain area southward to Fillmore Pass, south of the Organ Mountains. The buried soils mark times of general landscape

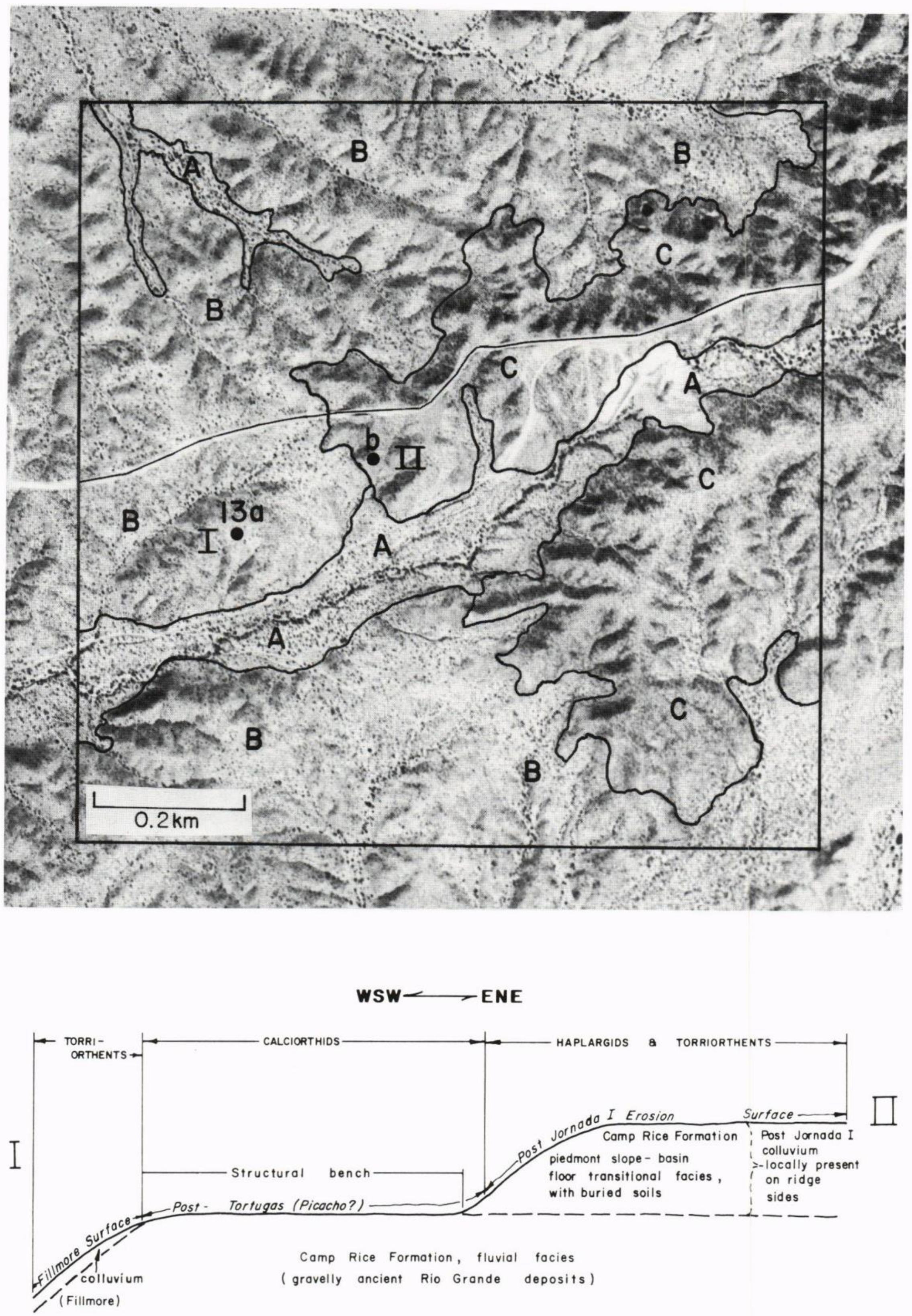


FIGURE 66—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 13. *Upper view:* map of soils; **A,** Arizo-Torriorthent complex (Fillmore and arroyo-channel surfaces); **B,** Caliza-Bluepoint complex (Fort Selden, Picacho); **C,** dissected Haplargids (Fort Selden, Picacho). I–II locates cross section. *Lower view:* diagrammatic section of soils, surfaces, and sediments (I–II on soil map).

stability, during which soils were formed, alternating with times of instability, during which there was erosion in some upslope areas and concurrent sedimentation downslope.

The buried soils must have formed during the time span occupied by development of the thick soils of La Mesa (Day 1). Morphology is very similar to soils in various places at the present land surface. This suggests that the climate during their development ranged no wider than from the Holocene climates to climates of the full-glacial maximum in the late Pleistocene (17,000-23,000 yrs B.P.).

Two pedons in these materials have been sampled (table 67). Both pedons occur on narrow ridges and, because of landscape dissection and associated soil truncation, have carbonate horizons that are essentially at the surface. The carbonate horizons have too little carbonate for a calcic horizon (table 67) and occur in deposits that are less than 50 cm thick above buried soils. Since diagnostic horizons are not present in the thin surficial deposits, classification is based on the underlying buried soil (3.16).

Organic carbon is very low, as is characteristic of most buried soils in the study area. Black coatings and filaments occur in the B horizons of both buried soils. Concentration of these black accumulations in the B horizon and their absence in the C horizon suggest that they were a feature of pedogenesis when the buried soils were at the land surface and were not emplaced from water associated with deposition of the overlying alluvium.

Carbonate C-14 dates for SND 59-9 (table 67) suggest that the carbonate in the B2tb horizon was emplaced from the land-surface soil. This interpretation is consistent with concentration of the carbonate in elongate bodies between structural units and with the noncalcareous interiors of many peds. Carbonate in the C horizon has an age exceeding 30,000 yrs, which is the only dead date obtained in the project area. The dead date may be due to deep burial of the carbonate and to occurrence of this soil high in a dissected landscape. These factors should reduce the possibility of C-14 youthening from deeply penetrating moisture of pluvials and from water tables.

En route to area 14. *Return to 1-25 North.* 2.0

7.6 Lohman Avenue interchange; *bear right on 1-25 North access road.* Continue north to the Jornada Range Road junction. See Day 2 road log, miles 3.3-9.5, for description of route. 2.4

10.0 Interchange, *bear right* to US-70 East. 2.7

12.7 Auto salvage yard to left. *Move to left lane;* prepare to turn left. 0.7

13.4 *Turn left through cattle guard onto graded Jornada Experimental Range Road.* Note extensive development of mesquite coppice dunes in this area. 1.1

14.5 Crossing Rio Grande-Jornada del Muerto drainage divide. Goat Mountain microsyenite plug on Mesilla Valley rim to left (2.44). 0.2

14.7 Well on west edge of road penetrated about 640 ft (195 m) of Santa Fe Group basin fill over lower Tertiary volcanics. The upper 190 ft (58 m) is mainly fluvial sand and gravel with a surficial zone of piedmont deposits including a veneer of Jornada II alluvium. Static water level here is about 270 ft (82 m) (fig. 9; King and Hawley, 1975). 0.6

15.3 Side road on right to Jeff Isaacks' Ranch. Dona Ana Mountains to the northwest are a tilted fault-block remnant of a middle Tertiary cauldron complex. Higher peaks are intrusive syenite to monzonite dated by K-Ar at about 35 m.y. Lower ridges and slopes are cut mainly on cauldron-filling rhyolite tuff and older volcanics of andesite-latite composition. A large area of Permian carbonate and clastic rocks is exposed in

TABLE 67—Laboratory data for two pedons with buried Haplargids; sand, silt, and clay on carbonate-free basis.

Horizon	Depth	Sand	Silt	Clay	Vol. >2 mm	Carbonate	Organic carbon
	cm	%	%	%	%	%	%
SND 59-12, Typic Haplargid, coarse-loamy							
K2	0-36	77	11	12	40	10	0.52
2B1tb	36-69	72	15	13	tr	4*	0.15
2B21tcab	69-91	76	11	13	tr	2	0.08
2B22tcab	91-122	79	9	12	tr	2	0.06
2B3tcab	122-152	80	9	11	tr	5	0.05
2Ccab	152-178	84	6	10	tr	6	0.05
SND 59-9, Typic Haplargid, fine-loamy							
K2	0-36	79	10	11	†	14	0.74
2B11tcab	36-51	82	8	10	tr	4	0.26
2B12tcab	51-64	86	6	8	tr	2	0.11
2B21tcab**	64-71	77	8	15	tr	1	0.11
2B22tcab**	71-135	69	10	22	tr	4	0.05
2B3tcab	135-165	69	14	18	tr	7	0.05
2C1cab††	165-226	74	14	12	tr	14	0.04

* Peds contain 1 percent carbonate; filling among peds, 5 percent.
† Limestone pebbles partially dissolved in procedure to remove carbonate.
** Nodular carbonate (including vertical stringers) from these horizons has a C-14 age of 20,300 ± 800 yrs B.P. (W-796).
†† Carbonate nodules from this horizon are dated at >30,000 yrs B.P. (W-797).

the northwest part of the mountains (2.42; Seager and others, 1976). 1.7

17.0 Cross Jornada Basin axis. The floor here is a narrow alluvial flat confined between piedmont slopes grading from the Organ and Doria Ana Mountains (2.21). Summer-storm runoff occasionally floods the flat resulting in short-term surface flow northeast into Isaacks Lake playa. The water table in this area is about 250 ft (76 m) below the land surface (fig. 9). *Prepare for right turn.* 0.2

17.2 Cattle guard. *Turn right on narrow ranch road to Isaacks Lake.* Continue north along zone of piedmont-slope and basin-floor mergence. A very thin veneer of late Quaternary alluvium covers the Jornada I surface and Camp Rice basin fill. 1.3

18.5 *Cross south end of Isaacks Lake playa and park vehicles near southeast edge.* 0.3

BASIN-FLOOR TO FAN-PIEDMONT TRANSITION

The remainder of Day 3 will be spent in the study of soils and landscapes in the closed basin. Fig. 67 shows the geomorphic setting of study areas 14 to 17. The transition from the piedmont slopes to the basin floor represents an important change in both soils and landscapes when compared to the stepped sequence of the river valley (fig. 4, 2.2). In the closed basin, episodic sedimentation has resulted in soil burial and a smooth basin-floor-distal-piedmont-slope topography (fig. 4b).

A study area in the vicinity of Isaacks Lake playa illustrates episodic sedimentation in and adjacent to a playa in the basin floor (area 14; fig. 68). Soils and deposits of at least four ages occur in this basin-floor area.

18.8 STUDY AREA 14. *Walk to pit in south-central part of playa.*

STUDY AREA 14

Vertisols of the Lake Tank surface; Haplargids of the Organ surface

SUMMARY OF PEDOGENIC FEATURES (table 66)—Torrert, with clay texture in playa, lacks horizons of pedogenic carbonate and clay accumulation due to mixing of the soil as it wets and dries; wedges and slickensides as features of soil structure; lack of soluble salts due to episodic deep flushing by run-in; gradation from Torrert in center of playa through fine and fine-loamy Haplargids to coarse-loamy Haplargids adjacent to the playa; Haplargids of four ages adjacent to the playa; contribution of clay and carbonate in overland flow to Bt and carbonate horizons.

SETTING—The Isaacks Lake playa floor is the lowest part of the southern Jornada del Muerto Basin (elevation 4,285-4,289 ft; 1,306-1,307 m). This ephemeral-lake plain, designated the Lake Tank geomorphic surface (2.61), is about 1 mi long and 0.5 mi wide and is occasionally flooded for periods of several months by runoff from adjacent areas. Between 1957 and 1978, such flooding was noted in the late summer and fall periods of 1957, 1959, 1963, 1967, 1972, and 1978. Fine-grained playa sediments form a lenticular body that is probably no more than 13 ft (4 m) thick at its thickest point. They rest on sandy to gravelly Camp Rice basin fill, which was deposited by the ancestral Rio Grande. The playa unit appears to comprise a wide range in ages and types of water-transported materials derived from a watershed area of about 170 sq mi (440 sq km). Some eolian material has probably also been contributed to the playa fill.

The lower piedmont slope east of the playa is crossed by a complex of drainageways, and it has been the site of significant amounts of sedimentation at various times since middle Pleistocene. Soil parent materials are derived primarily from monzonite. Slopes are smooth and there is little change in the

EXPLANATION (Figure 67)

LT	Lake Tank surface. Ephemeral lake plain (playa) underlain by fine-grained sediments (mainly late Quaternary), which are subject to mixing due to shrink-swell action under alternating flooding and desiccation conditions.
O **Od**	Organ surface (constructional phase). Fan and drainageway surfaces underlain by sandy, loamy, and clayey alluvial deposits of the Organ morphostratigraphic unit that are generally less than 6 ft (1.8 m) thick. ''O'' designates low ridges composed of coarser grained materials; ''Od'' signifies drainageway surfaces generally underlain by fine-grained deposits.
IR	Isaacks' Ranch surfaces (constructional phase). Fan and drainageway surfaces underlain by sandy to loamy deposits of the Isaacks' Ranch morphostratigraphic unit that are generally less than 6 ft (1.8 m) thick.
O-JII-WB	Complex of Organ and Jornada II surfaces; and Whitebottom—scarplet erosion—surfaces with associated thin toeslope deposits (less than 1 ft, 0.4 m; mainly Historical age).
JII **JIId**	Jornada II surface (constructional phase). Piedmont-slope surface (distal), underlain by loamy to gravelly alluvial deposits of the Jornada II morphostratigraphic unit that are less than 8 ft (2.4 m) thick. ''JIId'' designates fine-grained drainageway facies.
PT	Petts Tank surface constructional basin-floor surface, underlain by calcareous silty to loamy sediments of the Petts Tank morphostratigraphic unit; grades to JII unit.
JI	Jornada I surface (constructional phase). Basin-floor and piedmont-slope surface (distal) of late middle Pleistocene age. Approximates youngest depositional surface of the Camp Rice Formation and is underlain by fine-grained sediments that grade downward into ancient river (channel) sand and gravel deposits (Qcrf) within about 10 ft (3 m) of the surface.
	Hachures on contacts point towards overlapping deposits
......	Approximate northeast extent of relatively thick Isaacks' Ranch fan and drainageway deposits

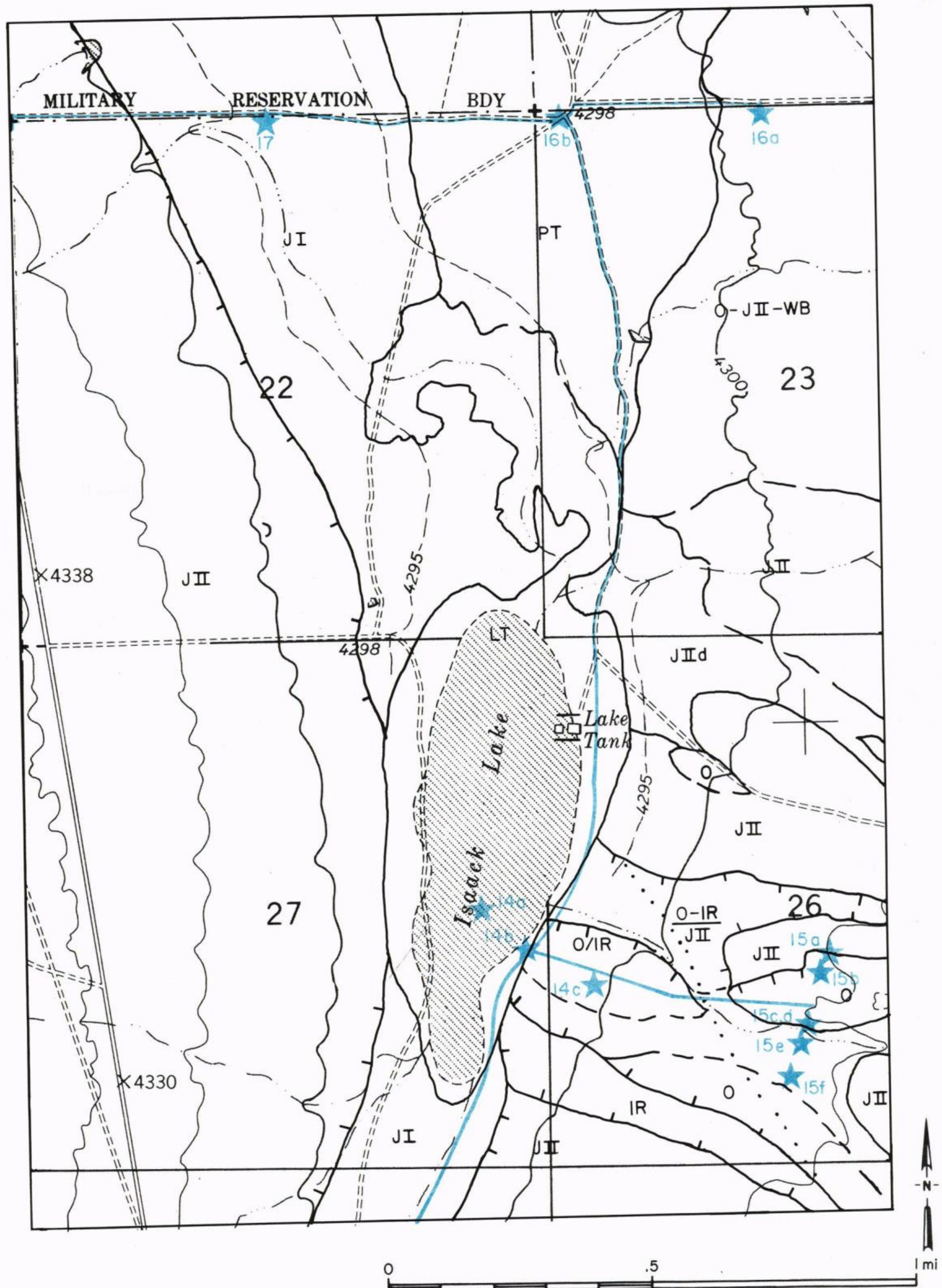


FIGURE 67—GEOMORPHIC SURFACES AND STRATIGRAPHIC UNITS, AREAS 14–17.

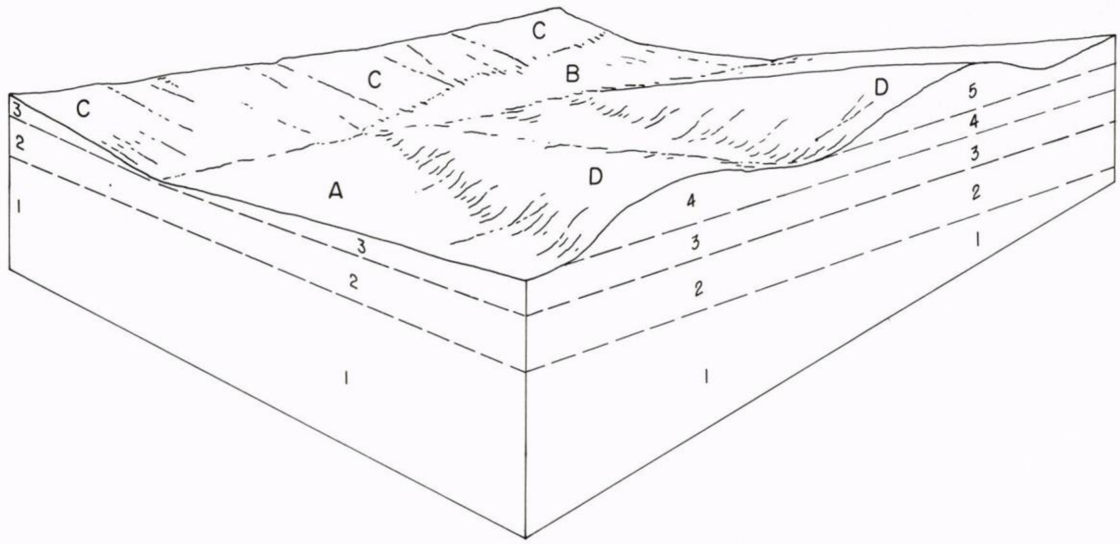


FIGURE 68—BLOCK DIAGRAM OF GEOMORPHIC SETTING, AREAS 14 AND 15, showing soil-landscape relationships and basin-fill stratigraphy in the vicinity of Isaacks Lake playa. Soil mapping units: **A,** Berino-Bucklebar association (Jornada II surface); **B,** Dalby clay (Lake Tank surface); **C,** Dona Ana sandy clay loam (Jornada II surface); **D,** Onite sandy loam (Organ and Isaacks' Ranch surface). Geologic units: **1,** upper Camp Rice Formation, fluvial facies (ancient river alluvium); **2,** Jornada I alluvium (youngest unit of the upper Camp Rice piedmont facies) and soils; **3,** Jornada II alluvium and soils; **4,** Isaacks' Ranch alluvium and soils; **5,** Organ alluvium and soils.

landscape to suggest the profound changes in soils, texture of parent materials, and geomorphic surfaces. Soils of the Organ, Isaacks' Ranch, Jornada II, and Jornada I surfaces occur in this immediate area.

SOIL OCCURRENCE—The pattern of soils at areas 14 and 15 (fig. 69) is determined by differences in soil age, landscape position, and texture. Vertisols (Dalby taxadjunct) occupy only the central and lowest part of the playa. Fine-loamy Haplargids (Bucklebar soils) occur at the margin of the playa. Coarse-loamy Haplargids (Onite soils) occur on slight ridges east of the playa.

Area 14a—Typic Torrert (Dalby taxadjunct) in Lake Tank alluvium

This area, in the lowest part of the playa, is level. Vegetation consists of scattered blueweed.

Dalby 60-16 (fig. 70 and table 68) occurs in the lowest part of Isaacks Lake playa. The developmental history of this soil is not known. It may have started developing as a Vertisol rather than going through an Argid stage because of the fine texture of the sediments when deposited. Dalby taxadjunct has a thin A horizon that grades into a C horizon with common slickensides, plates, and wedges. These distinctive structural features are related to high clay content and to landscape position. The clayey materials are subject to shrinking and swelling during cycles of flooding and desiccation. During the long dry seasons, a system of desiccation cracks that are several centimeters wide and decimeters deep form in the soil. During the summer rains, water from adjacent areas commonly moves into the playa and into the cracks. The water contains considerable clay, silt, and some of the finer sand fractions. Thus, even though the playa does not flood each year, fine sediments move down many of the cracks. Loose surface material adjacent to the cracks also falls into them. Repetition of the wet-dry process causes churning and prevents development of horizons of silicate clay and carbonate accumulation. The sediment is assumed to have originated primarily from surficial horizons of soils in the watershed. A mixed rather than montmorillonitic clay mineralogy and relative coarseness of the clay (discussed subsequently) are probably a consequence of this origin.

Table 68 contains laboratory data for Dalby 60-16. Silicate clay is nearly constant with depth. The clay is relatively coarse compared to the B2t horizon of Argids. The coarser clay in the surface horizon is common to all kinds of soils in the project area (3.84). COLE (coefficient of linear extensibility) is high but not excessively so. Many soils that are not Vertisols have similar COLE values because other factors such as the water regime and thickness of the highly extensible zone are important in determining whether the soil is a Vertisol. Carbonate content is low and constant throughout. Extractable sodium and potassium are both low. See study area 15 for a summary discussion of chemistry for soils of areas 14 and 15.

Walk eastward to a pit at the edge of the playa. The land surface gradually rises. Sediments of the Organ age extend into the playa and are responsible for part of the increase in slope.

Area 14b—Typic Haplargid (Bucklebar) in Organ alluvium

Slope is 1 percent. Vegetation consists of snakeweed, mesquite, and scattered tobosa. Note the prominent difference in vegetation along the edge of the playa as compared to the center of the playa.

This soil has an A2 horizon with a texture of sandy loam and a Bt horizon with a texture of sandy clay loam. The carbonate morphology (stage I) is typical of soils of Organ age. Note the prominent differences in structure between this Haplargid and the Vertisol seen at area 14a; the prominent slickensides and wedges are absent here.

Walk eastward on the Organ piedmont slope surface to the pit at area 14c.

Area 14c—Typic Haplargid (Onite 70-5) in Organ alluvium

The deep trench exposes a vertical sequence of three morphostratigraphic units: Organ, Isaacks' Ranch, and Jornada

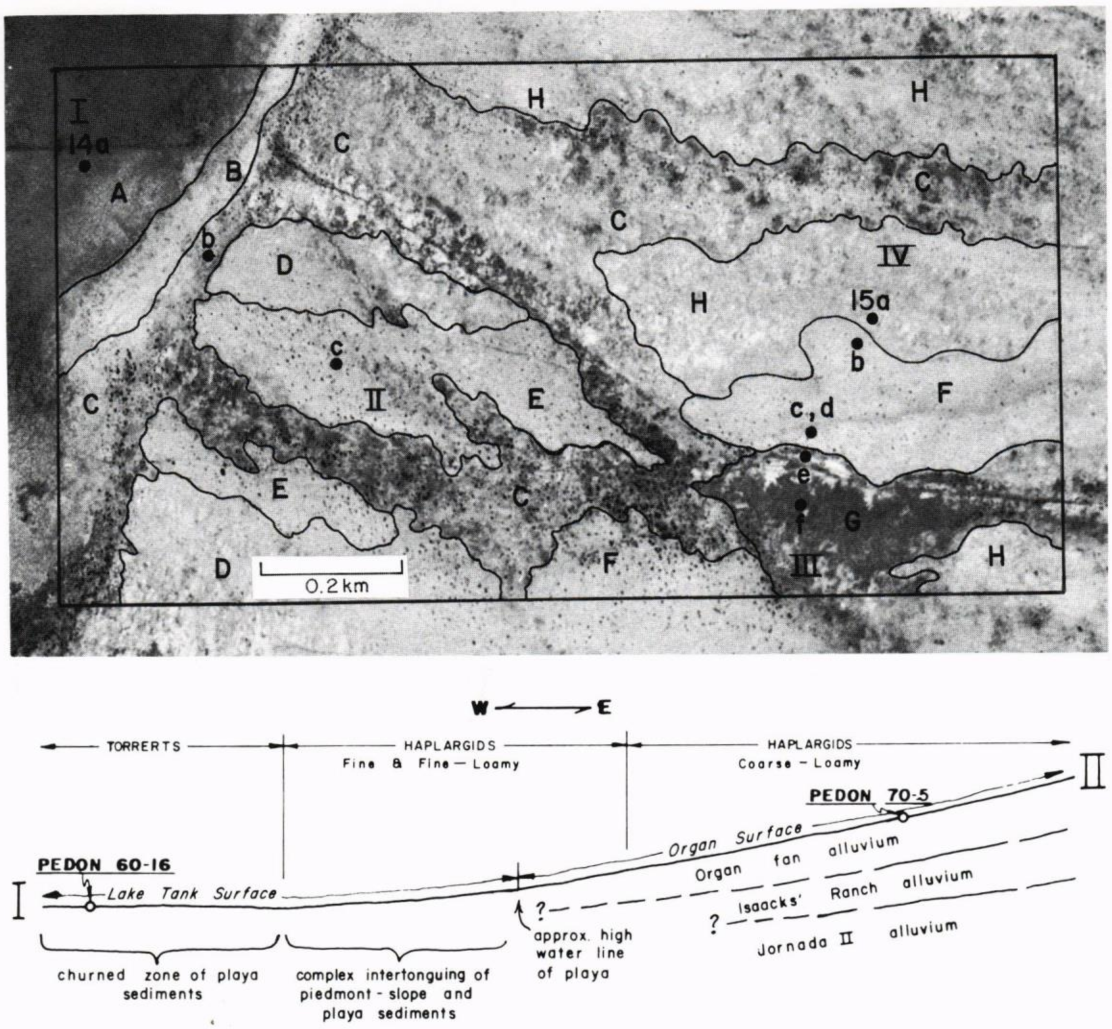


FIGURE 69—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREAS 14 AND 15. *Upper view:* **A**, Dalby, very fine taxadjunct, overflow phase (Lake Tank surface); **B**, Bucklebar, clayey subsoil variant, overflow phase (Lake Tank surface); **C**, Bucklebar, overflow phase (Organ, Isaacks' Ranch, and Lake Tank surfaces); **D**, Bucklebar sandy loam (Organ and Isaacks' Ranch surfaces); **E**, Onite sandy loam (Organ and Isaacks' Ranch surfaces); **F**, Onite-Pajarito complex (Organ surface); **G**, Headquarters, clayey subsoil variant, overflow phase (Organ surface); **H**, Berino sandy loam (Jornada II surface). I–II and III–IV (fig. 72) locate cross sections. *Lower view:* diagrammatic section of soils, surfaces, and sediments at area 14 (I–II on soil map).

II (fig. 71). Organ alluvium has buried an Isaacks' Ranch deposit. Both units pinch out to the north and south and the Jornada II surface emerges to form the piedmont slope (figs. 67 and 68). Slope is 1 percent. Vegetation is fluffgrass, *Yucca elata,* Mormon tea, and a few mesquite.

Three pedons were sampled in a transect (table 69). Only this soil—the northernmost—will be observed. This soil (fig. 73) has similar overall morphology to the soil at area 14b, but textures are coarser. The difference in clay between A and B horizons is greater than in many soils of Organ age in this landscape position (on a slight ridge, not in a drainageway). This soil may be of earliest Organ age and may have started its development in an interval analogous to the hiatus (5,800-7,100 yrs B.P.) mentioned by Haynes (1968a). Also, the greater clay content may be due partly to the initial texture of the sediments and partly to the broad ridge itself. The latter should insure maximum infiltration of precipitation for movement of clay. Carbonate accumulation (stage I) is typical for soils of Organ age.

Carbonate nodules (stage II) in the first buried soil are typical of soils of Isaacks' Ranch age. The upper part of the buried Bt horizon is noncalcareous; carbonates associated with pedogenesis in the thick deposit of Organ age have not reached the buried B horizon of Isaacks' Ranch age. The upper part of the Bt horizon in the second buried soil is noncalcareous in places, indicating that depth of illuviation during Isaacks' Ranch time at this spot was not great. The amount of the carbonate accumulation in this soil is somewhat greater than is usually encountered in soils of Jornada II age. This soil is possibly of Jornada I age.

Onite 70-6 (table 69) occurs on a very slight ridge about 700 ft (225 m) south of Onite 70-5. The stratigraphy indicates that the parent materials of soils on the Organ ridge at Onite 70-5 were inset against this ridge of older (Isaacks' Ranch) soils. The clay content of the argillic horizon is similar to that of Onite 70-5, indicating that the silicate clay maximum is not necessarily a reliable indicator of soil age. The parent materials of this soil apparently contained more sand than did those of Onite 70-5. This sand content would have lessened the amount of clay for illuviation. Onite 70-6 does have a stronger horizon of carbonate accumulation (stage II) than does Onite 70-5, consistent with its greater age.

The buried Haplargid in Onite 70-6 contains less carbonate than is common for Jornada II soils, possibly because of its

FIGURE 70—TORRERT ON LAKE TANK SURFACE, AREA 14a. Photograph of Dalby taxadjunct in Lake Tank playa sediments. Scale in meters (photographed October 1970).

drainageway position in which carbonates tend to be deeply leached (areas 8 and 9).

Berino 70-7 (table 69) occurs on the edge of a broad area that is level transversely, about 900 ft (300 m) south of Onite 70-6. No deposits younger than Jornada II occur in this area, which has not been covered by the drainageway deposits to the north. This soil contains less sand than the buried soil of Jornada II in Onite 70-6 and may be in a position away from the main channel of sediment deposition. Although grass clumps are common at Berino 70-7, organic carbon is not quite enough for the Ustollic Haplargids.

The Bcab-1 and Bcab-2 horizons at the base of the Jornada II contain more silt than do adjacent horizons (area 16). The buried Jornada I Haplargid has prominent maxima in silicate clay and carbonate. Black filaments occur both in the Btb and Kb horizons (area 8a for discussion).

On smooth slopes with little transverse relief and with soils texturally similar to or finer than Berino 70-7, during torrential rains much water moves across the land surface in an essentially continuous sheet. This water movement is termed *overland flow.* Fine materials in the water at the time of drying are deposited on the soil surface and may be subsequently

TABLE 68—LABORATORY DATA FOR A TYPIC TORRERT (Dalby 60-16); silt and clay on carbonate-free basis.

Horizon	Depth	Silt	Clay	Fine/total clay	COLE	Carbo-nate	Extractable bases Na	K	Organic carbon
	cm	%	%			%	me/100g		%
A	0-5	31	64	0.14		4	tr	tr	0.6
AC	5-23	28	66	0.31	0.068	4	tr	tr	0.5
C1	23-48	32	63	0.30	0.081	3	tr	tr	0.3
C2	48-81	29	66	0.43		3	0.1	0.1	0.2
C2	81-114	28	66	0.38	0.071	3	0.1	0.1	0.3

Organic carbon, 4.6 kg/sq m to 114 cm.

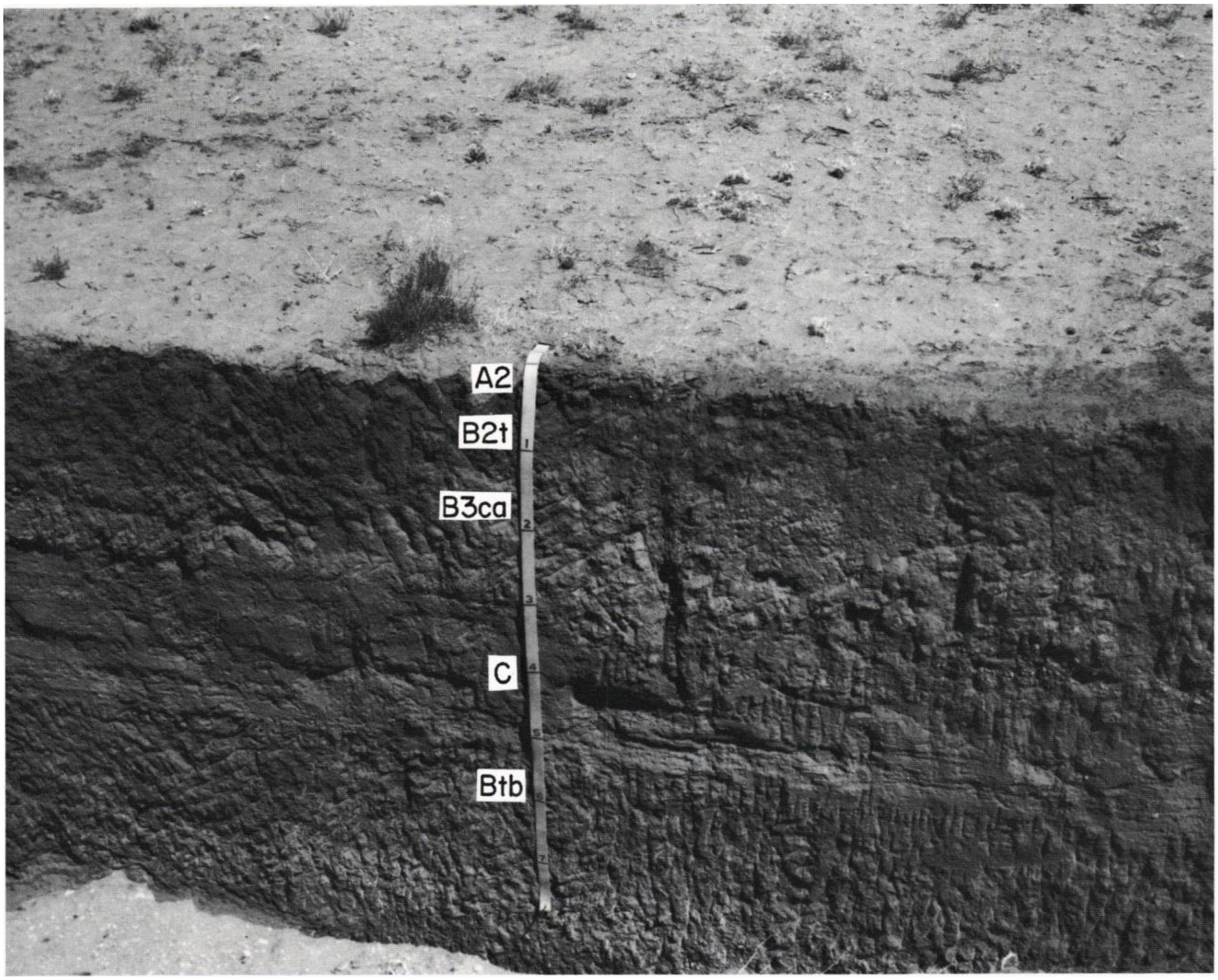


FIGURE 71 —TYPIC HAPLARGID ON ORGAN SURFACE, AREA 14c. Photograph of Onite 70-5 in Organ alluvium; buried soil (Btb) is in Isaacks' Ranch alluvium. Scale in feet (photographed April 1970).

moved into the soil upon wetting. Thus clay and carbonate from the water of overland flow may have contributed to the clay and carbonate in Berino 70-7.

En route to area 15. Continue east up the piedmont toe-slope. 0.6

19.4 STUDY AREA 15

Land surface and buried Haplargids of the Organ and Jornada II surfaces

SUMMARY OF PEDOGENIC FEATURES (table 66)—Buried soils at various depths and their emergence at the land surface; effect of wide differences in texture of parent materials on soil morphology; thin argillic horizons and change in thickness of control section; gradation from argillic to cambic horizon in soils of the same age; significance of thin surficial horizons to the development of barren versus vegetated strips; effect of increased moisture in drainageway on illuviation of clay and carbonate; organic carbon and Typic versus Ustollic subgroups; geologic versus pedologic clay.

SETTING—This north-south transect (figs. 67, 69, and 72) extends across a broad drainageway and an adjacent slight ridge. The drainageway and ridge deposits are of Organ age and are underlain by Jornada II deposits in most places, with a thin, discontinuous deposit of Isaacks' Ranch age occurring in some areas. The lenticular body -of Organ alluvium fills a broad depression on the Jornada II surface and the unit pinches out to the north between areas 15a and 15b. Two facies of Organ alluvium occur along a transect from areas 15b and 15f. Coarse-sandy to fine-pebbly deposits underlie slight ridges and grade laterally to fine-grained sediments in the drainageway. Slope is 1 percent to the west.

SOIL OCCURRENCE—The pattern of soils at area 15 (figs. 69, 72) is determined by differences in age, landscape position, and texture of parent materials. Typic Haplargids (Onite soils and variant) are most common on ridges of the Organ surface; Camborthids (Pajarito soils) also occur. Typic Haplargids (Berino soils) are adjacent to the ridge. Fine-loamy Typic Haplargids (Bucklebar soils) are most common in the drainageways. Ustollic Haplargids (Headquarters variant) are located in drainageways where textures are fine.

Area 15a—Typic Haplargid (Berino 68-9) in Jornada II alluvium

Here the Jornada II fan-piedmont surface and its soil are at the land surface. The soil surface is barren (west side of pit) where the whole pedon was sampled; a few burrograss and tobosa clumps occur just to the east (fig. 73). The transect (III to IV, figs. 69, 72) starts in soils of Pleistocene age, crosses a ridge of Holocene soils, and ends in drainageway soils of Holocene age.

TABLE 69—LABORATORY DATA FOR THREE TYPIC HAPLARGIDS, EAST AND SOUTH OF ISAACKS LAKE PLAYA; sand, silt, and clay on carbonate-free basis; tr(s), trace $CaCO_3$ detected only by qualitative procedure more sensitive than quantitative procedure used; -(s), none detected by sensitive qualitative test (6E2; Soil Conservation Service, 1972).

Alluvium	Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	>2 mm wt. (%)	Carbon-ate (%)	Organic carbon (%)	Extract-able sodium (me/100 g)
	Onite 70-5								
Organ I	A2	0–6	73	15	12	tr	tr(s)	0.22	0.0
	B21t	6–16	68	15	17	tr	tr(s)	0.20	tr
	B22t	16–32	59	21	20	tr	tr(s)	0.23	0.1
	B31tca	32–47	66	20	14	2	1	0.16	tr
	B32ca	47–74	74	16	10	4	1	0.08	tr
	C1ca	74–87	61	28	11	1	3	0.08	tr
	2C2	87–157	87	7	6	4	tr	0.01	0.1
	3C3	157–169	56	25	19	tr	1	0.08	1.1
Isaacks'	3B21tb	169–189	59	19	22	tr	tr	0.08	1.7
Ranch	3B22tca	189–215	46	28	26	tr	4	0.15	2.4
Jornada II	3B3tcab	215–239	50	29	22	tr	5	0.08	2.2
	3B1tcab2	239–255	70	15	16	1	tr	0.04	1.4
	3B2tcab2	255–268	48	8	44	tr	4	0.08	4.0
	3K2b2	268–278	51	8	41	tr	40	0.09	3.4
	Organic carbon, 1.9 kg/sq m to 87 cm								
	Onite 70-6								
Isaacks'	A2	0–6	78	10	12	tr	tr(s)	0.15	0.0
Ranch	B1t	6–15	77	9	14	tr	-(s)	0.15	0.0
	B21t	15–34	71	13	16	tr	tr(s)	0.15	tr
	B22tca	34–41	71	14	15	tr	4	0.18	tr
	B3ca	41–74	75	13	12	1	6	0.11	0.1
	2Cca	74–104	87	7	6	14	2	0.04	0.1
Jornada II	3B1cab	104–120	68	21	11	tr	2	0.04	0.4
	3B21tcab	120–136	75	12	13	tr	tr	0.04	0.5
	3B22tcab	136–165	73	8	19	tr	tr	0.07	0.9
	3B31tcab	165–194	79	8	13	tr	1	0.01	1.1
	3B32tcab	194–215	82	7	11	6	4	0.04	1.2
	Organic carbon, 1.7 kg/sq m to 104 cm								
	Berino 70-7								
Jornada II	A2	0–7	51	27	22	tr	tr(s)	0.81	tr
	B21t	7–18	52	17	31	2	1	0.54	0.1
	B22t	18–34	54	17	29	1	4	0.38	0.1
	B23tca	34–49	48	15	37	1	10	0.30	0.3
	K2	49–71	50	19	31	tr	23	0.27	0.5
	K3	71–100	40	30	30	—	24	0.08	1.4
	Bca	100–129	43	28	29	—	10		2.1
	Bcab-1	129–153	22	37	41	—	7		3.1
	Bcab-2	153–170	22	34	44	—	7		3.7
Jornada I	B1tcab2	170–182	49	20	31	tr	2		3.1
	B2tcab2	182–195	40	16	44	tr	3		3.4
	K1b2	195–215	59	14	27	tr	14		2.5
	K2b2	215–242	67	11	22	tr	25		2.3
	Organic carbon, 4.5 kg/sq m to 100 cm								

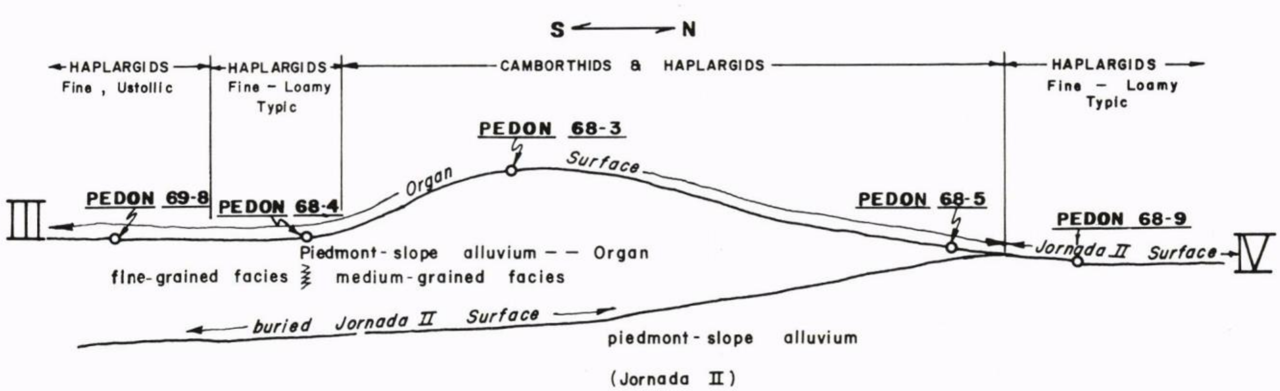


FIGURE 72—DIAGRAMMATIC CROSS SECTION OF SOILS, SURFACES, AND SEDIMENTS, AREA 15 (III–IV on soil map, fig. 69).

Berino 68-9 (fig. 73, table 70) is the northernmost pedon in the transect. The silicate clay maximum is distinct (table 70), and the carbonate horizon (stage III) is typical of soils of Jornada II age. Reddish-brown volumes in the K horizon indicate that the Bt horizon once extended deeper and has been largely engulfed by carbonate. The buried analogue of this soil extends beneath the Organ ridge to the south, as shown by auger borings and trenches.

The study trench crosses the contact of the grassy and barren strip (fig. 73). A thin C horizon, with sedimentary strata still preserved, overlies an A2 horizon in the grassy area. This C-horizon material has been in place long enough for burrograss clumps to become rooted in it but shows no evidence of development of an A2 horizon, which is preserved beneath it. The thin C horizon and underlying A2 horizon are not present beneath the barren strip, but all other horizons extend without change from the grassy strip into the barren strip. The disappearance of the thin C horizon and most of the A2 horizon exactly coincides with the boundary between the grassy and barren strips; truncation of these horizons must have caused development of the barren strip. Similar relations have also been observed in other parts of the project area.

Berino 68-9 is in the barren part of the study trench (fig. 73). To study the relation of organic carbon to vegetative status, 12 samples to a depth of 38 cm were taken by auger in both the barren and grassy strips just north of the sampling trench. Organic carbon contents are quite low and similar for both the barren and the grassy strip (0.35 percent and 0.31 percent, respectively), rather than being higher in the grassy strip. One reason for this may be the diluting effect of the 0-8 cm layer (in the grassy area), which contains very little clay and probably little organic carbon. The soils of both the barren and vegetated strips are in the same series and have too little organic carbon for the Ustollic subgroups.

Area 15b—Typic Haplargid (Onite thin-solum variant 68-5) in Organ alluvium over Isaacks' Ranch and Jornada II alluvium

The study trench exposes a section of thin deposits of Organ and apparent Isaacks' Ranch alluviums over Jornada **II** alluvium and its soil. The site is on the edge of a ridge that rises to the south. Vegetation consists of scattered snakeweed, *Yucca elata,* dropseed, and fluffgrass. The soil in Organ alluvium barely has enough clay increase for an argillic horizon. Note the prominent pipe in the buried soil of Jornada II age. The pipe does not extend upward into the younger sediments, demonstrating that it must have formed in the Pleistocene.

Area 15c—Typic Haplargid (Onite sandy subsoil variant 68-3) in Organ alluvium

This part of the trench shows the Organ surface and Organ fan alluvium in ridge-crest position (fig. 74). The alluvium contains fine gravel, abundant coarse sand, and little clay. Slope is 1 percent. Vegetation consists of scattered snakeweed, *Yucca elata,* and Mormon tea.

This soil (fig. 74) has an A2 horizon and a sandy-loam Bt horizon. The C-horizon material is well-stratified gravelly sand. The thin A2 horizon and coatings of oriented clay on sand grains in the underlying Bt horizon indicate illuviation of silicate clay. The control section extends from the top of the argillic horizon to 1 m depth because the lower boundary of the argillic horizon is shallower than 25 cm (3.1). Thus the soil is in the sandy family.

Prominent coatings of oriented clay on sand grains (and on pebbles if they are present) are a characteristic feature of Bt horizons in this and in other arid regions (3.7). Onite variant 68-3 has a Bt horizon of 5YR hue, and clayey material of 5YR hue also occurs in the C horizon. Thin sections were made of one of these layers in the 81- to 91-cm zone of the 2C4 horizon (table 70) to compare its micromorphology with that of the Bt horizon. Oriented clay was found on the sand grains, but only on one side of the grains—not all the way around the grains as in Bt horizons. This clay is clearly a depositional feature of the parent materials because these deposits are of Organ age and the Holocene Bt horizon is well above it. Thus, although oriented clay occurs in the C horizon, its origin is geologic rather than pedologic.

Area 15d—Typic Camborthid (Pajarito) in Organ alluvium

Downslope from the ridge crest, percentages of coarse sand and fine gravel decrease markedly, and the clay and finer sand fractions increase over a distance of only a few meters. Upper horizons of a satellite pedon 5 m south of Onite 68-3 do not show sufficient clay increase for an argillic horizon, although the Bt horizon is similar in morphology. This clay increase shows the incipient nature of the argillic horizon in the area. The zone above the carbonate maximum extends below 25 cm and hence is deep enough for a cambic horizon; the satellite pedon is a Camborthid in the Pajarito series. The pedons at areas 15c and 15d are the same age because sedimentary strata could be traced between them.

Note the prominent buried Haplargid exposed along the bottom of the trench at the edge of the drainageway. This soil marks the buried Jornada **II** surface and is of the same general age as the upper buried soil at area 9a.

Area 15e—Typic Haplargid (Bucklebar 68-4) in Organ alluvium over a buried analogue of Berino (Typic Haplargid) in Jornada II alluvium

The south end of the trench shows a section of the Organ surface and alluvium on the edge of the drainageway. The drainageway facies is much finer than the ridge facies to the north. Jornada II alluvium and its soils occur beneath the Organ alluvium. Vegetation consists of scattered clumps of burrograss, tobosa, and snakeweed.

Bucklebar 68-4 occurs on the edge of the drainageway. The clay difference between A and B horizons is greater than for Onite 68-3 on the ridge crest. Bucklebar 68-4 receives considerable drainageway water, and the sediment was initially more clayey. Both factors should favor more rapid clay illuviation. Bucklebar 68-4 also has more authigenic carbonate than Onite variant 68-3 on the ridge crest. This difference may be due to the Bucklebar's drainageway position and consequent more frequent wetting.

These soils derived from monzonite are high in sand and low in silt, with less fine silt than coarse silt. Their water retention against 1/3 bar is only about half that of silty soil materials such as those to be seen at area 16. This feature suggests that a given amount of infiltrated precipitation would wet these soils to greater depths than their silty analogues. The surface may not seal as tightly under a beating rain as would silty soils.

Haplargids of the ridge and along the margin of the drainageway contain relatively little organic carbon and are all Typic. The boundary between the Ustollic and Typic subgroups of the Haplargids occurs only several meters to the south. A composite of several samples to a depth of 38 cm

FIGURE 73 —**JORNADA** H **SURFACE AND HAPLARGID AT AREA 15a.** *Upper view:* landscape of the Typic Haplargid Berino 68-9 on the Jornada II surface; note barren and grassy strip just north of sampling trench; Doha Ana Mountains are on skyline at center and *left. Lower view:* closeup of barren and grassy strips and of Berino 68-9, just to right of tape. The Berino pedon to the far right (marked by knives) is formed in Jornada II alluvium. Disappearance of the grass coincides with truncation of the C horizon material (above the uppermost jackknife) and most of the A2 horizon (between the two jackknives). Scale in feet (photographed February 1969).

TABLE 70—LABORATORY DATA FOR FIVE HAPLARGIDS AT STUDY AREA 15; sand, silt, and clay on carbonate-free basis; tr(s), trace $CaCO_3$ detected only by qualitative procedure more sensitive than quantitative procedure used; –(s), none detected by sensitive qualitative test (6E2; Soil Conservation Service, 1972).

Alluvium	Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	>2 mm wt. (%)	Carbon-ate (%)	Organic carbon (%)	Extract-able sodium (me/100 g)
	Berino 68-9								
Jornada II	A2	0–3	62	21	17	—	tr(s)	0.29	0.2
	B21t	3–13	51	19	30	—	tr(s)	0.32	0.2
	B22t	13–28	60	15	25	4	tr	0.36	0.2
	B23tca	28–43	66	13	22	6	3	0.28	0.2
	K2	43–61	63	9	28	1	19	0.20	0.3
	Bca	61–84	71	9	21	2	12	0.11	0.4
	K	84–107	72	9	19	4	13		0.4
	K	107–132	80	7	13	5	11		0.4
	C1ca	132–157	84	6	10	8	7		0.3
	C2ca	157–185	84	6	10	6	4		0.1
	C*	0–8	84	8	8	tr	tr(s)		
Jornada II	A2*	8–14	65	18	17	tr	tr(s)		
	Organic carbon, 2.9 kg/sq m to 84 cm								
	Onite variant 68-5								
Organ I	A	0–5	77	14	9	17	1	0.26	0.2
	B21t	5–13	76	14	10	17	tr	0.21	0.2
	B22t	13–23	73	15	12	17	1	0.18	0.2
	Cca	23–38	70	17	13	24	4	0.21	0.3
Isaacks'	2B21cab	38–48	60	24	16	5	4	0.28	0.5
Ranch(?)	2B22cab	48–64	45	31	24	tr	5	0.30	1.1
Jornada II	2B1tb2	64–86	64	17	19	tr	2	0.15	1.4
	2B2tb2	86–104	61	12	27	—	4	0.15	2.6
	2K21b2	104–137	76	7	17	5	14	0.12	2.3
	2B22tb2	137–160	73	7	20	2	1	0.03	3.0
	Organic carbon, 3.1 kg/sq m to 104 cm								
	Onite variant 68-3								
Organ I	A	0–5	80	12	8	21	tr(s)	0.21	0.1
	A2	5–8	77	14	9	24	tr(s)	0.20	0.1
	B1t	8–13	78	12	10	29	tr(s)	0.25	0.2
	2B2t	13–23	81	7	12	45	tr	0.19	tr
	2C1ca	23–36	84	6	10	43	2	0.13	0.1
	2C2ca	36–51	88	4	8	46	1		0.1
	2C3	51–81	90	2	8	39	1		0.3
	2C4	81–117	92	3	5	35	1		0.3
Satellite	A2	0–3	75	14	11				
pedon	B21t	3–10	75	13	12				
	B22t	10–20	79	12	9				
	Organic carbon, 0.7 kg/sq m to 36 cm								
	Bucklebar 68-4								
Organ I	A	0–5	54	27	19	—	tr	0.71	0.2
	A2	5–15	65	21	14	tr	tr	0.43	0.1
	B1t	15–28	61	18	21	1	tr	0.28	0.2
	B2t	28–46	58	21	21	tr	tr	0.29	0.1
	B3tca	46–76	56	27	17	tr	3	0.20	0.2
	C1ca	76–130	55	30	15	tr	3	0.12	0.2
	C2	130–157	80	11	9	tr	1	0.08	0.2
Jornada II	B1cab	157–193	74	11	15	tr	1	0.08	0.3
	B2tcab	193–206	64	7	29	1	4	0.15	0.4
Organ I	A2	0–5	71	18	11	5			
Satellite	B21t	5–16	69	18	13	8			
pedon	B22t	16–25	69	19	12	10			
	Organic carbon, 3.3 kg/sq m to 76 cm								
	Headquarters variant 69-8								
Organ I	C	0–6	42	36	22		tr(s)	1.95	0.0
	A2	6–10	39	33	28		tr(s)	1.26	0.0
	B21t	10–23	26	28	46		2	0.86	0.1
	B22t	23–49	19	29	52		3	0.54	0.7
	B23t	49–79	16	36	48		4	0.54	2.0
	Cca	79–89	6	64	30		5	0.49	2.4
	B21cab	89–107	4	48	48		7	0.42	4.2
	B22cab	107–125	3	47	50		5	0.37	4.6
	2C	125–138	45	38	17		2	0.12	1.3
	Organic carbon, 8.7 kg/sq m 6 to 107 cm								

*Offset sample. C is a youthful surficial deposit probably less than 100 yrs old.

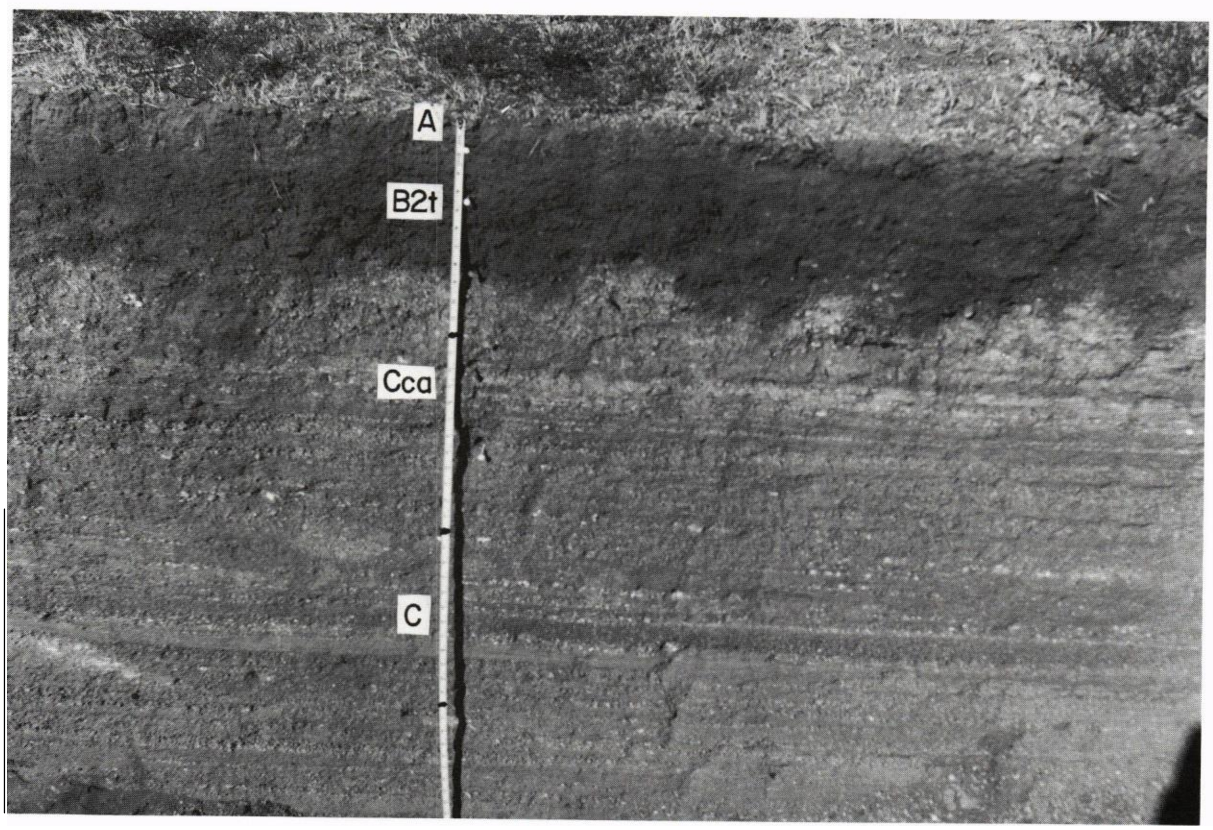


FIGURE 74—ORGAN SURFACE AND HAPLARGID AT AREA 15 c. *Upper view:* landscape of the Typic Haplargid, Onite variant 68-3, on ridge crest of Organ age (fig. 72). Dona Ana Mountains on skyline at center and right; Isaacks Lake playa in middle ground at right. *Lower view:* Onite variant 68-3 in Organ alluvium; marks on tape denote feet (photographed December, 1968).

south of the trench has 0.8 percent organic carbon, well within the range of the Ustollic subgroups. There is more moisture in the drainageway, more vegetation, and more clay. These factors are responsible for the marked increase in the organic carbon content.

Area 15f—Ustollic Haplargid (Headquarters variant 69-8) in Organ alluvium; buried analogue of Berino (Typic Haplargid) in Jornada II alluvium

At this site the Organ surface and alluvium are in the central part of a broad drainageway. Jornada II alluvium and its soils are buried beneath the Organ alluvium. Vegetation is tobosa grass. Organic carbon is much higher than at area 15e (table 67).

Composited samples (0-38 cm) from a barren area 40 m north average 0.78 percent organic carbon as compared to 0.94 percent organic carbon at the sample site. The organic carbon from both the sampled pedon and the composited sample is ample to place these soils within the Ustollic subgroups.

The Bt horizon has clay texture. In this drainageway position, the parent materials of this soil must have been quite high in clay. The soil has an argillic horizon because there is a clay increase from the A2 horizon to the Bt horizon, and there are distinct coatings of oriented clay around many sand grains in the Bt horizon. This site shows another effect of increased clay content of the parent materials on soil development: note the slickensides and wedge-shaped structures in the lower part of the Bt horizon. These structural features and cracks suggest a Vertisol, but the cracks are not wide enough at the surface and in the soil for a Vertisol. COLE for the B2t is 0.06, similar to that in the Vertisol at area 14a. The larger cracks in the Vertisol are a reflection of the greater size of the body that contracts as a unit, rather than of a difference in the extensibility of pieces of soil 10 cm across, which is the size of clod used for the COLE determination.

The wide difference in clay content in these soils of the same age (areas 15c-e) shows that silicate-clay content of the argillic horizon cannot be used as an indicator of soil age. The horizon of carbonate accumulation is a much better indicator, because the carbonate accumulations in the soils are morphologically similar; all are in stage I of carbonate accumulation.

EXCHANGE CHEMISTRY AT STUDY AREAS 14 AND 15

The exchange chemistry and soluble salt relationships for soils at study areas 14 and 15 are considered here. Comparison of the Vertisol (Dalby 60-16) of the playa with the fine-textured Haplargid (Headquarters variant 69-8) of the drainageway suggests how differences in water regime and vegetation for soils of comparable texture may affect the exchange chemistry. Dalby 60-16 has low extractable sodium and also low soluble salts, probably because of episodic flooding and a net downward water movement to below the depth of sampling and into the pervious alluvium beneath. In contrast, Headquarters 69-8 has appreciable extractable sodium above 1 m and associated considerable soluble salts. The difference is probably due to less net downward water movement in Headquarters 69-8 because it receives less water and is not subject to standing water for long periods.

The Dalby and Headquarters pedons differ markedly in extractable potassium. Headquarters 69-8 has 2 me/100 g of extractable potassium in upper horizons in comparison to only a trace at comparable depths in Dalby 60-16. The difference may be related to less vegetation and associated lower potassium mobilization for Dalby. In this regard, Headquarters 69-8 contains appreciably more organic carbon.

The two transects east of the playa provide an opportunity to examine the relationship of extractable sodium and soluble salts to landscape position and stratigraphy. Depth to extractable sodium above 1 me/100 g (abbreviated 1 me) equals or exceeds 0.5 m for all pedons. Soils of Organ age at the land surface have values below 1 me except for Headquarters 69-8, the fine-textured pedon in drainageway position. Increases with depth in extractable sodium to values exceeding 1 me are associated with most changes in sediment age. Buried Jornada II sediment usually has over 1 me of sodium (except for Bucklebar 68-4). Soils in Jornada II sediment at the land surface have less than 1 me of extractable sodium through the upper 0.5 m.

Water-soluble ions were determined on samples with over 1 me of extractable sodium. Sodium is generally the dominant water-soluble cation. Magnesium and calcium are present in roughly equal quantities in most samples. Sulfate generally is the dominant anion. Chloride exceeds sulfates in some samples, particularly in upper horizons of the zones analyzed. Nitrate was determined on samples where cations and anions did not balance closely. Onite variant 68-5 has appreciable nitrate in deeper horizons.

The two transects illustrate that organic carbon generally increases as clay content rises. Similar relations are also shown by other soils in the project area. This relationship may be partly due to the more favorable conditions for plant growth and organic carbon retention produced by greater amounts of clay. But, as these transects illustrate, clay content is higher in sites subject to increased moisture from run-in. This increase in moisture may be an important factor in producing a positive statistical correlation between amount of organic carbon and clay content (3.5). The significance of vegetation is shown at the Dalby site in the playa, where organic carbon is relatively low (despite high clay) because of the scarcity of vegetation.

En route to study area 16. Return to Isaacks Lake. 0.5

19.9 Edge of playa; *turn right.* Continue north on road along east edge of basin floor. **0.7**

20.6 Northeast edge of playa-lake plain. Crossing transition zone from Lake Tank to Petts Tank geomorphic surface (figs. 75, 76). On the piedmont slope to the east there is an abrupt shift in parent material composition that reflects the change in source bedrock lithology in adjacent mountain watersheds. As noted at mile 29 in the Day 2 road log, the San Agustin segment of the Organ-San Andres mountain chain includes a narrow transition zone from bedrock terranes dominated by monzonite to the south and carbonate rocks to the north. **0.2**

20.8 Petts Tank surface (2.61) extends to the north along the eastern part of the Jornada Basin floor. The Petts Tank surface is an alluvial flat that slopes to the south and west at a gradient of only a few feet per mile (less than 0.2 percent) and serves as a conduit for storm runoff toward Isaacks Lake playa. This constructional plain for the most part stabilized in Wisconsinan time. Some sections of the plain were probably flooded by a small perennial lake during the last major glacial interval. Thin increments of Holocene alluvium that locally bury the Petts Tank unit in this area are generally less than 20 cm thick. To the east,

FIGURE 75—MAP OF SOILS IN VICINITY OF AREAS 16 AND 17. **A,** Reagan, light subsoil variant (Organ surface); **B,** Algerita clay loam (Jornada II surface); **C,** Reagan clay loam (Petts Tank surface); **D,** Stellar clay loam, overflow phase (Jornada I surface); **E,** Dona Ana sandy clay loam (Jornada II surface). I–II and III–IV locate diagrammatic cross sections (figs. 77 and 78). **1**—denotes soil moisture site in a Stellar soil, Jornada Experimental Range.

Petts Tank basin-floor sediments merge with piedmont-slope alluvium of the Jornada II unit. To the west, Petts Tank deposits wedge out over the Jornada I surface on Camp Rice Formation basin fill. 0.9

21.7 *Pass through gate, turn right.* Continue east on section line road across the Petts Tank surface in an area transitional to the Organ-Whitebottom surface complex on the piedmont slope. To the east Organ alluvium overlaps the zone where Jornada II piedmont deposits grade to Petts Tank sediments. 0.3

BASIN-FLOOR-FAN-PIEDMONT TRANSITION IN HIGH-CARBONATE PARENT MATERIALS

Areas 16 and 17 (figs. 75, 76) are at the west end of a series of detailed study sites extending from the San Andres Range near Gardner Spring (area 12) to the Jornada Basin axis. Emphasis of investigations at piedmont-slope sites has been on the effects of high-carbonate parent materials on soil genesis and classification, as compared to low-carbonate materials to the south (areas 1-6, 8-11, 14, 15, and 20-22). Studies here, as in areas 14 and 15, also emphasize the effects of changing landscape position near the basin axis and differences in soil age.

22.0 *Cross first major Whitebottom scarplet.* Erosion-sedimentation patterns on the piedmont slope to the east, with a mountainward gradient equal to or exceeding 1 percent, contrast markedly with the nearly level basin-floor area to the west. 0.1

22.1 STUDY AREA 16

STUDY AREA 16

Calciorthids of the Organ, buried Jornada II, and Petts Tank surfaces

SUMMARY OF PEDOGENIC FEATURES (table 66)—Absence of reddish-brown B horizons found in low-carbonate materials; all soils strongly calcareous throughout; buried soils at various depths, and emergence at the surface; incipient calcic horizon in Holocene soil; contact of Holocene and Pleistocene deposits marked by sand and scattered pebbles at area 16a but not downslope; analogue of soil buried at 16a rises to the land surface at area 16b; high clay in B horizon of soil at 16b, but too much carbonate for recognition of argillic horizon.

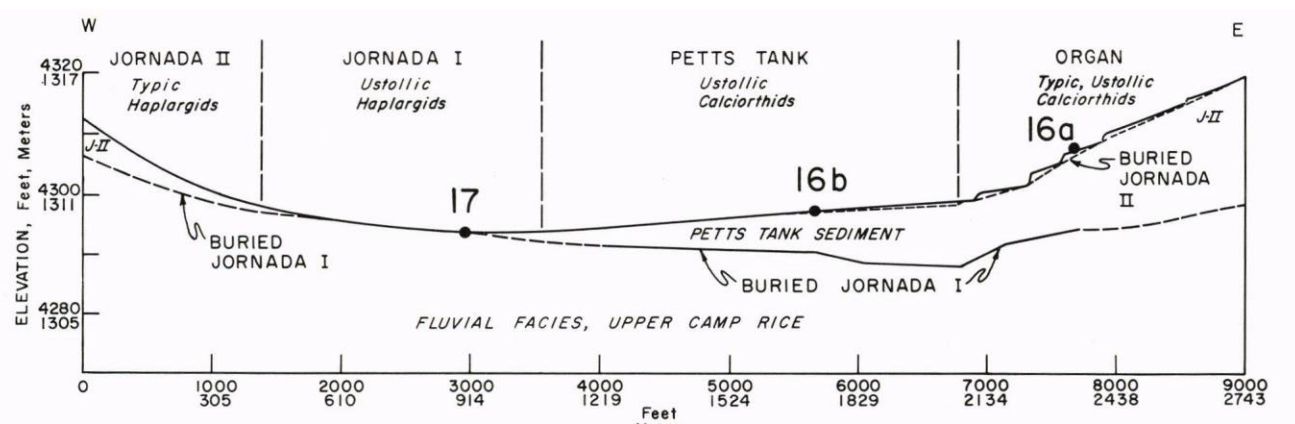


FIGURE 76—CROSS SECTION OF BASIN FLOOR AND LOWER PIEDMONT SLOPES, AREAS 16 AND 17 (fig. 75). The Whitebottom surface (primarily erosional) shown by scarplet modification of Organ alluvium. J-II denotes Jornada II alluvium. Camp Rice fluvial facies intertongues laterally with distal piedmont-slope alluvium.

SETTING—The transition from the piedmont slopes to the basin floor represents an important change in both soils and landscape (fig. 67). The transition is a very gradual one. Slopes are gentle and the landscape is subdued; landforms useful in predicting the occurrence of various soils are less apparent than at higher elevations on the piedmont slopes. Even the very gentle ridges to the south (area 15c) are not present here. Furthermore, coarse fragments that in many instances form prominent lithological discontinuities between buried soils of various ages are generally absent.

The erosion pattern here contrasts markedly with that seen in the less silty materials to the south. The fine-grained and cohesive Organ alluvium derived from carbonate and clastic sedimentary rocks (such as limestone, sandstone, mudstone, and shale) of the San Andres is very susceptible to development of steep, arcuate erosion scars, or scarplets. The repeated succession of low scarplet and footslope erosion surfaces grading to barren depositional toeslopes, which appears to have formed during Historical time, has been designated the Whitebottom surface by Ruhe (1964) (2.61). These unstable areas are encroaching upslope on grass-covered Organ surfaces, with erosion surfaces locally cut through the Organ deposits into Jornada II alluvium. Sediments derived from scarplet erosion locally bury Organ and Jornada II-Petts Tank deposits downslope.

The thin (about 0.5 m) Organ layer at this site is underlain by about 1.5 m of Jornada II alluvium that coarsens and thickens eastward. The Jornada II overlaps a silty basal zone of the Petts Tank unit that in turn rests disconformably on a well developed buried soil formed in uppermost beds of the Camp Rice fluvial facies (fig. 76). The top of this buried soil at a depth of about 3.5 m is the Jornada I surface. Towards the basin axis, near area 16b, the Organ unit pinches out.

The Jornada II unit, which here has local streaks of gravel, grades to silty to loamy alluvium of the upper Petts Tank unit. The buried Jornada I surface and associated buried soil dip slightly into a depression between areas 16a and 16b and then rise to intersect the land surface just west of the present Jornada Basin axis (area 17).

SOIL OCCURRENCE—The pattern of soils (fig. 75) is determined by difference in age, landscape position, and texture of parent materials. Ustollic Calciorthids (Reagan, light subsoil variant, fine-loamy) occur in thin deposits of Organ alluvium and are dominant at area 16b. Ustollic Calciorthids (Reagan soils, fine-silty) occur extensively in Petts Tank sediments, on the eastern part of the nearly level basin floor in the vicinity of area 16b. Because of the stability of much of the Petts Tank surface and because of uniformity of texture, landscape, and age, the soils of mapping unit C (fig. 75) are quite uniform and most are in the Reagan series.

Area 16a—Ustollic Calciorthid (Reagan variant 66-7), partly in Organ alluvium and partly in Jornada II alluvium

This is the Organ surface on the lower part of the piedmont slope. The buried Jornada II surface occurs at 51 cm. Slope is 1 percent to the west. Vegetation is burrograss, creosotebush, and tarbush.

Reagan variant 66-7 (fig. 77) is the easternmost of four pedons in a transect (table 71). The distinct platiness of the A horizon reflects the strong tendency for these soils to seal when wetted. The boundary between Organ and Jornada II alluvium is well marked by a distinct increase in sand at the base of the Organ deposits. A line of pebbles (with little or no gravel above or below) occurs at this depth all along the sample trench. Soil morphology supports the Organ designation; the carbonate horizon, with a few carbonate filaments on ped faces, is in stage I of carbonate accumulation as is typical of soils of Organ age. This carbonate accumulation is distinctly separate from the stage III carbonate horizon in Jornada II alluvium. Wide separation of the two zones of carbonate accumulation indicates that the upper, filamentary horizon developed in a younger deposit and is not the upper part of a bisequum (both carbonate horizons formed in a deposit of the same age). The carbonate horizon in Organ alluvium (from 18-41 cm, table 71) is a weak calcic horizon.

Comparison of study areas 14, 15, and 16 illustrates differences in soil development due to carbonate content of the parent materials. In contrast to the soils at areas 14 and 15, which have argillic horizons that are noncalcareous in their upper parts, soils at area 16 are strongly calcareous throughout and lack argillic horizons. In these high-carbonate parent materials, illuviation of silicate clay has not been demonstrated in Holocene soils; and little evidence of clay illuviation exists even in these soils of late Pleistocene age. Eastward, however, some of the soils of late Pleistocene age do have weak argillic horizons (Gile and Grossman, 1979); the sediments in these areas are somewhat coarser-textured and have a larger component of sediments from noncalcareous rocks.

Reagan 66-6 (table 71) occurs a short distance to the west at the margin of the basin floor, on the western border of the

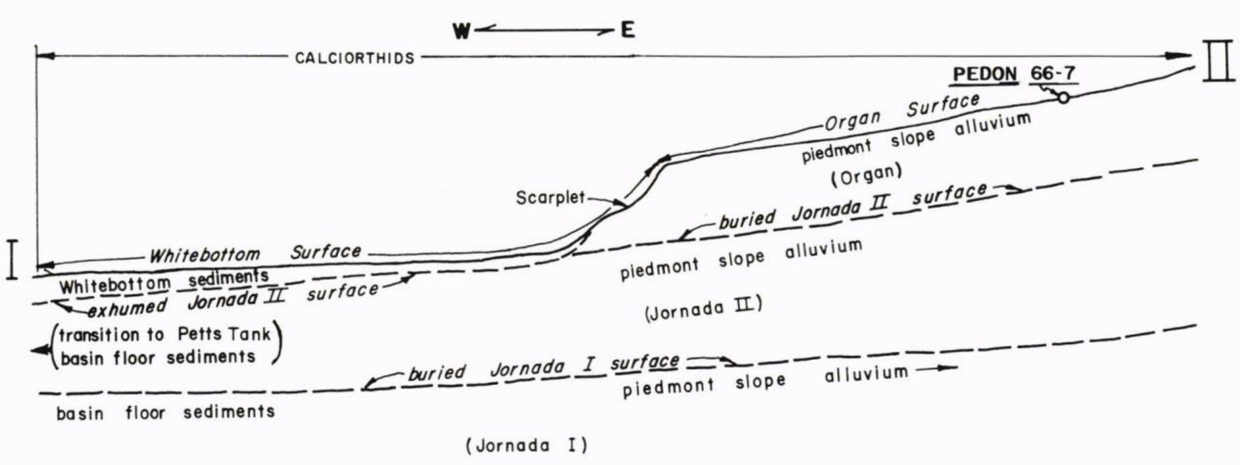


FIGURE 77—DIAGRAMMATIC CROSS SECTION OF SOILS, SURFACES, AND SEDIMENTS, AREA 16a (I–II on soil map, fig. 75). Buried Jornada I surface on Camp Rice Formation.

TABLE 71—LABORATORY DATA FOR FOUR PEDONS ILLUSTRATING THE TRANSITION FROM THE PIEDMONT SLOPE TO THE BASIN FLOOR; sand and clay are carbonate-free as percentage of carbonate-free material; carbonate removed from fine clay.

Alluvium	Horizon	Depth (cm)	Sand (%)	Clay (%)	Fine/total clay (%)	Carbonate <2 mm (%)	Carbonate <0.002 mm* (%)	Extractable sodium (me/100 g)	Extractable† potassium (%)	Bulk density (g/cc)	Water retention difference	Organic carbon (%)
	Ustollic Calciorthid (Reagan variant 66-7)											
Organ	A	0–8	43	26	0.24	12	2			1.37	0.19	1.17
	A	8–18	41	27	0.22	13	5			1.37	0.19	0.66
	B21ca	18–30	21	41	0.21	19	8			1.25	0.21	0.66
	B22ca	30–41	41	32	0.29	15	7					0.52
	2C	41–51	75	17	0.35	6	3					0.26
Jornada II	3B2cab	51–61	45	38	0.40	25	14			1.41	0.11	0.44
	3K2b	61–89	62	24	0.45	35	16			1.49	0.15	0.30
	3C1cab	89–112				25				1.80	0.15	0.12
	3C2cab	112–140				16				1.75	0.12	
	4C3cab	140–175				15						
	Organic carbon, 6.2 kg/sq m to 89 cm											
	Ustollic Calciorthid (Reagan 66-6)											
Organ	A	0–8	44	19	0.16	9	2			1.43	0.16	0.90
	B1	8–15	22	30	0.11	16	5			1.32	0.19	0.74
	B21	15–33	15	40	0.11	18	7			1.27	0.17	0.70
	B22ca	33–48	14	45	0.14	16	8			1.35	0.15	0.66
	B23ca	48–64	19	46	0.19	15	8			1.41	0.12	0.69
Jornada II	B21cab	64–81	48	32	0.26	13	6			1.59	0.10	0.37
	B22cab	81–114	43	36	0.43	21	11			1.40	0.14	0.34
	K2b	114–135	45	28	0.50	35	18			1.52	0.16	0.23
	C1cab	135–168	45	25	0.40	31	11			1.72	0.13	0.10
	C2cab	168–185	58	23	0.32	19	6					
	C3b	185–208	60	19	0.41	20	5					
	2C4b	208–259	27	30	0.33	28	8			1.39	0.22	
	2C4b	259–300	25	34	0.24	28	8			1.29	0.21	
	2C5b	300–325	21	38	0.23	28	8					
	3C6b	325–348	49	28	0.28	17	6			1.52	0.17	
Jornada I	3B2cab2	348–363	62	25	0.32	13	6					
	3K21b2	363–373	54	30	0.61	44	23					
	3K22b2	373–396	55	30	0.66	50	28			1.45	0.22	
	3K23b2**	396–437				28						
	3C1cacsb2**	437–457				6						
	3C2csb2**	457–518				3						
	Organic carbon, 8.8 kg/sq m to 114 cm											
	Ustollic Calciorthid (Reagan 60-17)											
Petts' Tank	A	0–8	26	34	0.13	10	5	tr	11			1.01
	B21	8–20	27	42	0.18	12	6	0.1	14			0.84
	B22	20–43	35	34	0.30	12	7	0.1	13			0.65
	B23ca	43–76	5	55	0.24	12	6	0.2	12			0.62
	K2	76–112	19	52	0.33	29	19	0.3	9			0.24
	C1ca	112–142	12	51	0.22	32	16	0.5	8			0.12
	C2ca	142–190	19	48	0.23	29	11					
Jornada I	Btbca	190–206	50	36	0.41	7	1					
	Organic carbon, 8.8 kg/sq m to 112 cm											
	Ustollic Haplargid (Stellar 60-21)											
Jornada I	A2	0–8	32	37	0.07	2		tr	12			1.22
	A3	8–13	32	45	0.23	tr		tr	11			0.65
	B1t	13–25	32	47	0.30	tr		tr	11			0.57
	B21t	25–51	31	44	0.29	3		tr	12			0.40
	B22t	51–79	31	49	0.47	6	2	0.1	11			0.27
	K1	79–99	36	48	0.51	24	14	0.1	10			0.17
	K21	99–130	59	29		51		tr	7			
	K22	130–155	64	25		46		0.1	7			
	K23	155–178	66	23		49		0.1	7			
	K24	178–216	68	21		36		0.1	8			
	K3	216–254	70	20		12		0.1	6			
	C1ca	254–284	78	15		9		0.1	6			
	2C2	284–305	87	9		1		0.2	6			
	Organic carbon, 6.0 kg/sq m to 99 cm											

*Percentage in <2 mm.
†Percentage of cation exchange capacity.
**Gypsum, respectively, zero, 80, and 70 percent, in lower three horizons.

piedmont toeslope. The Organ surface and its alluvium extend continuously from Reagan variant 66-7 to Reagan 66-6. This site illustrates some of the problems in recognizing younger deposits and soils on very gentle slopes where gravel or coarse sand is not present to form stone lines. The basal sand and pebbles between Organ and Jornada II at Reagan variant 66-7 are absent at Reagan 66-6. Although there is a change in texture along the contact (much less sand and more silt in Organ alluvium), the contrast is not as distinct as it is upslope. The carbonate morphology is also evidence of a younger deposit; the stage I horizon in Organ alluvium is separate from the stage III horizon of Jornada II. As at Reagan variant 66-7, the upper carbonate horizon is a weak calcic horizon.

A distinctive sediment, informally termed the Petts Tank silt zone, extends from 208 to 325 cm (table 71). It is remarkably like a zone from 129 to 170 cm in pedon 70-7 (about 1,600 ft south of area 14c) despite the considerable difference in lithology of the major sediments in the two areas. The sediment may have been deposited in a lake that temporarily flooded the basin floor rather than by streams.

A second buried soil occurs below the silt zone. Westward the first buried soil rises to the surface (Reagan 60-17; figs. 75, 76, 78); still farther westward the second buried soil rises to the surface (Stellar 60-21).

These two soils are discussed at areas 16b and 17.

En route to area 16b. Return through gate (mile 21.7), and park at trench southwest of gate. **0.4**

Area 16b—Ustollic Calciorthid (Reagan 60-17) in Petts Tank sediments

This site (figs. 75, 78) is the type area of the Petts Tank surface (2.61). Sediments of the Petts Tank morphostratigraphic unit extend to a depth of 1.9 m where they overlie a buried Jornada I surface and associated Camp Rice basin fill (fig. 76). The slope is nearly level, 0.5 percent or less to the southwest. Vegetation consists mainly of burrograss, with a few crucifixion thorn and sumac.

Reagan 60-17 (figs. 79, 80) is the same age as the buried soil in Jornada II alluvium upslope. Organic carbon content places the soil well within the Ustollic Calciorthids. A silicate clay maximum is apparent in the B horizon (carbonate-free basis) but oriented clay cannot be seen in thin section due to high carbonate content. The horizon of carbonate accumulation is quite similar to that of the Berino soil observed at area 15. The carbonate, however, is less hard and somewhat more diffuse because of the higher proportion of silt and clay in this soil.

This soil illustrates the retardation effect of high carbonate content on development of the argillic horizon in soils that started their development in late Pleistocene. These soils must have formed partly during a late Pleistocene full-glacial period. Even with greater effective moisture of the full glacial, abundant carbonate still remains in upper horizons.

The top of a buried soil occurs at about 190 cm; its argillic horizon is noncalcareous in places. This buried soil is developed on upper Camp Rice Formation basin fill and dates from middle Pleistocene time. It marks the surface of the ancient Jornada I basin floor, which was much more extensive than the present basin floor. The buried soil has been traced to the east (area 16b) by auger borings and by one deep trench where it is buried at still greater depths (at Reagan 66-6). To the west (area 17) it rises to the surface and emerges as the Stellar soil.

En route to area 17. Proceed west across basin floor. Petts Tank alluvium pinches out between areas 16 and 17 against a slightly higher Jornada I basin-floor surface. **0.5**

23.0 STUDY AREA 17

STUDY AREA 17

Haplargids of the Jornada I surface

SUMMARY OF PEDOGENIC FEATURES (table 66)—Emergence of soil buried at area 16b; one of the most prominent A2 horizons in the project area; thick argillic horizon without clay skins on ped surfaces, but with oriented clay within peds; runoff from adjacent slopes contributes moisture for soil development and vegetation.

SETTING—The Jornada I surface, buried to the east by sediments of the Petts Tank and Jornada II surfaces (figs. 67, 76, and 78), is here slightly higher than adjacent parts of the Petts Tank surface. The Jornada II surface occurs on the coalescent-fan piedmont to the west. Soil parent materials differ markedly from those in areas to the east. The soils of Jornada I have developed in fine-grained sediments of the Camp Rice basin-floor facies (derived mainly from andesite, rhyolite, and monzonite) that grade downward into clean fluvial sand and rounded-gravel of mixed composition. Locally thin overlays of late Quaternary alluvium form a veneer on the Jornada I surface. Vegetation is mainly tobosa with a very few snakeweed and mesquite.

SOIL OCCURRENCE—The fine-textured Ustollic Haplargids, Stellar soils, are dominant on the Jornada I surface. This mapping unit illustrates one that is not a soil complex because soils in the unit have quite uniform texture and age and are on a stable landscape. To the east are the Ustollic Calciorthids, Reagan soils, of the Petts Tanks surface; to the west are Typic Haplargids (Dona Ana soils) of the Jornada II surface.

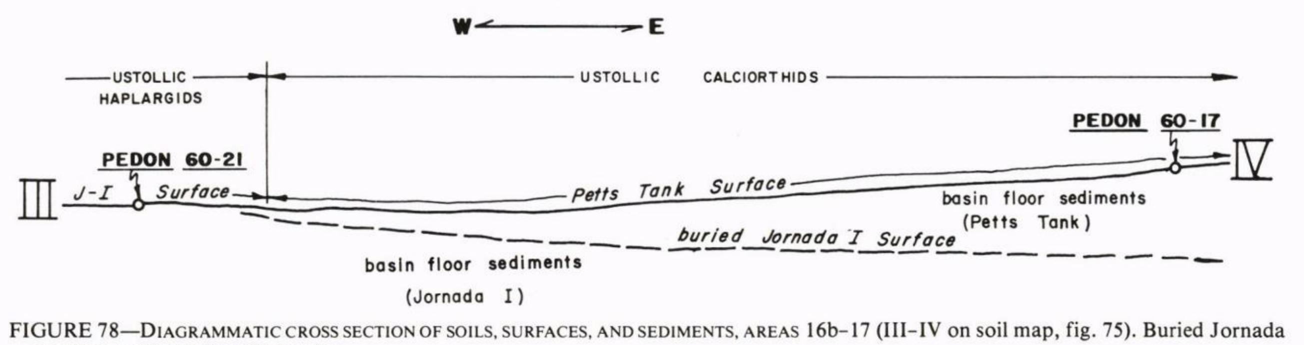


FIGURE 78—DIAGRAMMATIC CROSS SECTION OF SOILS, SURFACES, AND SEDIMENTS, AREAS 16b–17 (III–IV on soil map, fig. 75). Buried Jornada I surface on Camp Rice Formation.

FIGURE 79—PETTS TANK SURFACE AND CALCIORTHID, AREA 16b. Landscape of an Ustollic Calciorthid, Reagan 60-17, on Petts Tank surface. Vegetation consists mainly of burro grass, with a few crucifixion and sumac (photographed September 1970).

Ustollic Haplargid (Stellar 60-21) in Jornada I alluvium

This area receives runoff from the adjacent fan piedmont. The increased moisture has resulted in one of the best grass stands to be seen in the arid part of the study area. The tobosa grass forms an almost continuous cover, and organic carbon contents are high for the area as a whole. This soil falls well within the range of the Ustollic subgroups.

Stellar 60-21 (fig. 81) has an A2 horizon; a thick, fine-textured, argillic horizon; and a thick K horizon that engulfs the lower part of the zone of strong clay accumulation. The A2 horizon in this soil is one of the most prominent in the study area probably because of the increased moisture in this landscape position. The A2 horizons are commonly strongly calcareous, whereas horizons just beneath are noncalcareous. So much calcium is apparently being supplied to the soil surface (by run-in, in addition to contributions from dustfall and precipitation) that not all of it can be moved deeper into the soil.

Part of the clay of the Bt horizon may be inherited from the parent materials, which must have been quite high in clay in this basin-floor position. In thin section no clay skins are present on ped faces, but abundant oriented clay occurs within peds as grain coatings and as linear bodies. The Bt horizon is thicker than in adjacent soils; this thickness is apparently related to greater moisture, which would move clay and carbonate to greater depths.

The horizon of carbonate accumulation is very thick and although it started developing in middle Pleistocene time, a petrocalcic horizon has not formed—in marked contrast to the gravelly soils the same age on the Jornada I surface seen at area 4; the latter soils have petrocalcic horizons with multiple laminar horizons. Because of differences in gravel content, as discussed earlier, some soils with only calcic horizons can be the same age or much older than other soils with petrocalcic horizons.

Several general statements may be made concerning laboratory data for soils at areas 16 and 17 (table 71). Organic carbon is high. The silicate clay is finer in the B horizon and K horizon of the buried soils than in the overlying Petts Tank or Organ alluvium, which have relatively coarse silicate clay compared to the soils generally in the project. Carbonate of clay size is an appreciable proportion of the total carbonate in all horizons analyzed. Extractable potassium as a percent of the exchange capacity is particularly high (relative to other soils of the project) in the upper horizons of Reagan 60-17 and Stellar 60-21. Upper horizons with weak development in calcareous alluvium of Organ age may have bulk densities as low as about 1.3; this alluvium has 1/3 bar water retention of near 0.30-0.35 and a difference between 1/3 and 15 bar of 0.150.2. These values are relatively high compared to those of other soils of the project.

The clay mineralogy was determined for selected horizons in each pedon. All horizons examined contain montmorillonite, mica, and kaolinite. Reagan 66-6 has small quantities of chlorite.

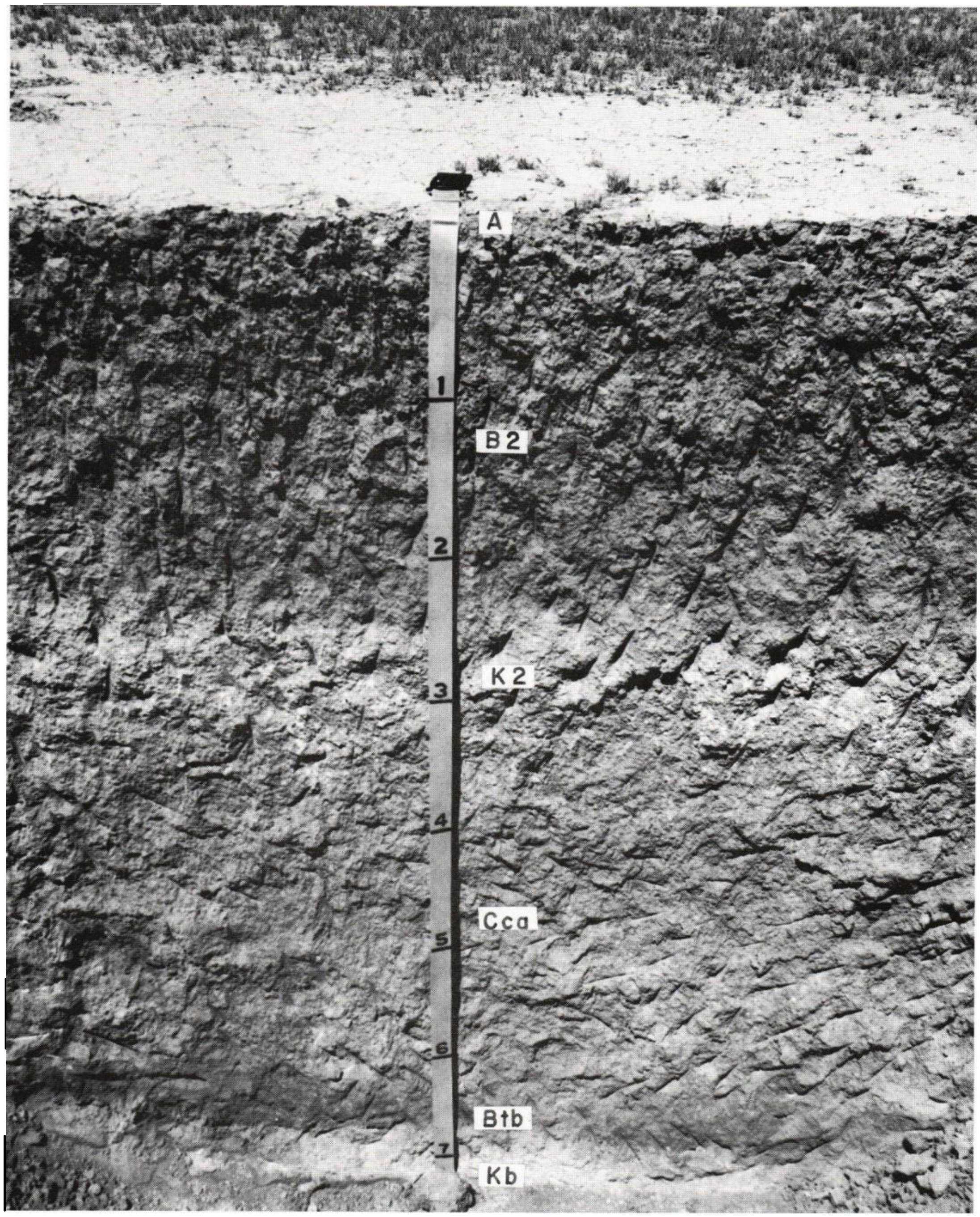


FIGURE 80--CALCIORTHID ON PETTS TANK SURFACE, AREA 16b. Profile of an Ustollic Calciorthid, Reagan 60-17, in Petts Tank sediments; buried soil (Btb/Kb) is in Camp Rice alluvium beneath Jornada I surface (fig. 78). Scale in feet (photographed September 1970).

Soil moisture for an Ustollic Haplargid; effect of run-in

One of the soil-moisture sites in the Jornada Experimental Range is located just north of Stellar 60-21. The site is in a Stellar soil, in basin-floor position near fan-piedmont slopes that contribute moisture to the soils. The basin floor is nearly level although run-in water from the adjacent slopes does not stand on the area but drains slowly to the playa about 1 mi south of these sites. Table 72 gives information on the setting, soil moisture, and morphology for the soil at the moisture site. Soil moisture was measured both inside and outside a sheet-metal cylinder. The cylinder was 3 m in diameter and was buried 15 cm in the soil. The soil-moisture units inside of the cylinder provided estimates of moisture due to precipitation. Those outside of the cylinder provided estimates of moisture due to precipitation plus run-in.

The average annual precipitation during 1960-1970 was 19.6 cm (table 72). During that period, soil moisture was recorded in two replications at depths of 10, 25, 40, 60, 90, and 120 cm, both inside and outside the metal cylinder. The soil moisture potential for the 1960-1970 period was between 0 and -15 bars for 48-53 days at the 40- through 120-cm depths outside the metal cylinder. It was between 0 and -15 bars 82 and 134 days for the 25- and 10-cm depths, respectively. At the 25-cm depth outside the cylinder, no moisture between 0 and -15 bars potential was recorded for 2 of the 11 years. There was moisture for 205 days at the 25-cm depth in 1962. No moisture was recorded for 7 of the 11 years at the

FIGURE 81—JORNADA I SURFACE AND HAPLARGID, AREA 17. Profile of upper horizons of an Ustollic Haplargid, Stellar 60-21, in basin-floor facies of Camp Rice Formation. Scale in feet (photographed February 1970).

90- and 120-cm depths. Inside the cylinder, the soil-moisture potential was between 0 and -15 bars for 92 days at the 10-cm depth and for 32-40 days for the remaining depths. At the 25-cm depth inside the cylinder, no moisture between 0 and -15 bars potential was recorded for 7 of the 11 years. A similar situation existed for all depths greater than 25 cm.

Comparing data inside and outside the cylinder, an average of 36 percent of the moist days was attributed to run-in. The 10 cm of the 10- to 30-cm control section that was wetted for the longest cumulative time was moist for 109 days. Even with run-in, these soils are not too moist for the Aridisols.

En route to area 18. Proceed west across basin floor. 0.3

23.3 Break in slope marks west boundary of Jornada Basin floor. The west piedmont slope of the basin rises towards the Dona Ana Mountains. Test augering in this area indicates that the Jornada I basin-floor surface continues some distance to the west as a buried surface below late Quaternary piedmont sediments before it merges with its piedmont-slope analogue. The piedmont slopes ahead are essentially Jornada II surface, locally subjected to Holocene modification along drainageways. The Dona Ana soils (Typic Haplargids) are dominant in this area. 0.5

23.8 Road junction at entrance to the Jornada Experimental Range of the Agricultural Research Service, U.S. Department of Agriculture. *Turn right on Range Road.* 0.6

24.4 The road descends slightly to a zone of mergence of the piedmont slopes and the basin floor. The Stellar soils occur on the fan toeslopes and the margin of the basin floor where tobosa grass is dominant. Dona Ana soils occur on steeper fan slopes to the west. 1.0

25.4 The road is now back on the broad basin floor of the southern Jornada del Muerto and on the Jornada I surface. Stellar soils occur adjacent to the road. 3.3

28.7 South Well Junction (Jornada Experimental Range Headquarters, 6 mi to the north; New Mexico State University Experimental Ranch Headquarters 3.5 mi to the west). *Angle right and continue east* along north boundary of the Desert Project area. Crossing complex of low sandy ridges and intervening flats. 0.5

29.2 STUDY AREA 18

STUDY AREA 18

Calciorthids of the Jornada I surface

SUMMARY OF PEDOGENIC FEATURES (table 66)—Evidence of soil mixing by fauna in the B horizon; irregular distribution of silicate clay; cambic horizon in position once occupied by argillic horizon; pipe, not now connected to argillic horizon, in a stage III carbonate horizon; accumulation of sodium and soluble salts; substantial gypsum in lower horizons, possibly of geologic origin.

SETTING—Low sandy ridges with intervening, level, slightly depressed areas characterize this basin-floor landscape (fig. 82); and the Jornada I and La Mesa surfaces occur in complex association. La Mesa remnants generally occupy the stablest parts of the ridges, with the Jornada I surface occurring in the

TABLE 72—SOIL MOISTURE, SOIL MORPHOLOGY, AND SETTING FOR STELLAR, AN USTOLLIC HAPLARGID; complete soil description in Herbel and Gile (1973). Days are number of days annually with moisture potential between 0 and −15 bars.

Soil series: Stellar

Classification: Ustollic Haplargid, fine, mixed, thermic

Landscape position and parent material: Nearly level basin-floor sediments from monzonite, rhyolite, andesite

Geomorphic surface and age: Jornada I; late middle Pleistocene

Dominant vegetation: Tobosa (*Hilaria mutica*)

Average annual production: Tobosa 1,055 kg/ha 1960–1970; 755 kg/ha 1960–66

Annual precipitation (cm) 1960–1970: Mean 19.6; range 11.8–32.0 (excluding daily amounts less than 0.63 cm)

Horizon and depth, cm	Soil morphology (in part)	Soil moisture (days at stated depths: the mean, range and simple correlation (r) between annual precipitation and days of moisture at each depth		
			Includes run-in	Excludes run-in
A2, 0–5	Clay loam, platy, slightly hard, calcareous	10 cm	134.4 33–205 0–65	91.8 18–172 0–79
A3, 5–9	Clay loam, blocky, hard, noncalcareous	25 cm	82.4 0–205 0–80	40.4 0–179 0.83
B21t, 9–23	Clay, prismatic, blocky, very hard, noncalcareous	40 cm	51.3 0–185 0–71	32.7 0–186 0.72
B22t, 23–44	Clay loam, prismatic, blocky, very hard, calcareous	60 cm	48.0 0–193 0.66	33.1 0–182 0.72
B23tca, 44–67	Clay, prismatic, blocky, very hard, calcareous	90 cm	52.6 0–196 0–50	32.8 0–181 0–71
B24tca, 67–87	Clay, prismatic, blocky, very hard, calcareous	120 cm	51–7 0–176 0.42	37.5 0–203 0.66
K & Bt, 87–118	Clay loam, blocky, hard, calcareous	12–22 cm*	109	
K21, 118–134	Clay loam, platy, hard, calcareous		not measured	

*The 10 cm of the moisture control section (from 10 to 30 cm in these soils) that is wetted for the longest cumulative time.

topographic lows and on less stable ridge surfaces. This study area is probably Jornada I.

Petts Tank sediments are known to underlie the plain to the east of these ridges, and the Jornada I surface occupies a broad low area to the west at the base of piedmont slopes ascending to the Doña Ana Mountains. Surficial basin fill in the area of the Jornada-La Mesa surface complex consists primarily of sediments of the Camp Rice Formation fluvial facies with local fine-grained veneers in the shallow depressions. Vegetation consists of scattered snakeweed, *Yucca elata,* burrograss, tarbush, and mesquite.

SOIL OCCURRENCE—The pattern of soils at area 18 (fig. 84) is determined by soil texture and degree of faunal activity, with the argillic horizon obliterated in some areas but not in others. Calciorthids (Algerita soils) are dominant. Doña Ana soils (Haplargids) occur in scattered spots on both the ridges and in the slight depressions. Both coarse-loamy Calciorthids (Algerita soils) and fine-loamy Calciorthids (Reagan, light subsoil variant) occur in the depressions, with the latter occurring in areas of finer-textured parent materials.

Typic Calciorthid (Algerita 61-2) in Camp Rice Formation basin fill

Algerita soils have A horizons, Bca horizons, and prominent horizons of carbonate accumulation. In marked contrast to area 17, the soil surface here is barren over extensive areas and there is no run-in. Also, textures are coarser than at area 17 (table 73). These factors tend to cause low organic carbon and Typic instead of Ustollic subgroups.

The reddish-brown fabric typical of the argillic horizon is not present in this soil although it is very old and has developed in sandy sediments with little or no carbonate. However, an argillic horizon was probably present at one time. Laterally these soils grade into soils that do have remnants of an argillic horizon (fig. 83).

Occasional pipes are filled with prominent, reddish-brown or red Bt material that is often noncalcareous and has distinct clay skins. An example of such a pipe is shown in fig. 83. The pipe must once have been connected to an argillic horizon above it, as in the buried Haplargids at areas 8 and 15. The pipe extends deeper than the cambic horizon and is therefore less subject to disturbance by soil biota. Distribution of silicate clay is irregular (table 73) and suggestive of a former Bt horizon that has been mixed and obliterated by termites and rodents, which have mixed the soil materials in many places. Rodent mounds are quite common on the ridges but are scarce in the slight depressions, where textures are heavier.

Gypsum in the C horizon may be of geologic origin. Extensive deposits occur at the surface to the north. The gypsum may have been deposited when the floor of the basin was

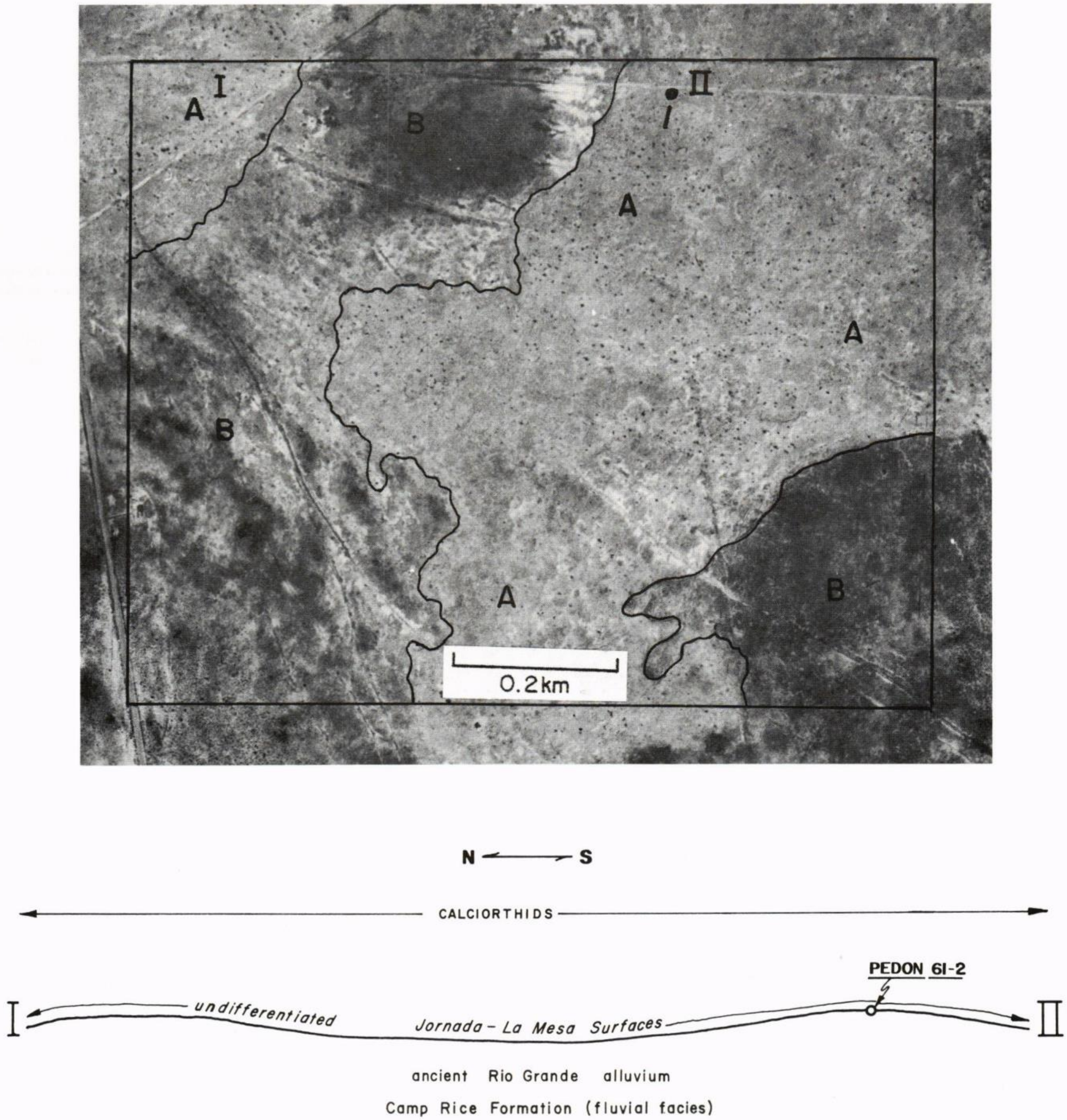


FIGURE 82—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 18. *Upper view:* map of soils; **A,** Algerita sandy loam (undifferentiated Jornada–La Mesa surfaces); **B,** Algerita complex (undifferentiated Jornada–La Mesa surfaces); I–II locates cross section. *Lower view:* diagrammatic section of soils, surfaces, and sediments (I–II on soil map).

flooded by a shallow pluvial lake. Its presence is probably also related to a gypsum source in the San Andres Mountains to the north.

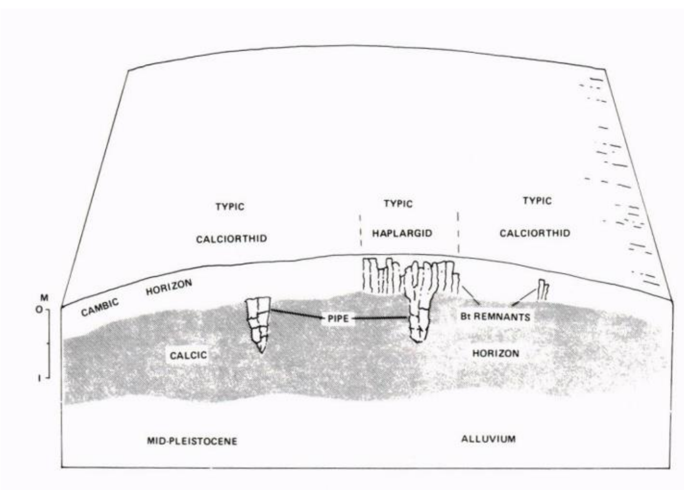
This soil has a moderate level of exchangeable sodium, appreciable extractable magnesium, and an electrical conductivity of 5 millimhos in the lower part of the K2 horizon. Accumulation of soluble salts is appreciable. Extractable potassium as a percentage of the exchange capacity is markedly lower than for the Ustollic Calciorthid (Reagan 60-17) at area 16 and the Ustollic Haplargid (Stellar 60-21) at area 17.

Algerita variant 61-1 was sampled slightly over a mile to the south. It differs from pedon 61-2 primarily in having a calcic horizon with considerable cementation, but not enough for a petrocalcic horizon. This soil also has an erratic distribution of silicate clay (table 73).

End of field study tour for Day 3. Return to Las Cruces.

TABLE 73—LABORATORY DATA FOR TWO TYPIC CALCIORTHIDS ON THE BASIN FLOOR; sand, silt, and clay on carbonate-free basis; extractable potassium as percent of cation-exchange capacity. Algerita variant 61-1 has a partially indurated K horizon. Both pedons are coarse-loamy. Percentages of noncarbonate clay on a whole-soil basis in parentheses for Algerita variant 61-1 (which has more clay than Algerita 61-2).

Horizon	Depth	Sand	Clay	Carbonate	Gypsum	Extractable sodium	Electrical conductivity	Extractable potassium	Organic carbon
	cm	%	%	%	%	me/100g	mmho/cm	%	%
Algerita 61-2									
A	8-13	74	16	8					0.6
B1ca	13-28	77	13	9					0.4
B2ca	28-38	70	16	10		0.1	0.5	4	0.4
K1	38-56	74	16	25		0.1	0.5	3	0.3
K21	56-76	82	10	34		0.4	0.7	3	0.1
K22	76-112	80	7	37		1.3	2	3	
K23cs	112-124	75	14	31	18	1.8	5	1	
K3cs	124-142	77	12	11	34	1.4	5	3	
C1cs	142-165	80	10	8	21	1.5	6	3	
C2ca	165-185	82	10	6	28	1.8	7	3	
Organic carbon, 2.7 kg/sq m to 76 cm									
Algerita variant 61-1									
A	8-13	80	10	6 (9)		tr	0.5	9	0.3
B1	13-20	79	12	7 (11)		tr	0.5	5	0.3
B21	20-33	82	9	7 (8)		0.2	0.4	4	0.4
B22ca	33-46	76	11	13 (9)	tr	0.4	0.4	3	0.3
K1	46-69	61	16	41 (9)	tr	0.2	0.7	3	0.3
K21	69-81	66	20	56 (9)	tr	0.2	2	4	0.2
K22	81-112	62	24	69 (7)	tr	1.1	5	3	0.1
K31	112-132	58	19	43 (11)	1	2.6	7	3	
K32	132-145	60	21	45 (12)	tr	2.6	7	3	
K33	145-173	55	29	32 (17)	6				
K34	173-196	28	29	29 (12)	30		8		
Organic carbon, 3.7 kg/m^2 to 112 cm									



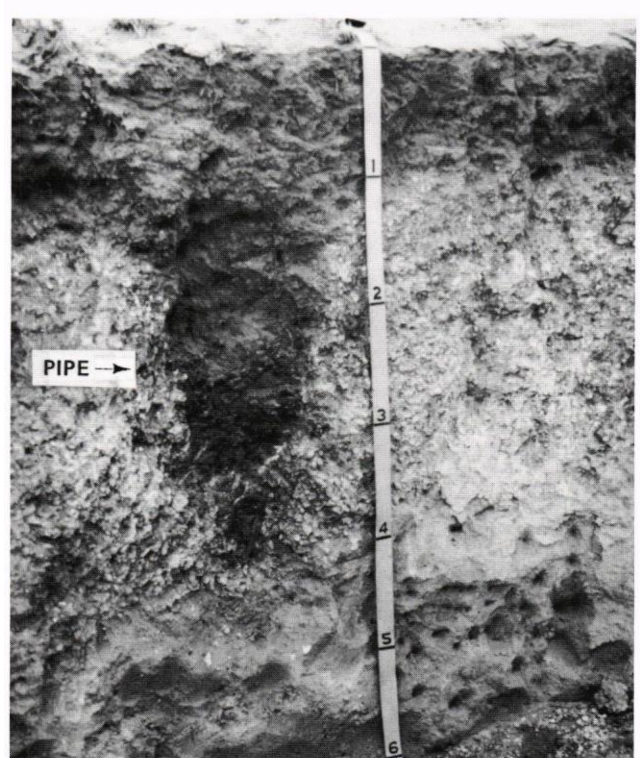


FIGURE 83—SOIL FEATURES ON JORNADA-LA MESA BASIN FLOOR, AREA 18. *Upper view:* block diagram of low ridge on basin floor. Calciorthids are dominant over the ridge crest because B horizons have been mixed by soil fauna, but remnants of Bt horizons have been preserved in places (see right). *Right view:* truncated pipe in a Typic Calciorthid near Algerita 61-2. The top of the pipe, which once must have been connected to an argillic horizon, has been mixed by soil fauna and is now part of a calcareous cambic horizon above the calcic horizon. Distinct clay skins occur in the remnant of the pipe, which is still noncalcareous in part. Scale in feet (photographed December 1968).

Day 4

(Low-carbonate materials): Entisols in sandy sediments of valley border; Aridisols on the fan piedmont below Organ Mountains; Mollisols along the front of Organ Mountains

The route of the field trip on the fourth day is shown in fig. 84. Some features of soils to be seen on Day 4 are summarized in table 74.

Mile

0.0 Assembly point. New Mexico State University Agriculture Building. Route to mile 1.3 (via Espina Street and University Avenue) is the same as Day 2. **1.3**

1.3 Crossing 1-25 overpass. (See Day 1 road log, miles 2.5 to 4.1.) **0.4**

1.7 Intersection; Telshor Boulevard. Continue east on Dripping Springs Road. **0.3**

2.0 Study area 2 to right. **0.3**

2.3 Route skirts north abutment of Tortugas Dam. **0.3** 2.6 Crossing Tortugas Arroyo channel. **0.3**

2.9 Road fork; *bear right on graded road.* **0.1**

3.0 Road curves to right just west of telephone line; continue south about 0.1 mi across arroyo valley and Picacho terrace remnant. *Turn vehicles around and park on right.* **0.1**

3.1 STUDY AREA 19. Walk about 200 ft to the east to study trench.

STUDY AREA 19

Torripsamments of Fort Selden surface

SUMMARY OF PEDOGENIC FEATURES (see table 74)—Young, weakly developed soils in a dissected landscape; noncalcareous B horizon, too coarse for a cambic horizon, has thin coatings of oriented clay on sand grains; lack of biotite in parent materials apparently responsible for lack of reddish-brown B horizon.

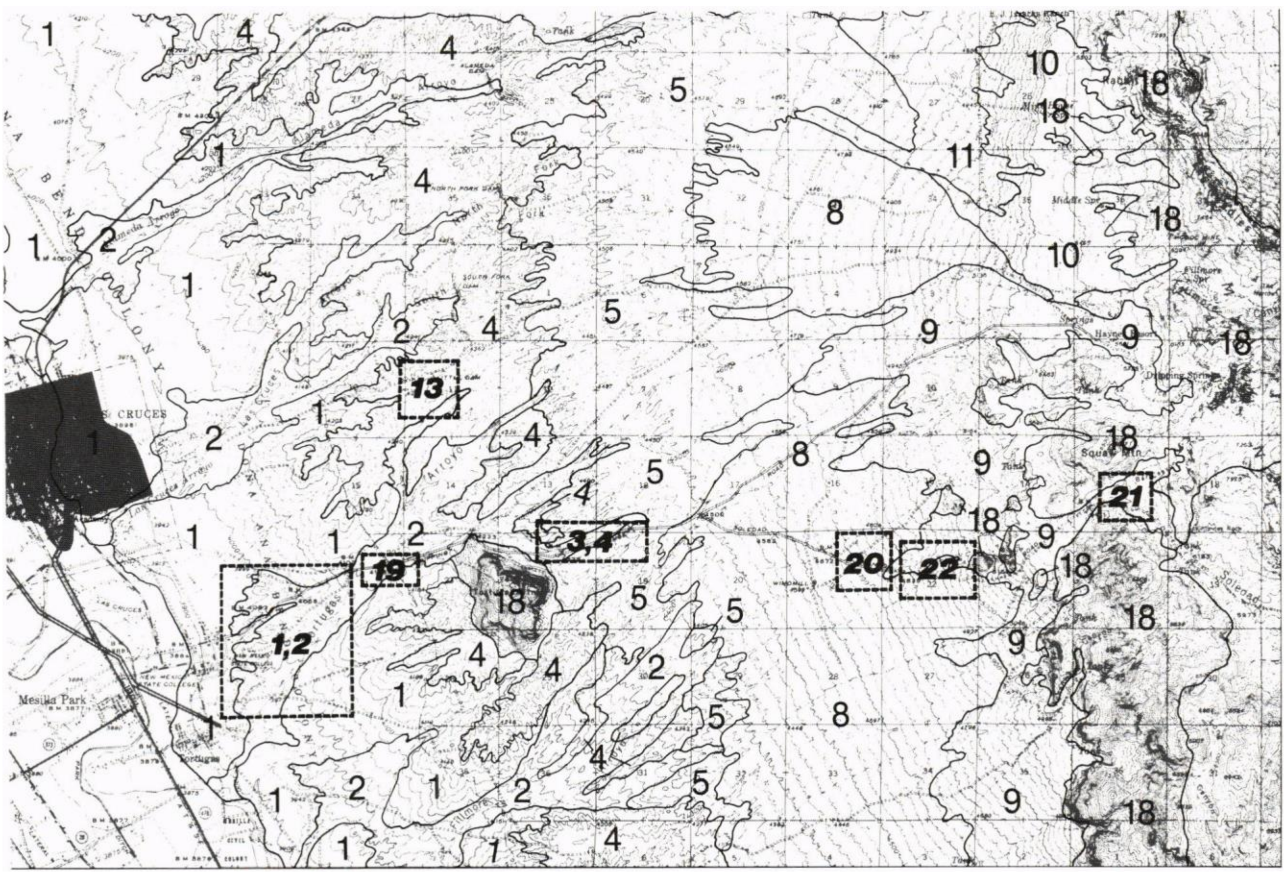


FIGURE 84—LOCATION OF STUDY AREAS 19-22, DAY 4. Explanation for this part of the general soil map (fig. 16):

1 Bluepoint association (Torripsamment-Torriorthent association) of Fillmore surface.
2 Nickel-Arizo-Kokan complex (Calciorthid-Torriorthent complex) of Fillmore and Picacho surfaces.
4 Caliza-Haplargids complex (Calciorthid-Haplargid complex) of Fillmore, Picacho, and Jornada **I** surfaces.
5 Monterosa-Algerita complex (Paleorthid-Calciorthid complex) of Jornada **I** and Fillmore surfaces.
8 Terino-Soledad association (Paleargid-Haplargid association) of Jornada II, Organ, and Jornada I surfaces.
9 Boracho-Terino-Santo Tomas association (Calciustoll-Haplustoll-Haplargid association) of Jornada II, Organ, Jornada I, and Dona Ana surfaces.
10 Caralampi-Nolam-Aladdin association (Haplargid-Haplustoll association) of Jornada and Organ surfaces.
11 Onite association (Haplargid association) of Organ surface.
18 Rock outcrop and soils of mountain slopes and summits, undifferentiated.

TABLE 74—FEATURES OF SOILS AND LANDSCAPES AT STUDY AREAS 19–22, DAY 4. Precipitation estimated from records at University Park and Boyd's Ranch. Trenches usually closed unless otherwise indicated. Symbols: l-sk, loamy-skeletal; sh, shallow; m, mixed mineralogy.

Study area	Precipitation (in., cm) elev. (ft)	Parent materials derived primarily from:	Geomorphic surface and age	Landform and percent slope	Nature of exposure	Classification: Subgroup	Classification: Family	Classification: Series	Diagnostic horizons	Stage of carbonate accumulation
19	8, 20 4,160	Noncalcareous sand	Fort Selden Holocene– latest Pleistocene	Ridge side, 6	Trench	Typic Torripsamment	m	Bluepoint	None	I
20 **a-c**	10, 25 4,720	Rhyolite	**a** Organ Holocene	**a** Crest of slight ridge, 4	**a** Trench	**a** Typic Haplargid	l-sk, m	Soledad	Argillic	I
			b,c Jornada II late Pleistocene	**b,c** Fan piedmont, 4	**b,c** North bank of arroyo	**b** Ustollic Haplargid **c** Petrocalcic Ustollic Paleargid	l-sk, m l-sk, m, sh	Caralampi Terino	Argillic Argillic, petrocalcic	II IV
21 **a,b**	15, 38 5,700	Rhyolite	**a** Organ Holocene	**a** Terrace, 7	**a** East bank of arroyo	**a** Pachic Haplustoll	l-sk, m	Santo Tomas	Mollic epipedon	—
			b Jornada I late middle Pleistocene	**b** High remnant of valley fill, 8	**b** East side of arroyo	**b** Ustollic Haplargid	l-sk, m	Caralampi	Argillic	I
22 **a,b**	10, 25 4,940	Rhyolite	**a,b** Jornada side-slopes of Doña Ana ridge remnant; late middle Pleistocene	Ridge side, 15	**a,b** Trenches	**a** Ustollic Paleorthid **b** Petrocalcic Calciustoll	l-sk, m, sh l-sk, m, sh	Monterosa Boracho	Petrocalcic Mollic epipedon, petrocalcic	IV IV

SETTING—This study area (figs. 19, 85) is located on the lower sideslope of a ridge remnant of the Camp Rice fluvial facies. The higher slopes of the ridge are underlain by very gravelly to gravelly deposits of mixed lithology, while the lower slopes are mainly sand, with scattered zones of gravelly material. Major units of stratification are internally cross-bedded, and discontinuous zones of nonpedogenic calcite cementation occur in places. This sequence of ancient Rio Grande deposits is discontinuously covered on upper slopes and almost continuously buried on lower slopes by a thin veneer of sandy colluvial and alluvial material that is a by-product of late Quaternary erosion and sedimentation. Materials of the Fillmore and Leasburg units are not readily separable in this geomorphic setting, and the general Fort Selden grouping is therefore used to describe this complex of surfaces and associated deposits of Holocene and later Wisconsinan age. Slope is 6 percent to the north. Vegetation is creosotebush, mesquite, and *Yucca elata.*

SOIL OCCURRENCE—The soil pattern (fig. 86) is determined by differences in soil age and particle size. In the complex of arroyo channels and Fillmore surface along Tortugas Arroyo, Torriorthents are in the channels and Torriorthents (Arizo soils) dominate the Fillmore terraces. Torripsamments (Blue-point soils) are dominant on the sides of ridges and on some ridge crests. Calciorthids (Nickel and Delnorte soils) dominate the Picacho ridge crests north of this slope.

Typic Torripsamment (Bluepoint 59-10) in Fort Selden alluvium

Bluepoint 59-10 (fig. 87) has a relatively thick noncalcareous zone, a stage I carbonate horizon and a C horizon with very little clay and carbonate (table 75). The noncalcareous zone tends to be thicker in Bluepoint soils of these ridges than in other soils along the valley border. This thickness is attributed to the high percentage of sand and uniformity of particle size (table 75). These factors would tend to maximize penetration of the wetting front and move carbonate to greater depths. The B horizon is slightly browner and darker than the C horizon, and thin sections show very thin coatings of oriented clay on sand grains in the **B** horizon. An atmospheric origin is postulated for some of the clay in the B horizon as well as for carbonate in Cca horizon.

The low extractable iron in the soil (table 75) reflects the scarcity of ferromagnesian minerals, such as biotite, which

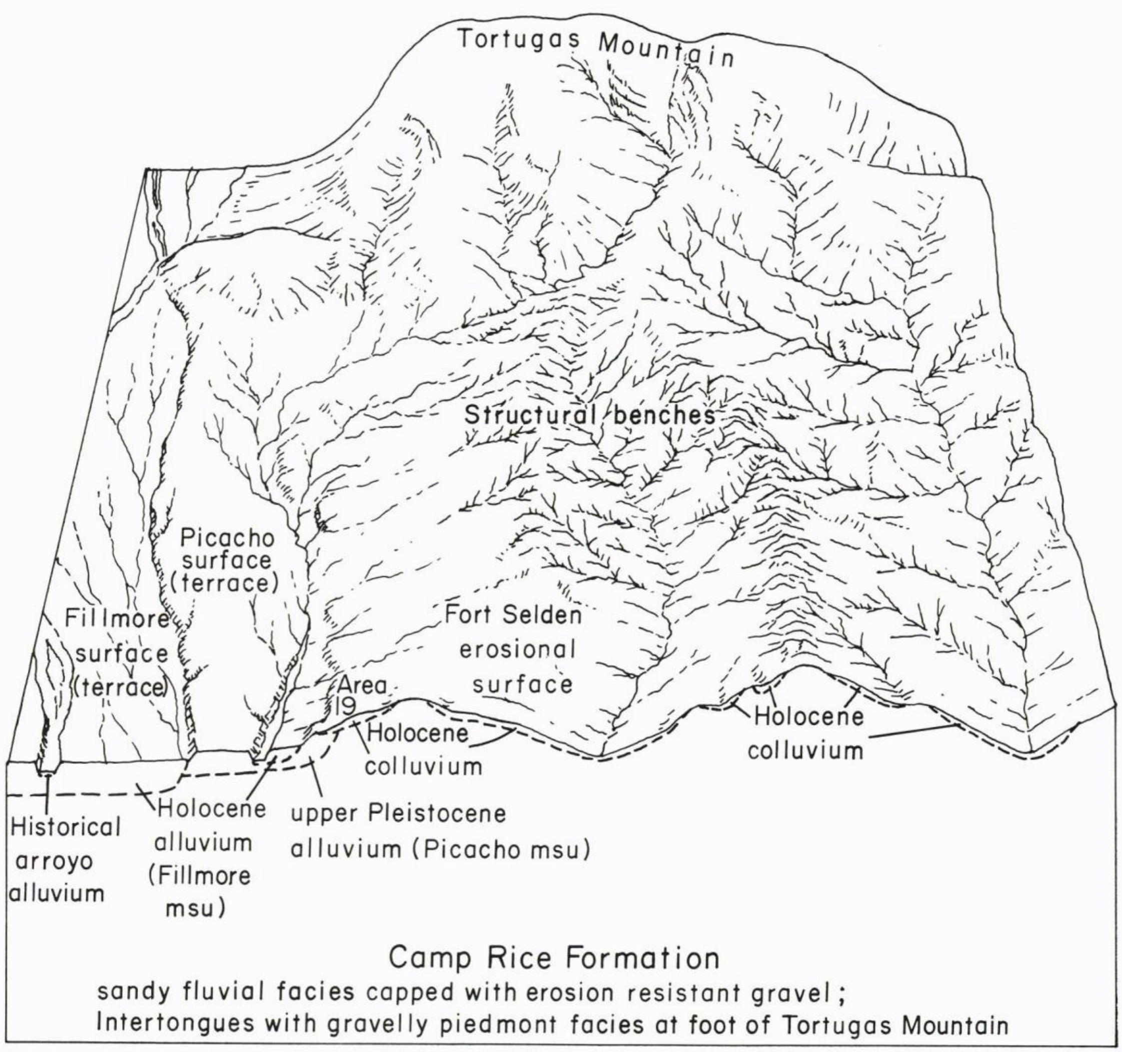


FIGURE 85—BLOCK DIAGRAM OF GEOMORPHIC SETTING, AREA 19, showing valley-border surfaces west of Tortugas Mountain (Permian limestone). Two alluvial terraces, Fillmore (Holocene) and Picacho (late Pleistocene), flank channels of Tortugas Arroyo. These deposits and hillslope colluvium (Holocene) of undifferentiated Fort Selden surface cover late Quaternary erosion surfaces cut in fluvial sand and gravel of Camp Rice Formation (middle Pleistocene). Erosion-resistant gravels, deposited by the ancestral river, cap the highest ridges west of the mountain and form a series of dissected structural benches (adapted from Gile, 1975, fig. 8, with permission).

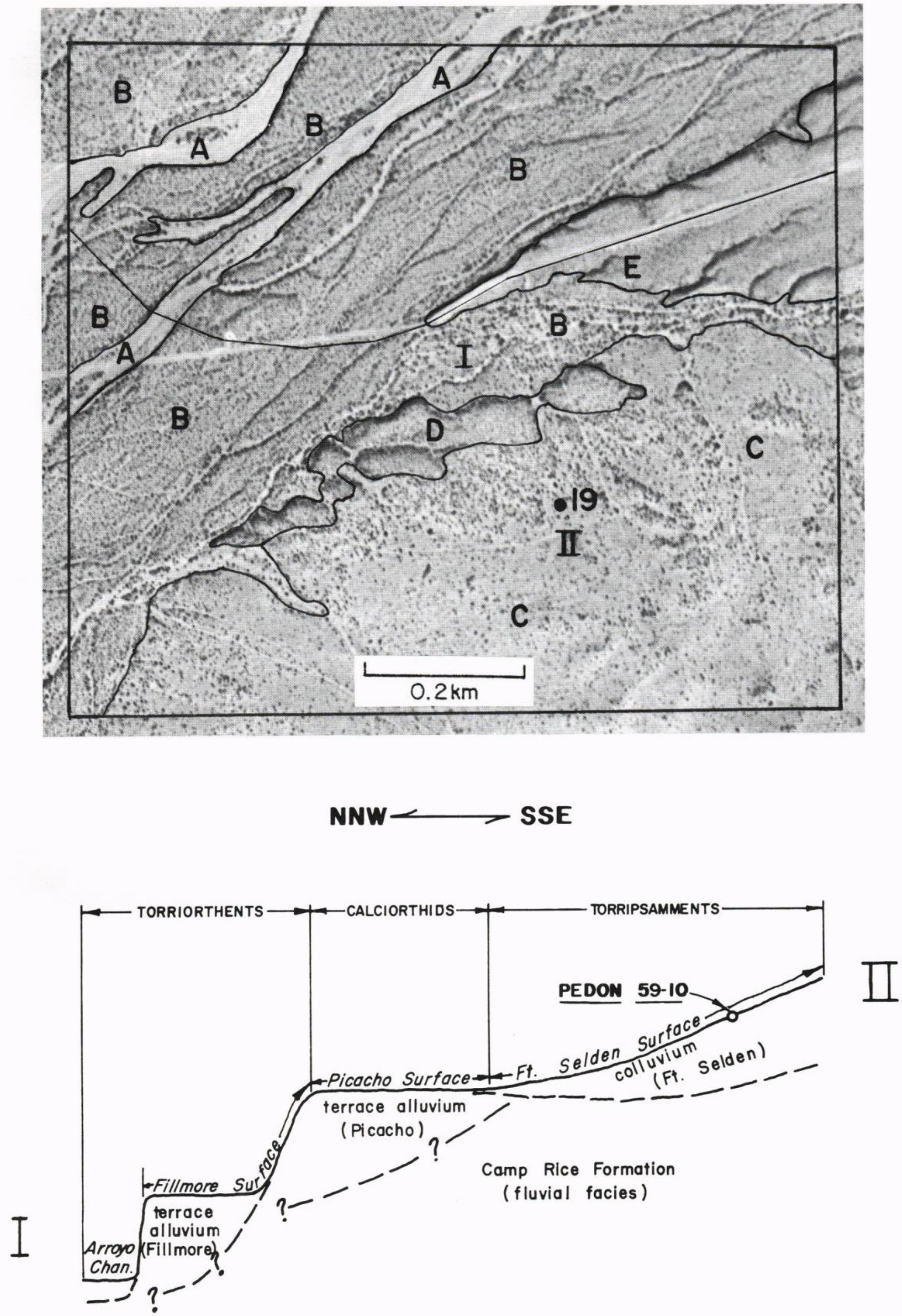


FIGURE 86—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 19. *Upper view:* map of soils; **A**, Torriorthents (arroyo-channel surfaces); **B**, Arizo-Torriorthent complex (Fillmore and arroyo-channel surfaces); **C**, Bluepoint sand (Fort Selden surface); **D**, Typic Calciorthids (Picacho surface); **E**, Delnorte complex (Picacho surface); I–II locates cross section. *Lower view:* diagrammatic section of soils, surfaces, and sediments (I–II on soil map).

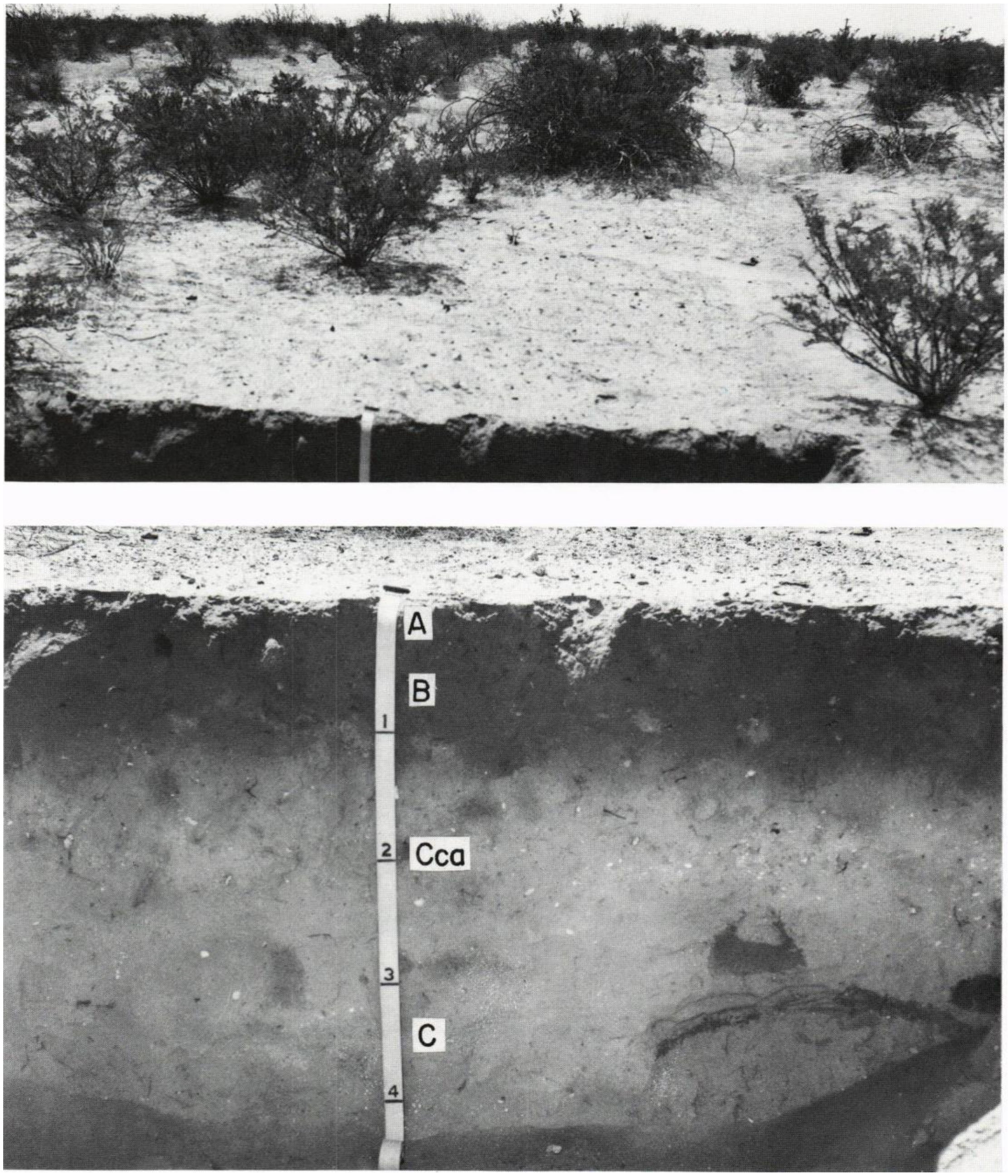


FIGURE 87—FORT SELDEN SURFACE AND A TORRIPSAMMENT AT AREA 19. *Upper view:* landscape of a Typic Torripsamment, Bluepoint 59-10, on an undifferentiated Fort Selden surface (probably early-phase Fillmore). *Lower view:* Bluepoint 59-10 in Fort Selden colluvium. Scale in feet (photographed April 1966; from Gile, 1975, fig. 9, with permission).

TABLE 75—LABORATORY DATA FOR A TYPIC TORRIPSAMMENT (Bluepoint 59-10); sand, silt, and clay on carbonate-free basis.

Horizon	Depth	Sand	Silt	Clay	Carbonate	Extractable iron	Organic carbon	Dry color
	cm							
A	0-13	90	5	5	0.1	0.4	0.14	10YR 5/2.5
B	13-43	90	5	5	0.5	0.4	0.11	10YR 5/2
C1ca	43-64	92	3	5	2.7	0.4	0.11	10YR 6.5/2
C2ca	64-114	94	3	3	2.4	0.3	0.05	10YR 6.5/2
C3	114-140				tr			10YR 7/2

Organic carbon, 1.4 kg/sq m to 114 cm

would be susceptible to weathering in an arid environment. These soils have formed in reworked river alluvium that is low in extractable iron (table 75); this low level may cause the lack of 5YR hues in the B horizon of Bluepoint 59-10. Hues redder than 7.5YR are typical of Holocene soils formed in piedmont-slope alluvium derived from rhyolite and/or monzonite (see areas 11 and 20 and Holocene soils in the arid zone, Days 1, 2, and 3).

En route to area 20. *Return to Dripping Springs Road.* 0.2

3.3 Intersection; *turn right and continue east on Dripping Springs Road around north spur of Tortugas Mountain* (see Day 1 road log, miles 4.1 to 6.2). 2.1

5.4 Area 3 (Day 1) on Picacho surface. 0.9

6.3 Area 4 (Day 1) on Jornada I surface. Electric-transmission-line crossing. Tributaries of Tortugas and Fillmore Arroyos have cut a system of shallow valleys across the piedmont slope ahead. Picacho and Jornada surfaces occur on broad interfluves and terraces that occupy much of the piedmont slope. Fort Selden surfaces are confined to narrow valleys. 0.7

7.0 Road fork; *bear right on Soledad Canyon Road.* Park on right for discussion stop. 2.1

MERGENCE OF TERRACED TERRAIN AND ARGID-ORTHID TRANSITION

The two topics to be discussed here (just east of area 4) are 1) the gradual mergence and ultimate disappearance of the terraced terrain towards the mountains and 2) the boundary between Orthids and Argids.

East of this area the effects of cyclic river entrenchment on stepped-sequence development (stops 1-5) become less evident, and the surfaces gradually merge to form an undulating piedmont slope (figs. 7, 25, and 88). At this transitional area, the distinct valley fills of the Jornada I to Fillmore sequence merge with their piedmont analogues, the Jornada Ito Organ sequence. To the east, younger fills begin to fan out as thin mantles on older interfluve surfaces. Topographic and chronologic relationships between various soil-landscape components are not well expressed. Detailed field studies involving physical tracing of surfaces, stratigraphic units, and soils were undertaken in order to determine the geomorphic and pedologic history of this complex piedmont terrain. These studies will be illustrated in area 20.

The transition from Argids to Orthids was observed on a local basis at areas 2 and 3; the Argids on ridge crests changed to Orthids on ridge sides. The Argid-Orthid transition also occurs on an extensive regional scale along the valley border as shown in the general soil map (fig. 84). West of the boundary, most soils are Orthids because of soil truncation associated with landscape dissection. East of the boundary there is a change to primarily Argids because most soils have been little affected by dissection.

In these soils (which range in age from late to middle Pleistocene) the argillic horizon is usually underlain by a calcic or petrocalcic horizon. If a calcic horizon is present, obliteration of the Bt horizon causes a change from a Haplargid to a Calciorthid. If a petrocalcic horizon is present, the change is from a Paleargid to a Paleorthid. The Argids occur on ridge crests that are level or nearly level transversely (fig. 89) and have been little affected by the dissection. Orthids occur on rounded ridge crests and in and near drainageways, where the argillic horizon has been truncated or engulfed by strong carbonate accumulation.

The boundary between Argids and Orthids along the valley border is very sinuous because the transition in terraced terrain differs in different parts of the terrain. Where the argillic horizon has been obliterated on the highest (Jornada I) ridges, it is still preserved on younger, less dissected Picacho terraces below. With increasing dissection valleyward, the argillic horizon is finally obliterated on the Picacho terraces also.

9.1 *Turn left on subdivision road;* park about 0.1 mi north. 0.1

9.2 STUDY AREA 20

STUDY AREA 20

Argids of the Organ and Jornada II surfaces

SUMMARY OF PEDOGENIC FEATURES (table 74)—Chronological reversal of stepped-sequence topography of the valley border; discontinuous soil burial and emergence of buried soils at the land surface; radiocarbon age of pebble coatings accords with Holocene age of soil; base of B horizon is about twice as deep as at lower elevations.

SETTING—Changes in names of geomorphic surfaces (Organ, Isaacks' Ranch, and Jornada II versus Fillmore, Leasburg, and Picacho) reflect the change from a setting dominated by effects of episodic shifts in the Rio Grande base level to one in which the local base level of erosion has been relatively stable since middle Pleistocene time (figs. 7, 25, and 88).

There are two levels above the arroyo channel (fig. 90); and, in this sense, the topography is similar to the terraced terrain along the valley border. Here, however, the chronological relationships are reversed and the highest of the two surfaces is the youngest. This topographic high is the Organ surface of Holocene age and its sediments bury the soils of Jornada II surface of late Pleistocene age (compare with areas 15 and 16). The parent materials are derived almost entirely from rhyolite. Water-table depths range from 140 to 180 ft (40-55 m), decreasing mountainward (fig. 9).

SOIL OCCURRENCE—Soils of this general area occupy a position intermediate in location and morphology between the desert area to the west and the semiarid mountains to the east. Precipitation is probably greater here than in the valley-border area and may reach about 25 cm annually. Horizons of silicate clay accumulation tend to be thicker, and horizons of carbonate accumulation tend to be deeper and more diffuse than they are in desert areas to the west.

Typic Haplargids (Soledad soils) occur on the topographic high, the Organ surface (figs. 90, 91). Ustollic Haplargids (Caralampi and Nolam soils) and Petrocalcic Ustollic Paleargids (Terino soils and Terino, moderately deep variant) occur on the Jornada II surface of the next lower level. The occurrence of Terino, moderately deep variant, in the eastern part of this area (fig. 91) reflects a deepening of the petrocalcic horizon to depths greater than 50 cm, the limit of the shallow families. Torriorthents occur in the arroyo channels, with low terraces just above the channels commonly occupied by the Arizo soils; in places there are small areas of the Camborthids—Vado or its sandy-skeletal variant.

The mapping unit, Soledad very gravelly sandy loam, illustrates soils that can be separated at a scale of 1:15,840 and that are largely in one series. Reasons for this are that 1) the alluvium is nearly all very gravelly, and so there is essentially only one particle-size class; 2) the soils are all old enough to have accumulations of silicate clay to place them in the Argids but not old enough for intermittent development of calcic or

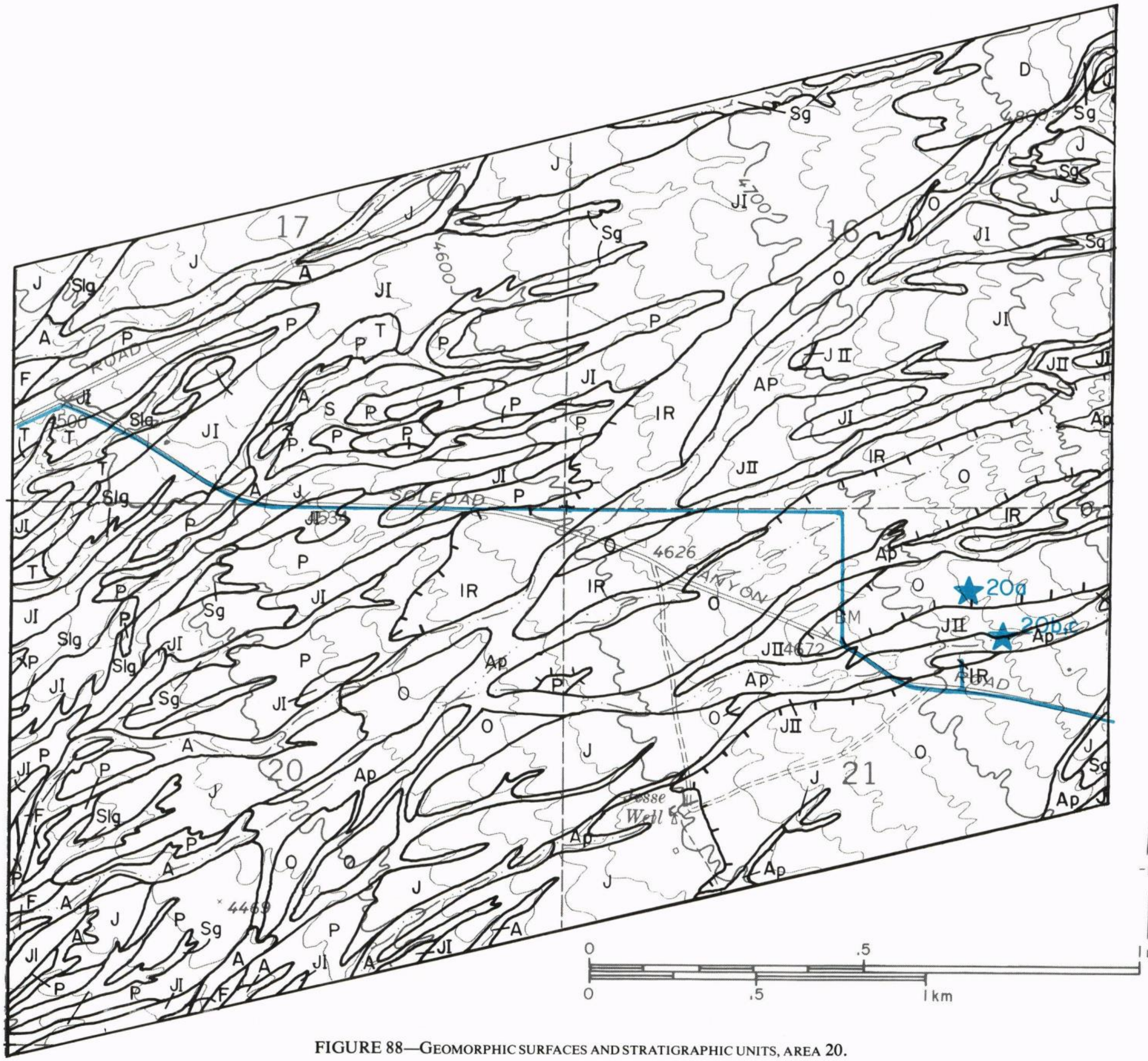


FIGURE 88—GEOMORPHIC SURFACES AND STRATIGRAPHIC UNITS, AREA 20.

EXPLANATION

A, Ap Arroyo surfaces (major channel areas). Associated sediments of Historical age partly fill channels cut into older units.

A—Valley-border arroyos, with minor inclusions of Fillmore morphostratigraphic unit.

Ap—Piedmont-slope arroyos, with minor inclusions of Organ morphostratigraphic unit.

F Fillmore surface (constructional phase). Arroyo-valley terrace surfaces in valley-border zone; underlain by gravelly alluvial deposits of the Fillmore morphostratigraphic unit (Holocene); minor inclusions of arroyo-channel and Picacho alluviums.

O Organ surface (constructional phase). Piedmont-slope analog of the Fillmore surface. Fan and terrace surfaces underlain by gravelly alluvial deposits of the Organ morphostratigraphic unit (Holocene). Unit locally overlaps older piedmont surfaces or partly fills shallow drainageways cut below such surfaces and contains minor inclusions of arroyo and Isaacks' Ranch alluviums.

Sg, Slg Fort Selden surfaces—Leasburg and Fillmore undifferentiated and arroyo-tributary channels.

Sg—Complex of erosional surfaces, in ridge-sideslope and channel-floor positions, cut into gravelly Picacho and older alluviums; with minor constructional-surface inclusions and associated thin colluvial-alluvial fills.

Slg—Complex of erosional surfaces in ridge-sideslope positions, cut into loamy to gravelly piedmont-slope deposits of the Camp Rice Formation that overlap and intertongue(?) with the Camp Rice fluvial facies (Qcrf) south of Tortugas Mountain. Contains minor inclusions of Picacho and Tortugas surface remnants.

IR Isaacks' Ranch surface (constructional phase). Piedmont-slope fan and terrace surfaces underlain by gravelly alluvial deposits of the Isaacks' Ranch morphostratigraphic unit (latest Pleistocene to early Holocene). Unit locally overlaps older piedmont surfaces or partly fills shallow drainageways cut below such surfaces.

P Picacho surface (constructional phase). Arroyo-valley terrace surfaces in valley-border zone; underlain by gravelly alluvial deposits of the Picacho morphostratigraphic unit (late Pleistocene).

T Tortugas surface. Several levels of erosion-surface remnants of late Pleistocene age that are intermediate in position between Picacho and Jornada I surfaces and are cut in the younger piedmont-slope facies of the Camp Rice Formation (Qcrp).

JI Jornada I surface (constructional phase). Piedmont-slope complex of middle Pleistocene age graded to basin-floor levels approximated by the youngest parts of La Mesa surface. Underlain by gravelly to loamy alluvium of the Camp Rice Formation—younger piedmont facies that overlaps and intertongues with gravel and sand of the Camp Rice fluvial facies near Tortugas Mountain.

JII Jornada II surface (constructional phase). Piedmont-slope analog of surfaces ranging from Picacho to Tortugas(?) in age. Underlain by gravelly alluvial-fan, coalescent-fan, and terrace deposits of the Jornada II morphostratigraphic unit (late Pleistocene).

J Jornada I and II piedmont-slope surfaces and associated deposits—undifferentiated.

D Doña Ana surface (constructional phase). High-level remnants of ancient fan surfaces (locally preserved in mountain footslope areas) that predate development of the Jornada I surface; probably of early to middle Pleistocene age. Underlain by gravelly alluvium (locally indurated) of the Camp Rice Formation older piedmont facies.

 Hachures on contacts point towards overlapping deposits

NOTE: Lithology of all units reflects the Soledad Rhyolite composition of source watersheds in the Organ Mountains.

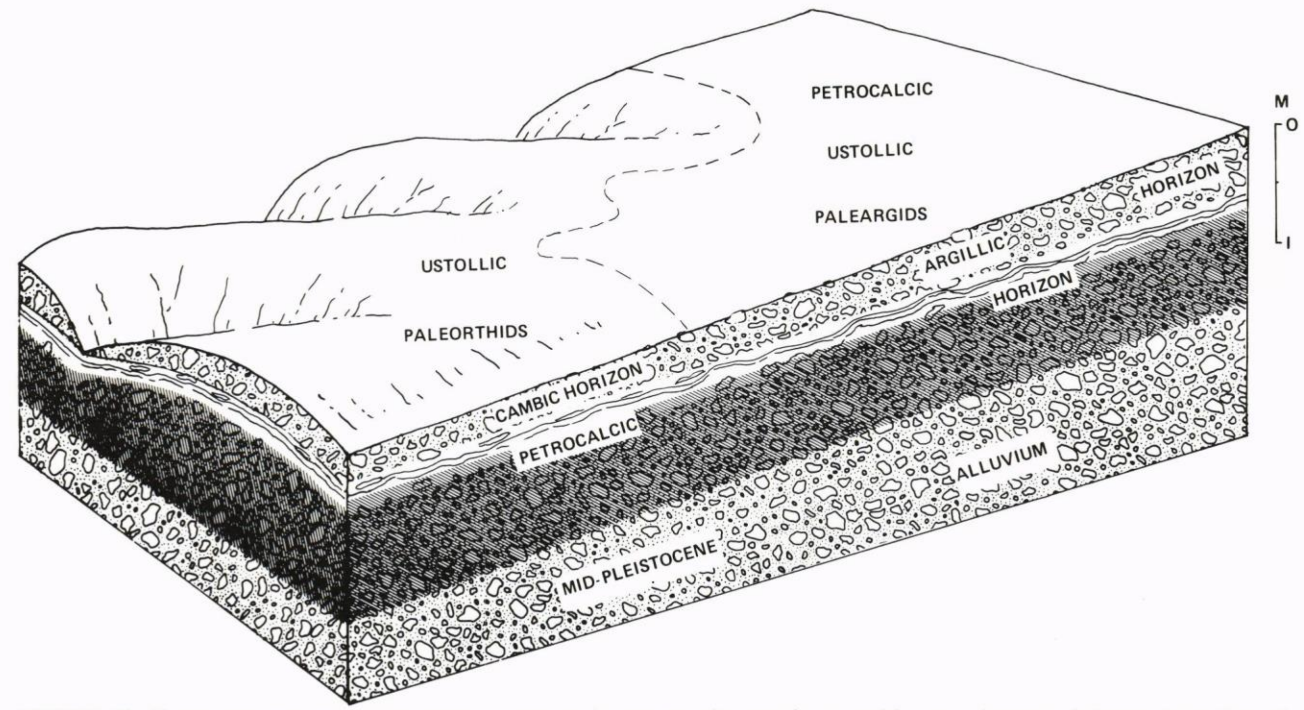


FIGURE 89—BLOCK DIAGRAM SHOWING BOUNDARY BETWEEN ARGIDS AND ORTHIDS in a transition zone between piedmont slopes little affected by stream dissection (transversely level interfluve summits) and dissected terrain of the valley border. Paleargids occur on the relatively undissected piedmont surfaces. Paleorthids occur on rounded ridge crests and in and adjacent to drainageways (figs. 3 and 22).

petrocalcic horizons that would place some soils in different classes; and 3) texture of upper horizons is sandy loam, which in this area indicates that organic carbon is too low for Ustollic subgroups.

Area 20a—Typic Haplargid (Soledad 67-4) in Organ alluvium

In the study trench about 5 ft (1.5 m) of Organ fan deposits are exposed over Jornada alluvium. The Organ unit wedges out to the south (fig. 91), and the Jornada II unit emerges as a low arroyo terrace at areas 20b, c. Soil and geomorphic tracing from sites dated to the north (Isaacks' and Gardner Spring radiocarbon sites) indicate that the Organ surface in this area stabilized about 2,000-6,000 yrs ago. Slope is 4 percent to the west. Vegetation consists of mesquite, Mormon tea, cholla, snakeweed, ratany, desert thorn, and scattered clumps of fluffgrass.

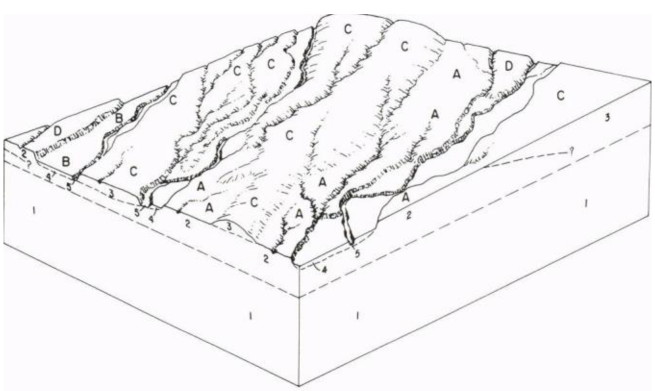


FIGURE 90—BLOCK DIAGRAM OF GEOMORPHIC SETTING, AREA 20, showing soil-landscape relationships on piedmont slopes west of southern Organ Mountains. Soil mapping units: **A,** Terino-Nolam complex (Jornada, undifferentiated surfaces); **B,** Arizo complex (Organ and arroyo-channel surfaces); **C,** Soledad very gravelly sandy loam (Organ surface); **D,** Terino, moderately deep variant (Jornada, undifferentiated surfaces). Geologic units: **1,** upper Camp Rice Formation (piedmont facies); **2,** Jornada alluvium and soils; **3,** Organ alluvium and soils; **4,** Organ alluvium (late) and soils; **5,** arroyo-channel alluvium.

The soil of the Organ surface (table 76; figs. 92, 93) has a thin A2 horizon, a very gravelly argillic horizon, and a very gravelly Cca horizon. The soil morphology and Holocene age indicate that all horizons are within reach of wetting at the present time and are forming now. Silt is highest in upper horizons, and the C horizon contains very little clay. Some of the silt, probably much of the silicate clay, and essentially all of the carbonate apparently were derived from atmospheric sources. The very gravelly desert pavement should tend to slow runoff and help trap these materials in the dustfall.

Horizons of silicate clay and carbonate are deeper than in similar parent materials along the valley border because of greater precipitation in this area. The accumulations of carbonate and silicate clay are quite discrete and separate from each other; they usually overlap in soils of Pleistocene age. Flaky carbonate coatings on pebbles from the Cca horizon have been dated at 3.4 kyrs (3.83), which falls within the estimated range in age (from 2 to 6 kyrs) for this soil.

Walk southward to arroyo exposure of Jornada II fan-piedmont deposits.

Area 20b—Ustollic Haplargid (Caralampi 59-15) in Jornada H alluvium

This soil is formed in alluvium of the Jornada II surface. Slope is 4 percent to the west. Vegetation on the soils of Jornada II consists of snakeweed, mesquite, Mormon tea, fluffgrass, a few creosotebush, and a few clumps of black grama. Vegetation in the adjacent arroyo is mainly brickellbush, desert willow, mesquite, sumac, and creosotebush.

This soil has an A2 horizon and an argillic horizon. The size of the clay bulge (twofold higher than in Pinaleno 67-4) is probably responsible for the higher content of organic carbon because landscape positions do not differ greatly. Silicate clay

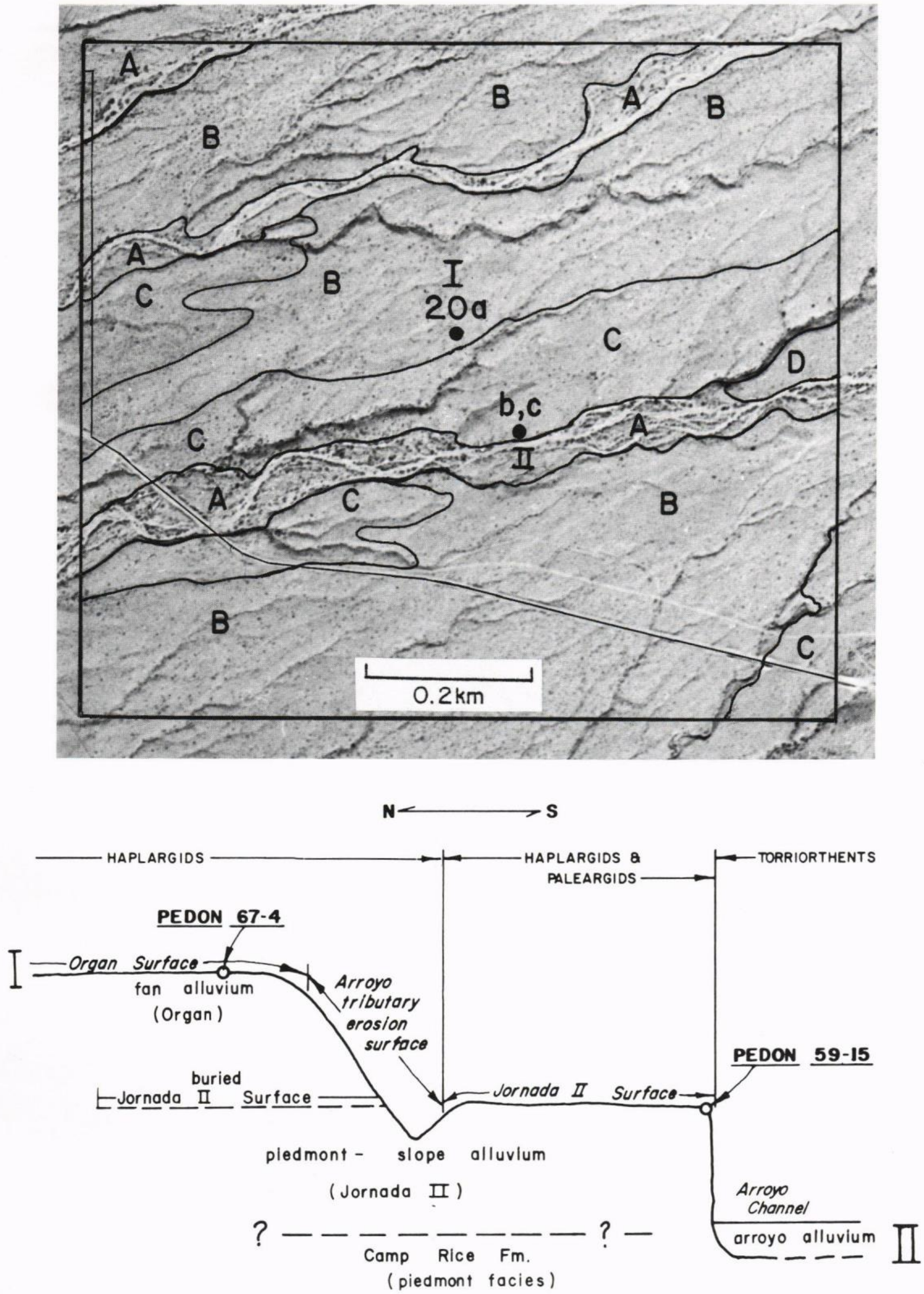


FIGURE 91—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 20. *Upper view:* map of soils; **A**, Arizo-Torriorthent complex (Organ and arroyo-channel surfaces); **B**, Soledad very gravelly sandy loam (Organ surface); **C**, Terino-Nolam complex (Jornada, undifferentiated, surfaces); **D**, Terino, moderately deep variant (Jornada, undifferentiated, surfaces). I–II locates cross section. *Lower view:* diagrammatic section of soils, surfaces, and sediments; I–II on soil map (from Gile, 1977, fig. 3, with permission).

TABLE 76—LABORATORY DATA FOR A TYPIC HAPLARGID AND AN USTOLLIC HAPLARGID; sand, silt, and clay on carbonate-free basis for Caralampi 59-15 only; tr(s), trace $CaCO_3$ detected only by qualitative procedure more sensitive than quantitative procedure used; -(s), none detected by sensitive qualitative tests (6E2; Soil Conservation Service, 1972).

Horizon	Depth	Sand	Silt	Clay	>2 mm Vol.	Carbon-nate	Extrac-table iron	Organic carbon
	cm	%	%	%	%	%	%	%
Typic Haplargid (Soledad 67-4)								
A2	0-5	68	23	8	50	tr(s)	0.9	0.2
B1t	5-18	67	22	11	50	tr(s)	0.9	0.3
B2t	18-30	65	20	15	65	tr(s)	0.9	0.3
B3t	30-51	68	19	13	65	tr(s)	0.8	0.2
C1ca	51-71	72	19	9	65	2	0.7	0.1
C2ca	71-94	75	17	8	65	1	0.7	
C3	94-147	86	11	4		1	0.7	
Btb	147-178	45	21	34		1	1.3	
Composite	0-38		25	14				0.4
Organic carbon, 0.9 kg/sq m to 94 cm								
Ustollic Haplargid (Caralampi 59-15)								
A2	0-6	59	29	12	50	-(s)	0.9	0.4
B21t	6-23	51	23	26	70	-(s)	1.0	0.7
B22t	23-43	55	17	28	70	tr(s)	1.0	0.6
B3ca	43-71	74	13	14	85	4	0.7	0.3
K&C	71-109	71	16	13	55	10	0.7	0.1
Cca	109-145	79	13	8		6	0.6	
Organic carbon, 1.7 kg/sq m to 109 cm								

FIGURE 92—ORGAN SURFACE AND HAPLARGID, AREA 20a. Landscape of a Typic Haplargid, Soledad 67-4, on Organ surface. Vegetation consists of mesquite, Mormon tea, cholla, snakeweed, ratany, scattered clumps of fluffgrass, and a few *Condalia lycioides*. Slope is 4 percent (photographed October 1967; from Gile, 1977, fig. 4, with permission).

and carbonate maxima extend deeper in this soil—a reflection of greater depths of leaching in the Wisconsinan full glacial. Extractable iron does not show an appreciable increase from the A2 to the B2t horizon, despite the large increase in clay percentage. For this pedon and several others in the vicinity, the extractable iron to clay ratio is markedly higher for the A2 horizon.

Carbonate contents are also greater in Caralampi than in Pinaleno (table 76). Caralampi 59-15 lacks a calcic horizon; the 15 percent carbonate required for many calcic horizons (3.1) could be waived for this soil except that the carbonate is not soft and powdery as required in the definition. Laterally the soils do have 15 percent or more carbonate and thus have calcic horizons (Nolam soils); in places they have petrocalcic horizons (Terino soils). The local shifts from stage II to incipient stage IV of carbonate accumulation in the soils of Jornada II seem to be due to local changes in the pattern of moisture penetration. The soils of Jornada **II** formed partly in the Wisconsinan full glacial and here are located in a zone transitional to a more moist environment in the mountains. Thus, episodic deep leaching is likely. Local variations in depth and frequency of deep wetting (due to soil truncation and subtle shifts in gravel content) should be expected.

Another difference between this soil and the Haplargid at area 20a is the overlap here between the carbonate and silicate clay accumulations. The carbonate of Holocene age is emplaced as filaments and coatings in the B3tca horizon, which must have been essentially carbonate-free during the full-glacial interval.

Soil morphology is useful in identifying the age bracket of soils and surfaces where the soil-landscape relations are complex, and relative ages of the various deposits are not clear. Soil morphology is particularly useful in distinguishing between soils of Holocene and Pleistocene age. At area 20a, for example, the Bt horizons of Holocene soils have hues no redder than 5YR and chroma no higher than 4; and the carbonate horizon is stage **I.** In contrast, Bt horizons of soils of late Pleistocene age (area 20b) are usually 2.5YR in part and chromas are commonly 6 or 8. The carbonate horizons range from stage **II** to incipient IV in the soils of late Pleistocene age.

Area 20c—Petrocalcic Ustollic Paleargid (Terino) in Jornada II alluvium

The Terino soil has a very gravelly argillic horizon and a petrocalcic horizon (in places, stage IV) that here ranges from about 25 to 40 cm below the soil surface. This soil and the Ustollic Haplargid, pedon 59-15 (area 20b), illustrate a transition from the Haplargids to the Paleargids. The western edge of this soil starts approximately 4 m east of pedon 59-15 at area 20b. The vegetation and longitudinal slope are about the same. However, the transverse slope, instead of being nearly level, is 3-4 percent to the south; some soil truncation seems to have occurred at this site. Such truncation would increase

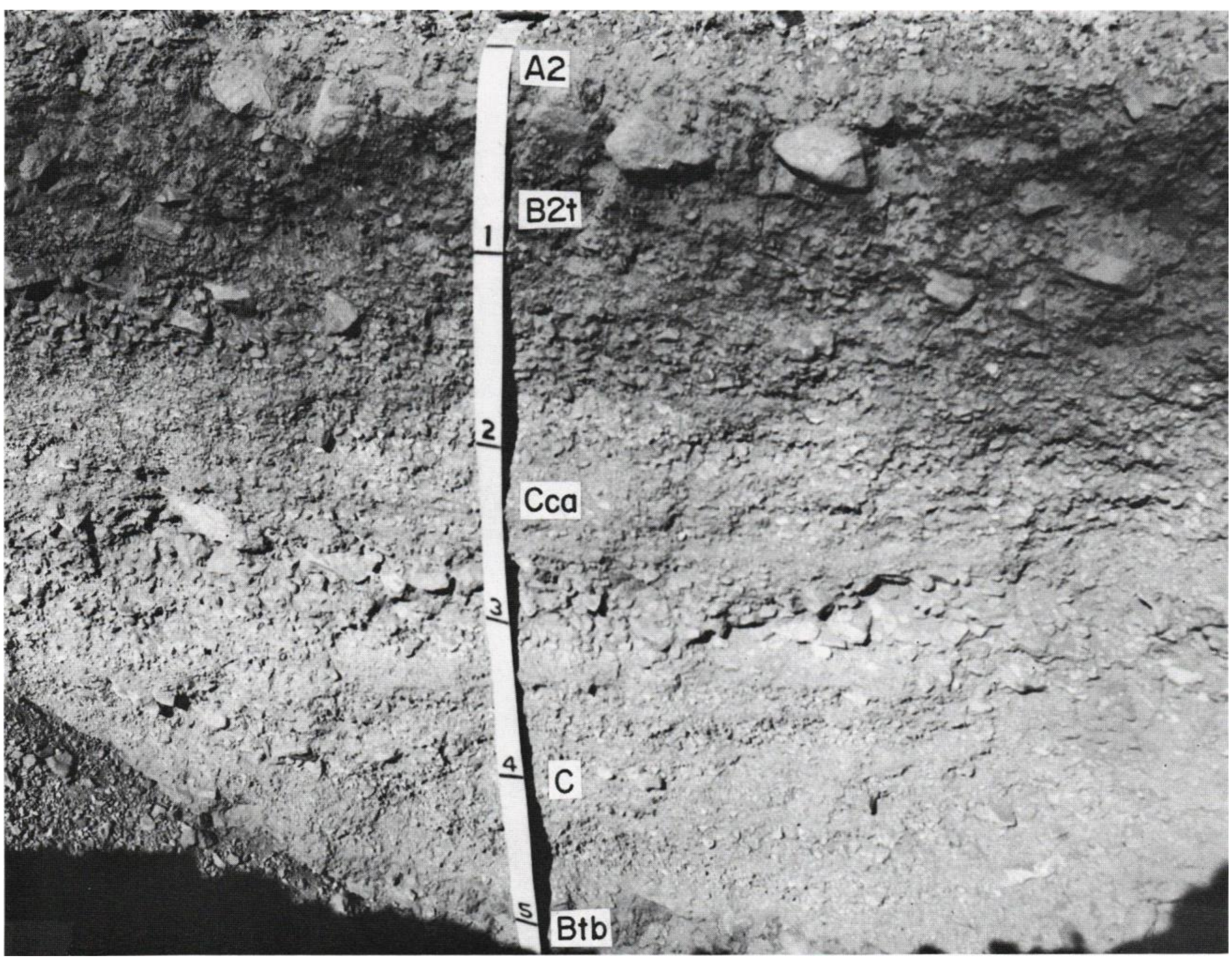


FIGURE 93—HAPLARGID ON ORGAN SURFACE, AREA 20a. Profile of a Typic Haplargid, Soledad 67-4, in Organ sediments; buried soils (Btb) is in Jornada II alluvium (fig. 91). Scale in feet (photographed October 1977; from Gile, 1977, fig. 5, with permission).

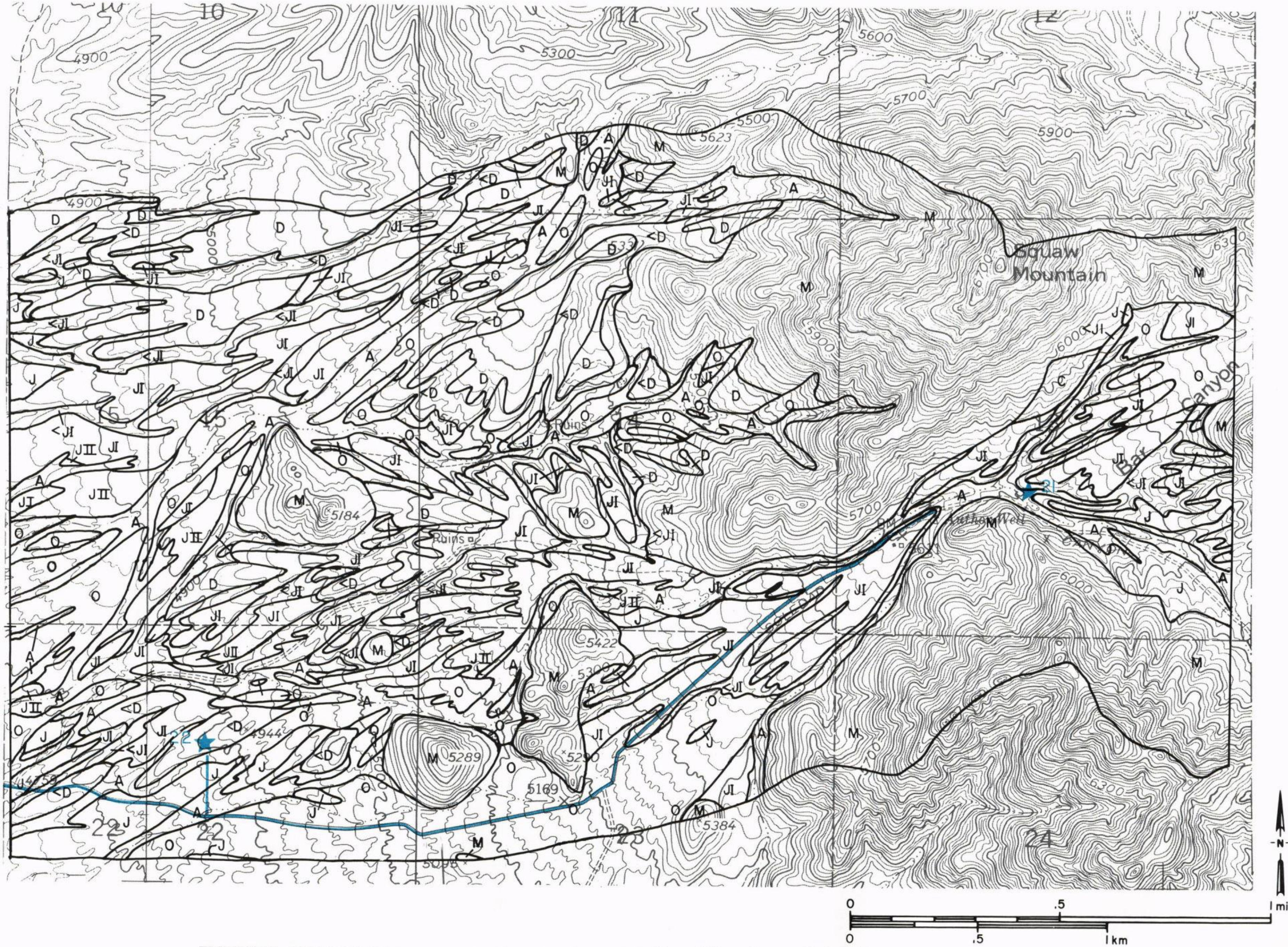


FIGURE 94—GEOMORPHIC SURFACES AND STRATIGRAPHIC UNITS, AREAS 21 AND 22 in and west of Soledad Canyon, south Organ Mountains.

EXPLANATION

A Arroyo surfaces (major channel areas). Associated sediments of Historical age partly fill channels cut into older units; inclusions of Organ morphostratigraphic unit.

O Organ surface (constructional phase). Piedmont-slope analog of the Fillmore surface. Fan and terrace surfaces underlain by gravelly alluvial deposits of the Organ morphostratigraphic unit. Unit locally overlaps older piedmont surfaces or partly fills shallow drainageways cut below such surfaces and contains minor inclusions of arroyo and Isaacks' Ranch alluviums.

JI Jornada I surface (constructional phase). Piedmont-slope complex of middle Pleistocene age graded to ancestral basin-floor levels approximated by the youngest parts of the La Mesa surface. Underlain by gravelly alluvium of the Camp Rice Formation—younger piedmont facies.

<JI Post-Jornada I valley sideslopes. Erosional surfaces of middle to late Quaternary age mainly cut in Camp Rice alluvium

JII Jornada II surface (constructional phase). Piedmont-slope analog of surfaces ranging from Picacho to Tortugas(?) in age. Underlain by gravelly alluvial-fan, coalescent-fan, and terrace deposits of the Jornada II morphostratigraphic unit (late Pleistocene age). Contains minor inclusions of Isaacks' Ranch and Organ units.

J Jornada I and II piedmont-slope surfaces and associated deposits—undifferentiated.

D Doña Ana surface (constructional phase). High-level remnants of ancient fan surfaces, locally preserved in mountain footslope areas, that predate development of the Jornada I surface; probably of early to middle Pleistocene age. Underlain by gravelly alluvium (locally indurated) of the Camp Rice Formation older piedmont facies.

<D Post-Doña Ana valley sideslopes. Erosion surfaces of middle to late Quaternary age cut in Camp Rice alluvium.

C Undifferentiated lower mountain slopes and associated colluvial deposits.

M Organ Mountain slopes. Complex of erosion surfaces and minor slope deposits of middle to late Quaternary age.

NOTE: Lithology of all units reflects the Soledad Rhyolite composition of source watersheds in the Organ Mountains.

runoff and thereby decrease the depth of wetting, leading to increased carbonate accumulation at shallow depths and development of the petrocalcic and stage IV horizons.

10.0 Area 22 to left; continue east towards Soledad Canyon. Small foothills of Soledad Rhyolite (Dunham, 1935; Seager, 1981), here mainly ash-flow tuff, are located to the north and east. 1.0

11.0 Spur of rhyolite hill to left. Crossing apex area of Soledad Canyon fan with longitudinal slopes increasing to 8 percent. The fan has geomorphic-surface components ranging from Jornada I to Organ (fig. 94). 1.0

12.0 Gate. Please do not enter this area without permission of ranch owner. *Proceed past ranch house* into Soledad Canyon. Park vehicles near Author Well windmill and stock tank and walk east about 'A mi to area 21. 0.5

SOIL CHRONOLOGY AND THE MOUNTAIN-FRONT STEPPED SEQUENCE

A stepped sequence of terrace levels is apparent in places along the mountain fronts. The terraces are most prominent downslope from Ice and Soledad Canyons, because their watersheds are large and have high relief. Relative age relations are similar to those along the valley border: the age of stable terraces and their soils increases with increasing elevation of the steps (fig. 94).

Table 77 gives the stages and ages of carbonate accumulation for rhyolite parent materials in the mountain canyons. The chronology of the stages differs from the arid zone down-slope because of greater precipitation.

12.5 STUDY AREA 21

STUDY AREA 21

Haplustolls and Haplargids of the Organ and Jornada I surfaces

SUMMARY OF PEDOGENIC FEATURES (table 74)—Precipitation probably about 35 cm annually; boundary between Ustollic subgroups of Aridisols and the Mollisols; Holocene Haplustoll lacks a carbonate horizon, but sensitive analyses reveal very small amounts of carbonate throughout; Ustollic Haplargid has chroma too high for mollic epipedon, a stage I carbonate horizon that contrasts with stage IV horizon in soils of the same age in the arid zone and discontinuous black coatings on peds and pebbles in the Bt horizon.

SETTING—This study area is located in a small open basin just above the bedrock constriction that forms the mouth of Soledad Canyon, one of the major canyons in the Organ Mountains (fig. 94). Precipitation at Boyd's Ranch in Ice Canyon (1.5 mi to the north) is nearly twice that of desert areas between the mountains (1.2) and is thought to be about 35 cm annually here.

TABLE 77—STAGES OF CARBONATE ACCUMULATION FOR SOILS OF A STEPPED SEQUENCE IN THE MOUNTAIN CANYONS (rhyolite parent materials).

Stage (gravelly sequence)	Youngest geomorphic surface on which stage of horizon occurs and age	
0 or I	Organ	Holocene
I	Jornada II	Late Pleistocene
I	Jornada I	Late middle Pleistocene
III, IV	Doña Ana	Middle Pleistocene

High-level, Jornada I terrace remnants occur as constructional surfaces on upper Camp Rice Formation basin fill in parts of the area. Near the canyon mouth, Santa Fe Group deposits extend to a depth of about 65 ft (20 m) below the arroyo floor or about 100 ft (30 m) below the reconstructed Jornada I surface. To the west these deposits merge with older fan materials of the Soledad Canyon fan. Only the lowermost part (probably less than 10 ft, 3 m) of these sediments is presently saturated with ground water.

The older basin fill has been partly removed during Jornada II and younger episodes of mountain-valley incision. Thin bodies of Jornada II, Organ, and arroyo alluvium are recognized in the younger valley-fill sequence, and the constructional surfaces of the former two units are locally preserved above arroyo channel floors (figs. 7, 94). Soil-geomorphic relationships of the Organ and Jornada II surfaces will be examined in this study area.

SOIL OCCURRENCE—The soil pattern (fig. 95) is determined by differences in soil age and truncation. Pachic Haplustolls (Santo Tomas soils) and Torriorthentic Haplustolls (a Torriorthentic variant of Santo Tomas) are dominant on the terraces of the Organ surface; Ustollic Haplargids (Caralampi soils) are dominant on high-level remnants of the Jornada **I** surface. Aridic Argiustolls (Earp, light subsoil variant) occur on the Organ surface in a few places. Torriorthents occur in arroyo channels.

The mapping unit, Caralampi very gravelly sandy loam (fig. 95), illustrates a unit that is not a soil complex. Nearly all its soils are in one soil series, Caralampi, because: 1) soil erosion has mostly involved the A horizon so that most soils have thick Bt horizons; 2) essentially all soils are in the same particle-size class (loamy-skeletal) due to the very gravelly alluvium and similar textures of the B horizon; and 3) soils of this age and location lack a calcic or petrocalcic horizon within a depth of a meter, thus are not placed in another class owing to the presence of these diagnostic horizons in some places but not in others.

Area 21a—Pachic Haplustoll (Santo Tomas 60-12) in Organ alluvium

The Organ surface here occurs as a terrace inset against the higher Jornada I and II surfaces. Vegetation is snakeweed, squawbush, cholla, fluffgrass, with scattered clumps of black grama and blue grama. Slope is 7 percent.

The A horizon of Santo Tomas 60-12 (fig. 96) is dark, thick, and meets the requirements for a mollic epipedon (table 78). Thickness of the A horizon seems to be due mainly to sedimentation during soil development or deep wetting of pervious sediments (area 11 b). The soil is noncalcareous, but sensitive analyses reveal very small amounts of carbonate (table 77). This soil is about the same age as the Entisols at area 1, and these morphological differences (thick, dark A horizon; high organic carbon; and lack of carbonate horizon) are attributed to greater precipitation in this area. Santo Tomas 60-12 has no stage I carbonate horizon but finer-textured soils of Organ age do.

Area 21b—Ustollic Haplargid (Caralampi) in Jornada alluvium

This high remnant is the Jornada **I** surface, in places deeply dissected by arroyos. However, the areas between arroyos appear quite stable, with only a few slight drainageways. Vegetation is snakeweed, black grama, blue grama, *Yucca baccata,* and catclaw. Slope is 8 percent.

The Bt horizon is thick and the horizon of carbonate accumulation is stage I. Laboratory data for a similar soil are presented in table 78. Organic carbon is high (table 78), and the soil is well within the Ustollic subgroup of Haplargids.

Note the high chroma of upper horizons that precludes a mollic epipedon since moist chromas must be less than 3.5. The high chromas are probably due to soil truncation (as indicated by very slight drainageways across the remnant), which has brought high-chroma Bt horizons very near the surface. In contrast, the soils of the Organ surface are much younger, have undergone much less erosion, and their A horizons are generally preserved (recall the thick dark A horizon of Santo Tomas 60-12). Soils illustrating these relations—the mollic epipedon preserved on stablest sites but truncated in less stable areas—occur extensively along the mountain fronts here and elsewhere in the Southwest.

Note the prominent coatings of clay on the sand grains and pebbles in the Bt horizon and the discontinuous black (Fe? Mn?) coatings in the lower part of the Bt horizon. In land-surface soils of the same age in the arid zone, black coatings in a similar position would be masked by prominent carbonate accumulations.

Soils of these mountain canyons illustrate the effect of greater precipitation on development of the stages of carbonate accumulation. As illustrated by this soil, the soils of Jornada I—which have thick stage IV carbonate horizons in very gravelly materials of the valley border—have only stage I horizons here. This carbonate is thought to be of Holocene age because it is morphologically similar and occurs in similar textures and at similar depths as the carbonate of Holocene soils. Most or all carbonate leached in Pleistocene pluvials must have moved out of the soils of Jornada I and II because they lack the prominent accumulations in soils of the same age downslope. However, the morphogenetic sequence (in gravelly materials) is completed in ancient soils of the Doña Ana surface (table 78, pedon 60-5). A much longer time is required for completion of the carbonate sequence in the mountain canyons than along the Rio Grande valley because of greater precipitation in the mountains.

En route to area 22. *Retrace route* on Soledad Canyon road. **2.0**

14.5 *Turn right* on subdivision road; park vehicles about 0.2 mi to the north at base of ridge (fig. 94). **0.2**

14.7 STUDY AREA 22

STUDY AREA 22

Paleorthids and Calciustolls of Jornada sideslopes of Doña Ana remnants

SUMMARY OF PEDOGENIC FEATURES (table 74)—Effect of aspect on soils and vegetation; Ustollic Paleorthid on south-facing slope has epipedon very nearly dark enough for mollic; Petrocalcic Calciustoll on north-facing slope.

SETTING—From this vantage point the regional geomorphic setting can be observed and reviewed. To the west and south are the broad plains of the Mesilla Bolson, flanked on the east by the southern Organ-Franklin-Juarez Mountain chain and on the west by the Potrillo Mountains and Aden-Rough and Ready Hills. The Mesilla Valley of the Rio Grande cuts through the east part of the bolson. A large area (more than 700 sq mi, 1,800 sq km) of the ancient floor of this bolson, the La Mesa geomorphic surface, is preserved west of the valley. La Mesa is a remnant of an ancestral Rio Grande plain that was graded to basin areas of northern Chihuahua in early to

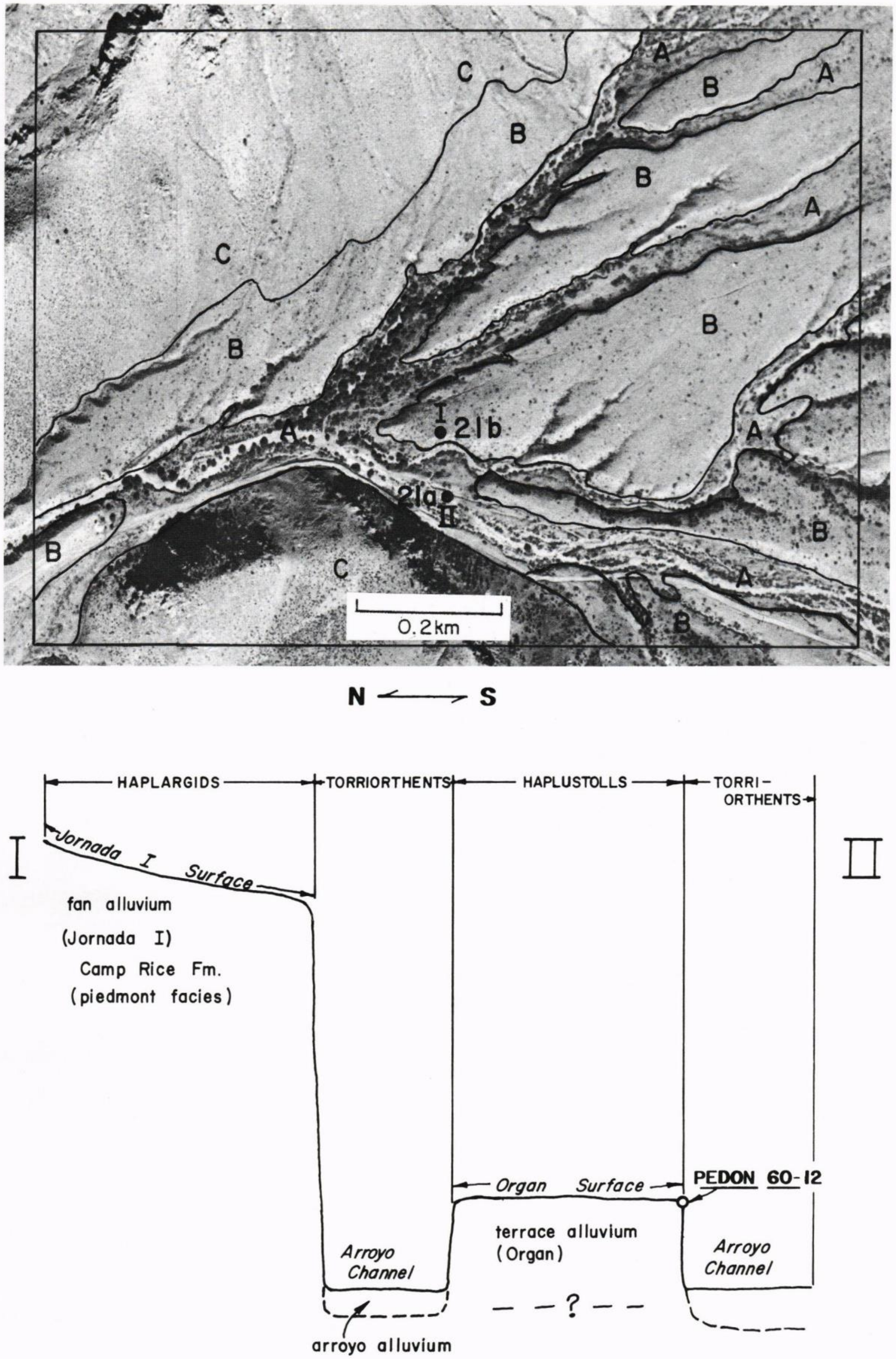


FIGURE 95—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 21. *Upper view:* map of soils; **A,** Santo Tomas-Torriorthent complex (Organ and arroyo-channel surfaces); **B,** Caralampi very gravelly sandy loam (Jornada I surface); C, Haplargids, Argiustolls, and rock outcrop (mountain slopes and summits, undifferentiated). I-II locates cross section (from Gile, 1977, fig. 6, with permission). *Lower view:* diagrammatic section of soils, surfaces, and sediments; **I-II** on soil map (from Gile, 1977, fig. 7, with permission).

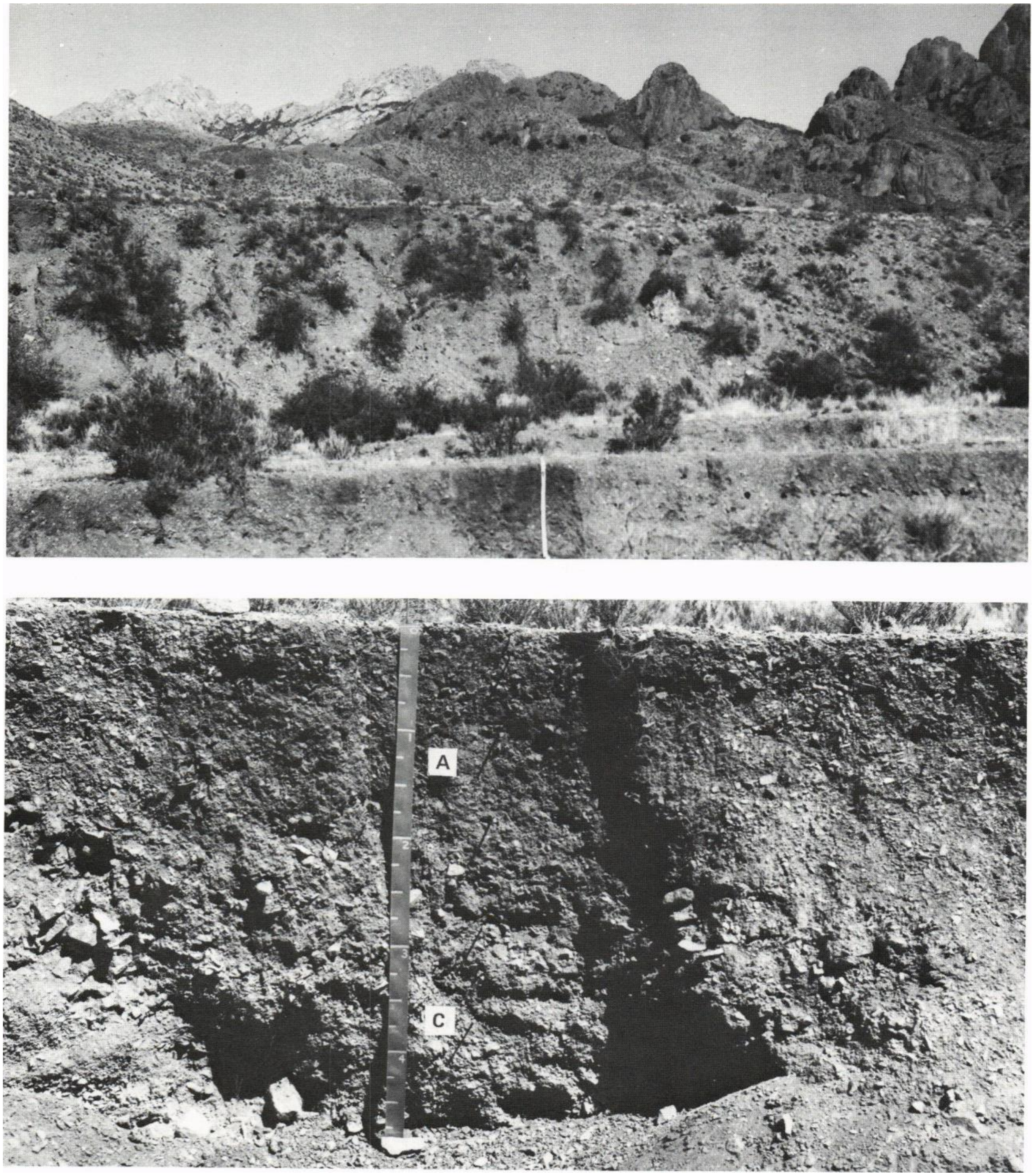


FIGURE 96—ORGAN SURFACE AND HAPLUSTOLL, AREA 21a. *Upper view:* landscape of a Pachic Haplustoll, Santo Tomas 60-12. Organ terrace in foreground; Jornada I remnant and area 21b on the next level, in middle ground; Organ Mountains on skyline. *Lower view:* Santo Tomas 60-12 in Organ alluvium. Scale in feet (photographed April 1960; from Gile, 1977, fig. 8, with permission).

middle Pleistocene time. To the north is the Jornada del Muerto Basin, another large bolson flanked at its southern end by the Doña Ana Mountains on the west and the southern San Andres-San Agustin-northern Organ Mountain chain on the east.

The terrain in this area is typical of many upper piedmont slopes in the Basin and Range province (fig. 94). Landscape dissection is more prominent than at area 20 to the west (fig. 88). Remnants of ancient alluvial fan deposits and surfaces form the uppermost level of a stepped sequence of surfaces, with progressively younger units being associated with the successively lower valley surfaces (fig. 7). In order of increasing age and elevation, major geomorphic surfaces in this area include arroyo channel, Organ, Isaacks' Ranch, Jornada II, Jornada I, and Doña Ma surfaces. The latter is the oldest piedmont-slope remnant in the Desert Project area and is probably a general age equivalent of the La Mesa surface complex (study areas 5 and 6). Profiles of the various surfaces converge to the west, incision of older alluvial fills dies out, and younger morphostratigraphic units (such as Organ) spread out to form thin aprons of fan deposits on older surfaces. Jornada I and younger episodes of erosion have cut into the Camp Rice fan alluvium (Qcrc, fig. 7) associated with the Doña Ma surface; and only a few narrow, ridge-summit

TABLE 78—LABORATORY DATA FOR SOILS OF A STEPPED SEQUENCE IN THE MOUNTAIN CANYONS; sand, silt, and clay on a carbonate-free basis; tr(s), trace CaCO, detected only by qualitative procedure more sensitive than quantitative procedure used; -(s), none detected by sensitive qualitative tests (6E2; Soil Conservation Service, 1972).

Horizon	Depth	Sand	Silt	Clay	>2 mm vol.	Carbonate	Organic carbon
	cm	%	%	%	%	%	%
Pachic Haplustoll (Santo Tomas 60-12)							
C	0-3	66	26	8	40	tr(s)	1.00
A11	3-8	59	30	12	50	tr(s)	1.32
A12	8-28	59	29	12	50	tr(s)	1.18
A13	28-53	61	27	13	45	tr(s)	0.81
A3	53-79	60	28	12	45	tr(s)	0.47
C	79-104	64	25	11	50	tr	0.30
Organic carbon, 4.6 kg/sq m to 104 cm							
Ustollic Haplargid (Caralampi 59-14)							
A	0-5	59	28	13	50	tr(s)	0.76
A1	5-20	51	30	19	60	-(s)	0.83
B1t	20-46	38	29	33	80	tr	0.88
B21t	46-76	48	22	31	60	tr	0.36
B22tca	76-97	46	29	25	60	tr	0.31
B3tca	97-147	52	28	20		1	0.11
Cca	147-173	62	23	15		1	0.10
Organic carbon, 2.6 kg/sq m to 97 cm							
Petrocalcic Ustollic Paleargid (Terino variant 60-5)							
A1	0-8	61	25	14	45	-	0.88
B1t	8-20	49	28	23	60	-	1.16
A2	20-23	51	34	15	50	-	0.70
B21t	23-38	21	16	63	25	-	0.87
B22tcs	38-58	18	8	74	35	1	
K1*	58-64	28	12	60	20	60	0.40
K1†	58-64	34	9	57	5	87	0.27
K21m**	64-71	40	18	42	5	88	0.21
K21m††	64-71	52	11	37	5	90	0.20
K22m	71-86	61	12	27	45	62	0.05
K31	86-114	63	13	23	45	39	
K32	114-142	45	31	23	55	39	
K&Cca	142-168+	74	15	12	55	17	

* Non-indurated
† Indurated plates
** Laminar
†† Plugged

remnants are preserved in this area. The two sites visited in the study area are on ridge sideslopes that are younger than Data Ana and are thought to be of Jornada **I** age.

SOIL OCCURRENCE—The soil pattern (fig. 97) is determined by differences in soil age, degree of truncation, and aspect. The soil patterns in this vicinity are some of the most complex in the project area (refer to Gile and Grossman, 1979, for more detailed discussion). Torriorthents occur in the arroyo channels; Torriorthents (Arizo soils) dominate the low Organ terraces above the channels. Typic Haplargids (Soledad soils) of the Organ surface are slightly higher than the youngest Organ terraces. Ustollic Haplargids (Caralampi soils) of the Jornada II surface occur at approximately the same elevation. Petrocalcic Ustollic Paleargids (Terino soils, moderately deep variant) of the Jornada **I** surface occur on the higher fan remnants that are level or nearly level transversely. Petrocalcic Ustollic Paleargids (Terino and Casito soils) occur on the Jornada I surface where it is less stable; truncation has brought the petrocalcic horizon to within 50 cm, the lower limit of shallow families. Ustollic Paleorthids (Monterosa soils) occur only on south-facing ridge sides of Dona Ana and Jornada I. Petrocalcic Calciustolls (Boracho soils) dominate the north-facing sides of the ridges. Argids occur on some of the stablest spots downslope from ridge crests but do not occur on narrow ridge crests because of strong truncation. Small areas of Torriorthents and Haplustolls occur on lowest parts of ridge sides and bordering small arroyos between the ridges.

Area 22a—Ustollic Paleorthid (Monterosa) in Jornada colluvium and older alluvium beneath

Ustollic Paleorthids (Monterosa soils) are one of the most common soils on south-facing ridge sides, such as at this stop (fig. 98). Slope at the site to be examined is about 15 percent. There are scattered rills and small gullies. Vegetation is mainly creosotebush with a few ratany and clumps of fluffgrass.

The upper 18 cm contains enough organic carbon for a mollic epipedon (table 79). However, the upper 18 cm when mixed is not quite dark enough (7.5YR, 3.5/3 moist) and the soil is therefore an Ustollic Paleorthid. (The Japanese color book was used to make the determination because the chips needed are not available in the Munsell color charts.) This color contrasts with that of the Calciustolls on the north-facing side of

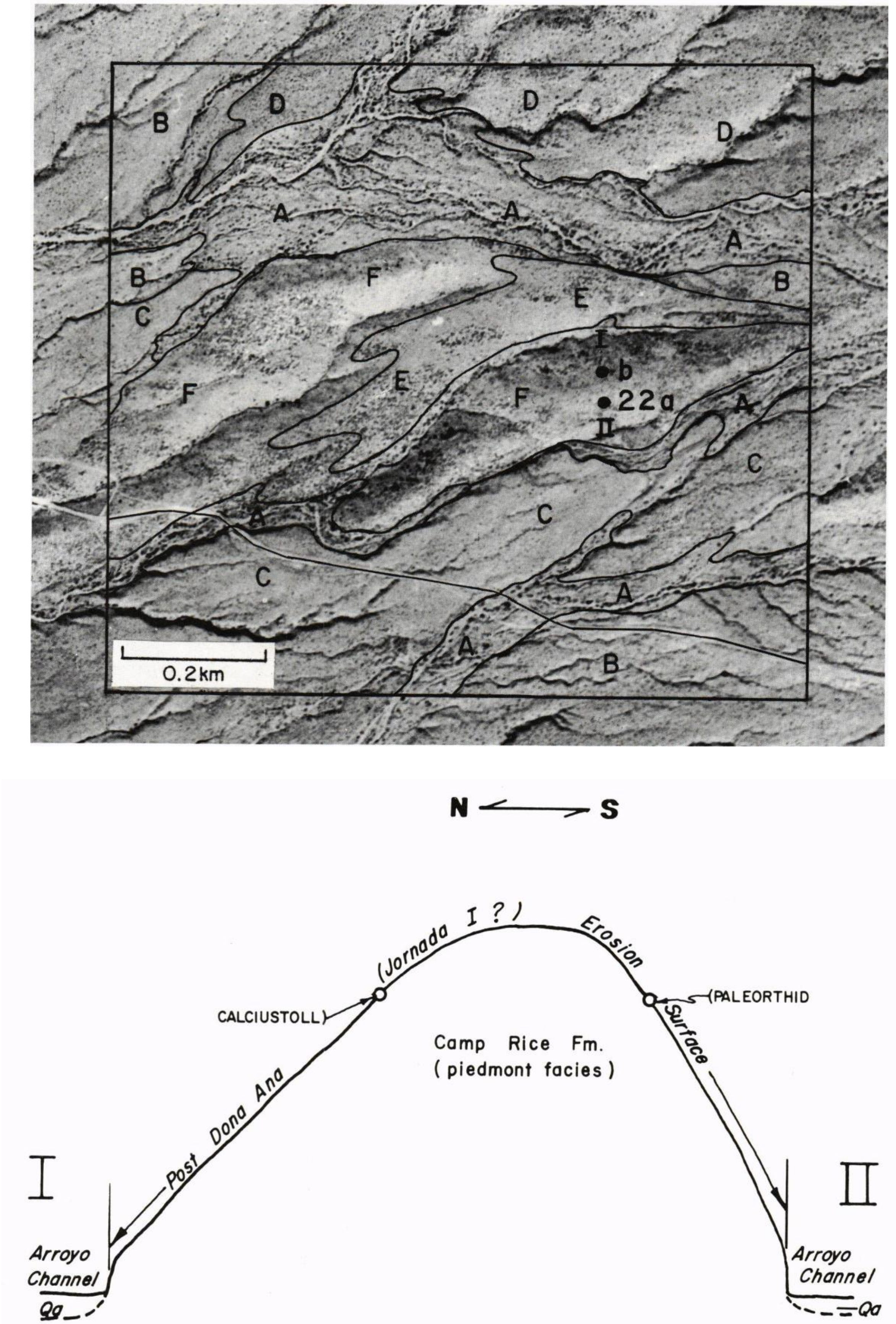


FIGURE 97—MAP AND CROSS SECTION OF SOILS IN VICINITY OF AREA 22. *Upper view:* map of soils; **A,** Arizo-Torriorthent complex (Organ and arroyo-channel surfaces); **B,** Soledad very gravelly sandy loam (Organ surface); C, Caralampi complex (Jornada, undifferentiated, surfaces); **D,** Terino, moderately deep variant (Jornada I surface); **E,** Terino complex (Jornada I surface); **F,** Monterosa-Boracho complex (Doña Ana and younger surfaces). I-II locates cross section. *Lower view:* diagrammatic section of soils, surfaces, and sediments (I-II on soil map).

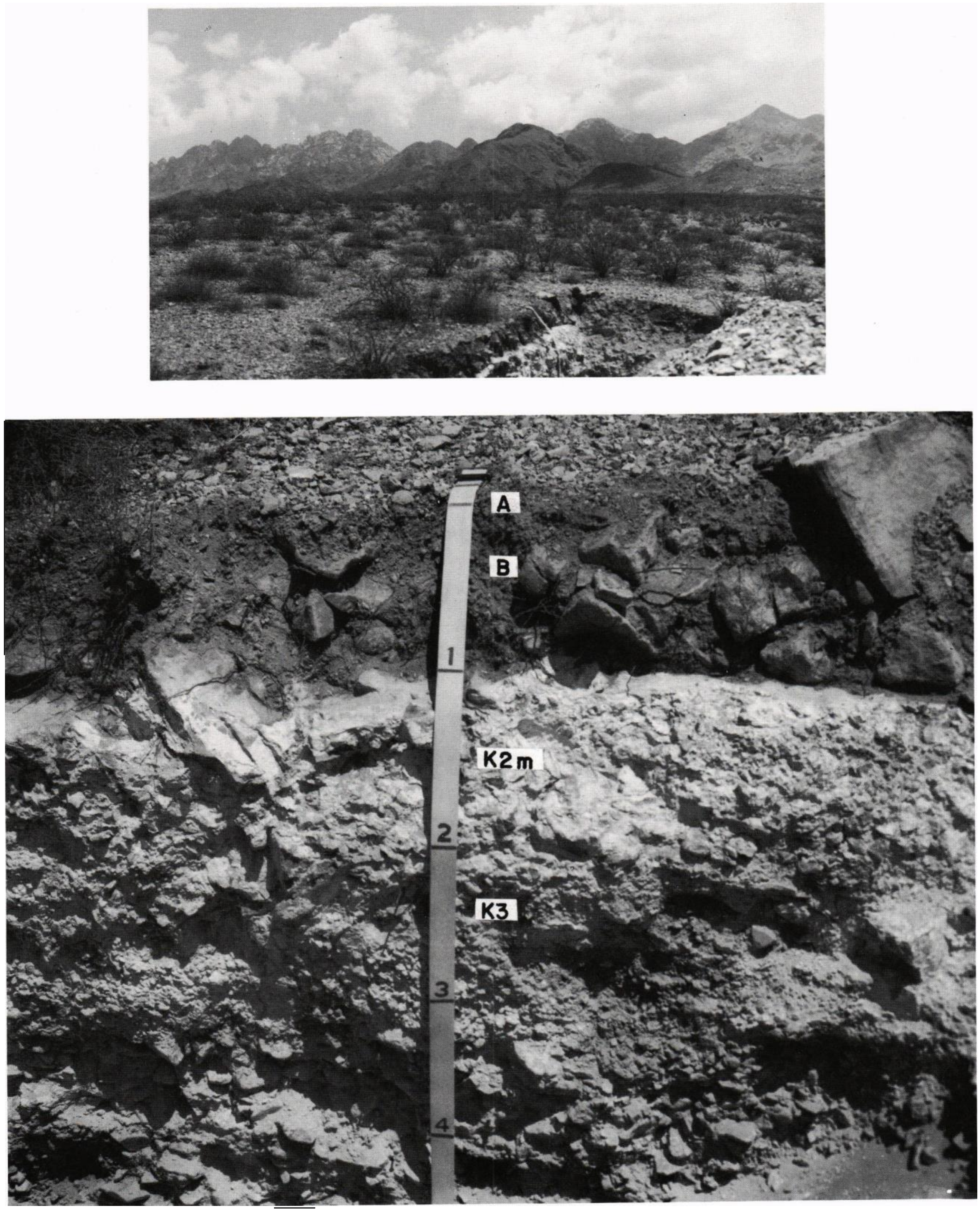


FIGURE 98—JORNADA I EROSION SURFACE AND USTOLLIC PALEORTHID, AREA 22a. *Upper view:* landscape of an Ustollic Paleorthid, Monterosa, on ridge sideslope cut in Camp Rice piedmont facies (Qcrc, fig. 7); Organ Mountains on skyline. *Lower view:* profile of Monterosa in Camp Rice fan gravel. Upper horizons are almost dark enough for a mollic epipedon. Scale in feet (photographed July 1971).

TABLE 79—ORGANIC CARBON AND PARTICLE-SIZE DISTRIBUTION FOR AN USTOLLIC PALEORTHID ON A SOUTH-FACING SLOPE AND A PETROCALCIC CALCIUSTOLL ON A NORTH-FACING SLOPE.

Depth	Sand	Silt	Clay	>2 mm vol.	Organic carbon
cm	%	%	%	%	%
Ustollic Paleorthid (Monterosa) on south-facing slope					
0–18	55	31	14	60	0.72
Petrocalcic Calciustoll (Boracho) on north-facing slope					
0–18	47	35	18	40	0.86

this high, narrow ridge (area 22b). In some areas, however—particularly eastward at higher elevations—upper horizons of south-facing slopes are dark enough for a mollic epipedon.

Area 22b—Petrocalcic Calciustoll (Boracho) in Jornada colluvium and older underlying alluvium

There are common rills, a few centimeters deep, but between these rills the surface is quite stable. Slope is about 15 percent at the site to be examined. Vegetation consists of creosotebush, *Yucca baccata,* ratany, prickly pear, and scattered clumps of three-awn.

This soil is a Petrocalcic Calciustoll. Enough organic carbon occurs in the upper 18 cm for a mollic epipedon (table 79), and the epipedon is dark enough (7.5YR, 3/3 moist). Similar relationships also occur on other narrow, high east-west ridges of this character. Soil aspects and associated differences in soil temperature and evaporation apparently contribute to the pedologic and vegetative differences.

Although argillic horizons were not observed here, soils on ridges of older surfaces (Doña Ana and Jornada) along the mountain fronts illustrate the transition from soils with argillic horizons (Argids or Paleustolls) on stable sites to soils without them (mostly Calciustolls) in dissected areas. Thus landscape dissection can obliterate the argillic horizon in the semiarid zone as well as in the arid zone (see discussion stop earlier today). However, the shift is commonly to the Mollisols instead of to the Orthids as is the case in the arid zone at lower elevations.

End of field-study sessions; *return to Las Cruces.*

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