Supplement to the Desert Project Guidebook, with Emphasis on Soil Micromorphology

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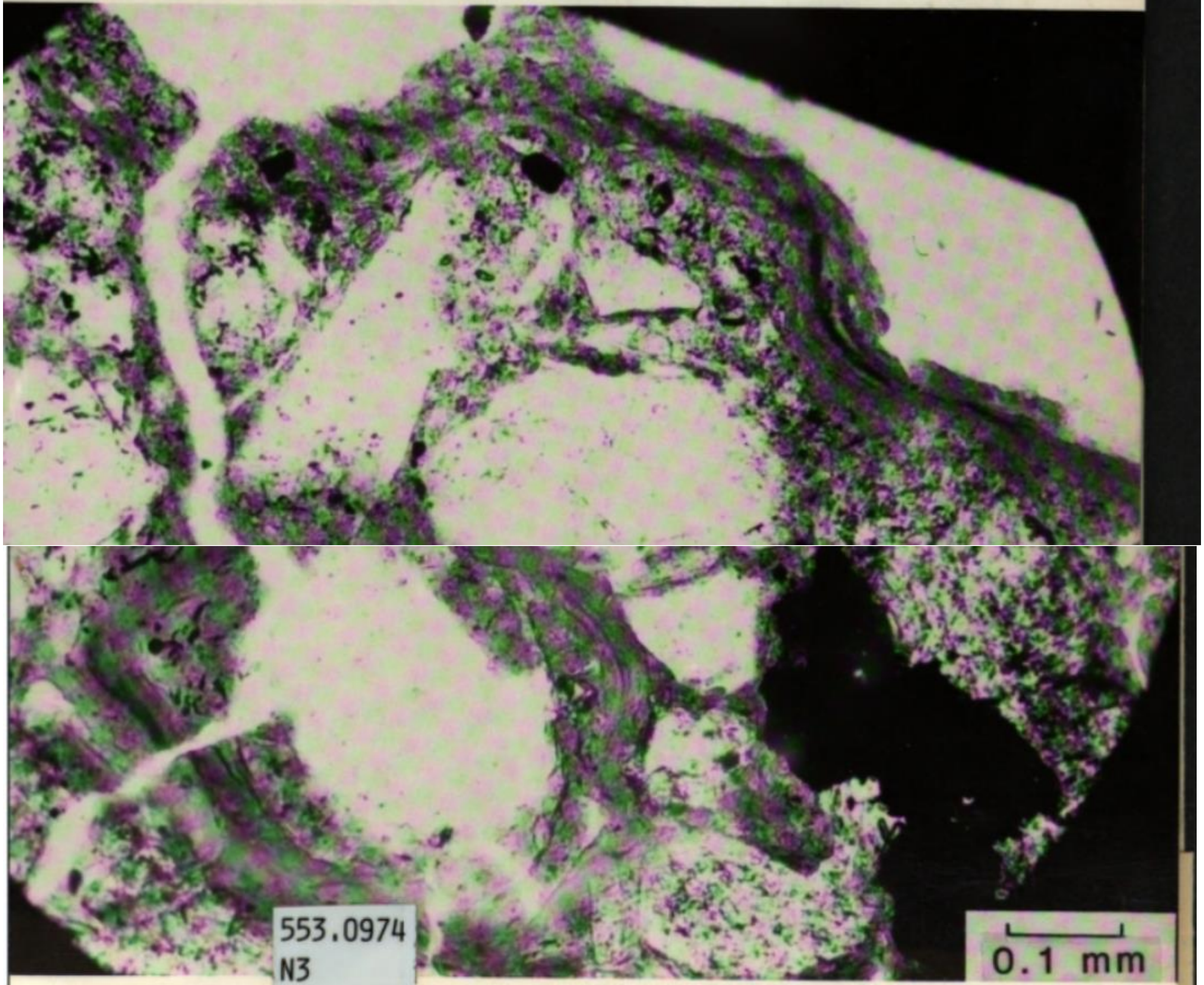

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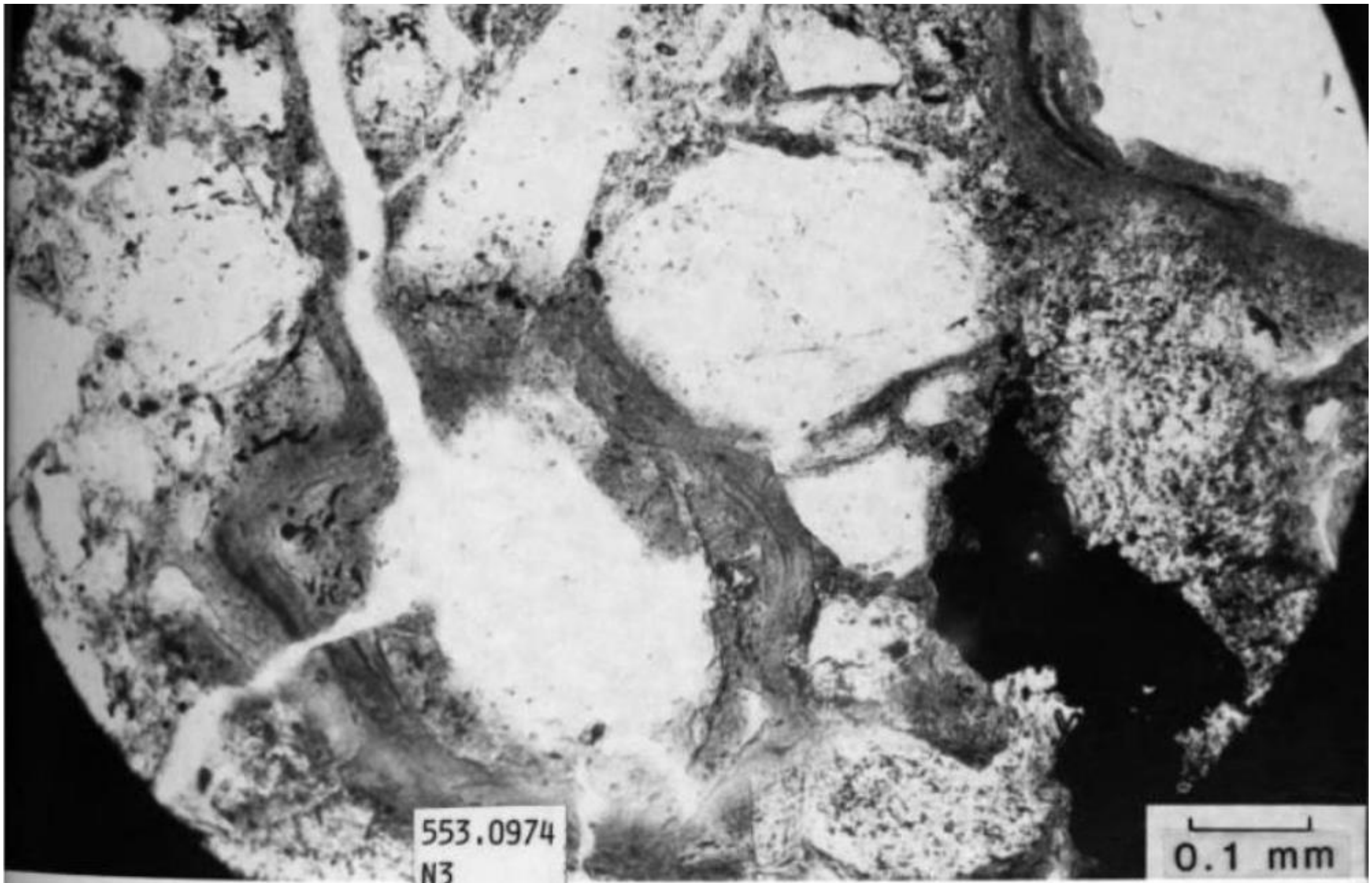

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Supplement to the Desert Project Guidebook, with emphasis on soil micromorphology

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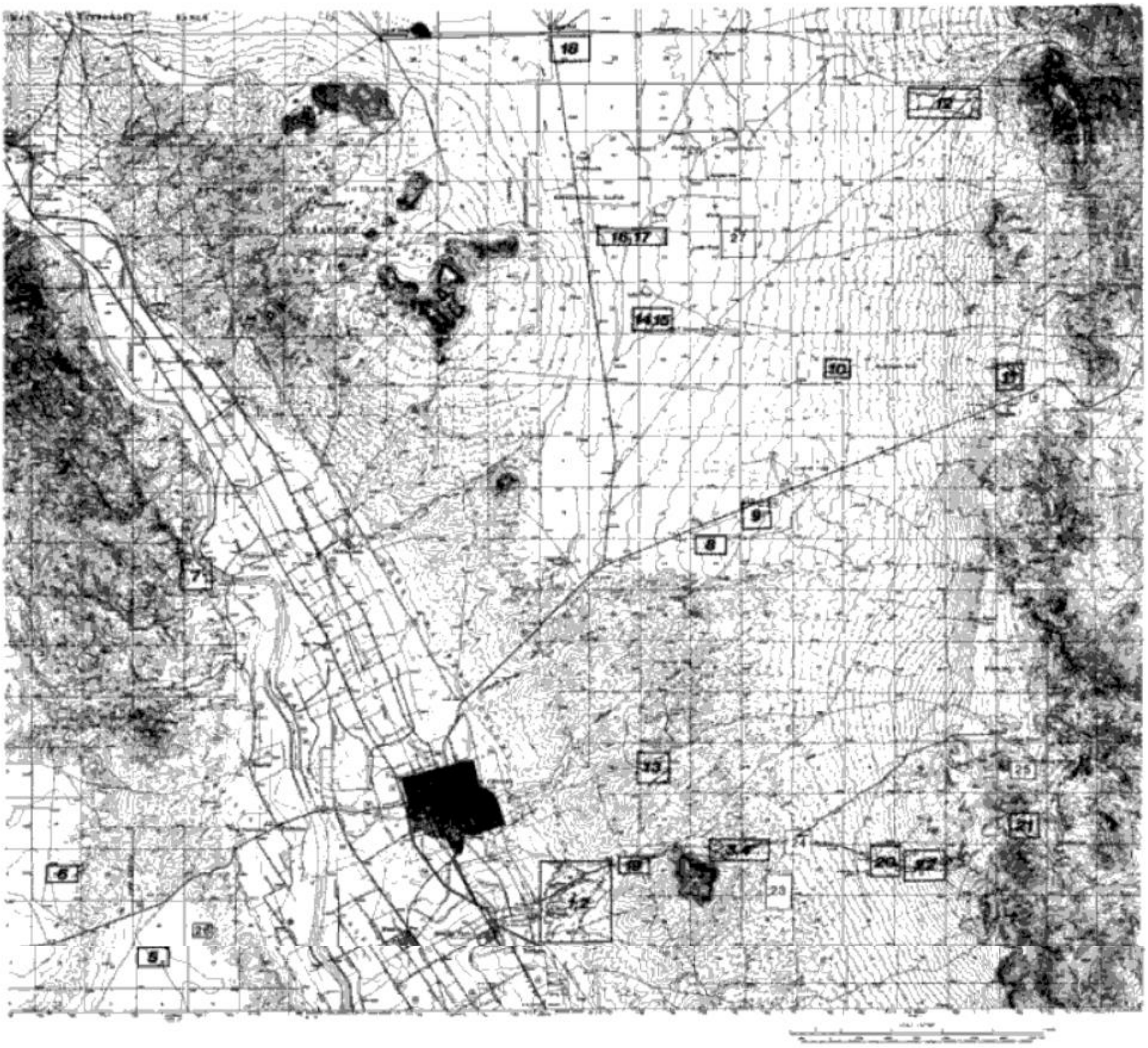

FRONTISPIECE—The Desert Project area, showing selected study areas that are near roads to expedite access. Areas 1–22 were presented in the Desert Project Guidebook; additional information for most of them is in this Supplement. New study areas 23–27 (this Supplement) are outlined with thinner lines and numbers to distinguish them from areas 1–22.

Abstract

This Supplement to the Desert Project Guidebook presents new study areas 23–27, and additional information for other study areas and thin section studies. New study area 23 is near pipeline and power line roads that cross terraces and soils ranging in age from late Holocene to late middle Pleistocene. In area 23, morphology of the laminar, plugged, and adjacent horizons of an Argic Petrocalcid was related to the radiocarbon chronology of their carbonate. This pedon was the first so studied in the Desert Project and the first to be reported in the world literature on genesis of carbonate horizons.

Study area 24 illustrates a complex of Typic Haplocalcids and Argic Petrocalcids on a dissected landscape with ridge remnants of late middle Pleistocene age and the transition to a broad stable landscape of the same age dominated by Argic Petrocalcids. Area 24 illustrates a facies change from low-gravel to high-gravel materials and profound changes in carbonate morphology (stage III to IV) and soil classification (Typic Haplocalcid to Typic Petrocalcid) that accompany the facies change. Thin sections show evidence of dissolution of primary grains in the calcic horizon of the Haplocalcid.

Study area 25, in Ice Canyon of the Organ Mountains, illustrates a bedrock-defended ancient fan and an Argic Ustic Petrocalcid dating from middle to early Pleistocene. This soil has a red, clay Bt horizon with a subhorizon that has more than 70% clay, and illustrates stage IV of carbonate accumulation in soils of the mountain canyons. Thin sections show argillans on sand grains but not on ped faces. Prominent striae of oriented clay occur within peds and may represent former argillans.

Study area 26 is along and near the scarp of a middle Pleistocene relict basin floor that borders the Rio Grande valley. At area 26, the deep petrocalcic horizon of a Typic Petroargid illustrates stage IV of carbonate accumulation in low-gravel materials. Thin sections show evidence of dissolution of primary grains in the petrocalcic horizon and accumulation of silica below it. Electron microscopy, soil column and culture studies indicate that soil microorganisms are involved in precipitation of fine-grained calcite in horizons of carbonate accumulation. Microscopic and chemical evidence indicates that palygorskite was neoformed in the petrocalcic horizon.

Study area 27 is in a distinctive scarplet terrain in which the scarplets cut fan-piedmont sediments derived largely from sedimentary rocks such as limestone. The scarplets expose a Holocene Haplocalcid and the Bt horizon of an underlying Calciargid of late Pleistocene age. An argillic horizon has not formed in high-carbonate parent materials of late or middle Holocene age, but has formed in the underlying soil of late Pleistocene age. This suggests that moister climates of Pleistocene pluvials may have been involved in leaching the bulk of the carbonates so that the argillic horizon could form. Thin sections of the buried argillic horizon show both prominent argillans and some limestone grains. This shows that not all of the primary carbonate must be leached from the parent materials for an argillic horizon to form. Argillans were not found on limestone grains.

Photomicrographs illustrate illuvial clay and carbonate in soils that range in age from late Holocene to middle to early Pleistocene. Coatings of oriented clay on sand grains and pebbles (grain argillans) are characteristic of the Bt horizons. Grain argillans of many Bt horizons have been partly to completely obliterated by carbonate. Calcified root hairs, calcite filaments, and framework grain coatings (calcitans) are the youngest forms of carbonate accumulation. They are currently forming and are the major morphological expression of carbonate in late Holocene soils. Progressively older carbonate forms increase in density and hardness with increasing carbonate content. Thin sections show evidence of dissolution of primary grains in soils of late middle Pleistocene age and older.

Introduction

When the Desert Project began in August, 1957, one of the problems for study concerned the origin of horizons of silicate clay accumulation. At the time, the prevailing opinion was that horizons of clay accumulation in desert soils formed by weathering in place; desert soils "are not subject to leaching and do not develop either eluvial or illuvial horizons" (Nikiforoff, 1937, p. 124). This view was still common well into the 1960s when a joint 1964 publication of Agricultural Experiment Stations and the Soil Conservation Service had this statement about desert soils (1964, p. 13): "Generally, the quantity of moisture is insufficient to illuviate clay; and Bt horizons when present are due largely to weathering in place."

Thin section studies are one way of learning more about the origin of these horizons. In August, 1960, a visit by Dr. Roy Brewer provided an additional stimulus for thin section work. During the visit we showed Dr. Brewer several reddish-brown and red B horizons with ped faces that had smooth, reflective surfaces suggestive of clay skins (now commonly termed argillans, Brewer, 1964; Bullock et al., 1985). At each site, when questioned about the possibility of clay skins, Dr. Brewer's answer was the same: "I should like to see this in thin section."

Thin sections showed that nearly all ped surfaces and pores lacked clay skins in the arid part of the study area, pipes being the only exception (see cover). Instead, coatings of oriented clay on sand grains and pebbles were found to be characteristic of the Bt horizons. Field studies, laboratory analyses and thin sections all indicate that the red to brown horizons of silicate clay accumulation in the Desert Project area contain illuvial clay. A summary of Bt horizons and evidence for illuviation is presented in the Guidebook (pp. 71–75).

Laboratory analyses for study areas 4a, 11c, and 26 were done by Curtis Monger, except for organic carbon at area 11c, which was done by the Soil, Water, and Plant Testing Laboratory at New Mexico State University. All other laboratory analyses were made by the National Soil Survey Laboratory at Lincoln, Nebraska. Thin sections illustrated at sites 8, 16, 17, 19, 20, and 25 were made using the method of Gile (1967). The other thin sections were prepared with clear epoxy as the impregnating medium. The photomicrograph on the cover was taken in 1965 by Gile with an American Optical microscope and a Crown Graphic camera. Photomicrographs for the plates were taken in 1989 by Monger with a Nikon microscope and Minolta 35mm camera.

Horizon terminology

Some of the data and description sheets used in this Supplement are from the Desert Project Soil Monograph (Gile and Grossman, 1979). Since the Monograph was published, changes have been made (Soil Survey Division Staff, 1993) in the long-standing horizon designations used in the 1951 Soil Survey Manual (Soil Survey Staff, 1951) and its 1962 Supplement. Table 1 gives approximate equivalents of horizon designations used in the Monograph and in the revised Soil Survey Manual (Soil Survey Division Staff, 1993). However, the K horizon nomenclature (Gile et al., 1965) continues to be used in Desert Project and other publications because, as noted by Birkeland (1984), "most pedologists and geologists working in arid lands find it a very useful term."

Soil taxonomy

Major changes have been made in classification of the Aridisols (Soil Survey Staff, 1994), which formerly consisted of two suborders, Orthids and Argids. Now there are seven suborders—Cryids, Salids, Durids, Gypsids, Argids, Calcids, and Cambids. Of these, three occur in the Desert Project—the Argids, Calcids and Cambids. The main changes involve the suborder, great group and subgroup. Table 2 gives the classification of soils discussed in this Supplement, and compares classification of both the old and new systems at the subgroup level. The new classifications have been entered in all affected data and description sheets.

In the Guidebook, the young sediments of arroyo channels were designated Entisols. These materials are termed Streamwash in this supplement. This term designates unstabilized areas of sandy and gravelly materials that are flooded and reworked by streams so frequently that they have no pedogenic horizons and little or no vegetation. Streamwash is similar to Riverwash (Soil Survey Staff, 1993), and is used here instead of Riverwash because the streams of this study are not rivers. Arroyo channels and associated Streamwash commonly show as light-colored, narrow, linear patterns on aerial photographs.

Field study sessions

Five new study areas and detailed soil maps have been added. Location of all study areas is shown on the frontispiece. The new study areas and other features (e.g., exposures of soils) are located on the soil maps. Micromorphological information available for the pedon at the time of Monograph publication is on the pedon description page. Table 3, an updated version of table 8 in the Guidebook, gives estimated ages of the geomorphic surfaces and their associated sediments and soils.

Study area 3—Haplocambids of the Fillmore surface; Calciargids and Petrocalcids of the Picacho surface

Refer to pages 104–108, Guidebook, for discussion of study area 3 as a whole.

Area 3a—Typic Haplocambid (Tugas) in Fillmore alluvium

Figures 1 and 2 show the Typic Haplocambid at site 3a. Clay contents of the E and Bt horizons are 7.2 and 8.7 percent respectively (data from the National Soil Survey Laboratory, Lincoln, Nebraska). The clay increase from E to B is too slight for an argillic horizon, but the Bt horizon is fine enough and thick enough for a cambic horizon. Sands and pebbles in the Bt horizon have the thin coatings of oriented clay (grain argillans, Plate 1) that are typical of Bt horizons in this and other desert areas.

The 5YR hue of the Bt horizon contrasts with the 10YR

TABLE 1—Approximate equivalents of horizon designations in the Desert Project Soil Monograph (Gile and Grossman, 1979) and in the revised Soil Survey Manual (Soil Survey Division Staff, 1993).

Horizon designations, Monograph		Horizon designations revised Soil Survey Manual	
Without vertical subdivision	**With vertical subdivision**	**Without vertical subdivision**	**With vertical subdivision**
A1	A11 A12	A	A1 A2
A2	A21	E	E1
	A22		E2
A3		AB or EB	
B1t	B11t B12t	BAt	BAt1 BAt2
B2t	B21t B22t	Bt	Bt1 Bt2
B3t	B31t B32t B32tca	BCt	BCt1 BCt2 BCtk
C	C1 C2	C	C1 C2
	If a K horizon is present		
K1	K11 K12	Bk	Bk1 Bk2
K2	K21 K22		Bk3 Bk4
K3	K31 K32		Bk5 Bk6 Bk7

hue of the B horizon of the Torripsamment at study area 19 (Guidebook), which is thought to be about the same age. Development of the 5YR hues here and not at study area 19 is attributed to a difference in parent materials. The soil here at study area 3a has formed in dominantly rhyolite alluvium that contains ferromagnesian minerals such as biotite, that would be susceptible to weathering in an arid environment. Combination of extreme summer heat with the moist season is thought to promote enough weathering of these minerals in the E horizon to give the 5YR hues in the Bt. In contrast, the Torripsamment at study area 19 has formed in reworked river alluvium that is low in extractable iron. This reflects the scarcity of ferromagnesian minerals, and is apparently responsible for the lack of 5YR hues in the B horizon.

Areas 3b and 3c (see new study areas 4a, 4b)

Because of roadwork, study areas 3b and 3c are no longer suitable to illustrate soils of a stable Picacho surface (see new study areas 4a, 4b).

Area 3d—Argic Petrocalcid (Casito 60–1) in Picacho alluvium; the plugged horizon

Casito 60–1 at area 3d was selected to illustrate the stage III plugged horizon in the morphogenetic sequences of carbonate accumulation (Gile et al., 1966, pp. 349–351). Figure 3 shows the site as it appeared just before cleaning the exposure and sampling the pedon in 1960. Although the arroyo bank has eroded considerably since 1960, the site is still used for study tours because it illustrates so many features of soils of Picacho age (see Guide-

FIGURE 1—Landscape of the Typic Haplocambid at area 3a. The Tortugas surface is on the skyline. Scale is in feet. Photographed October 1981.

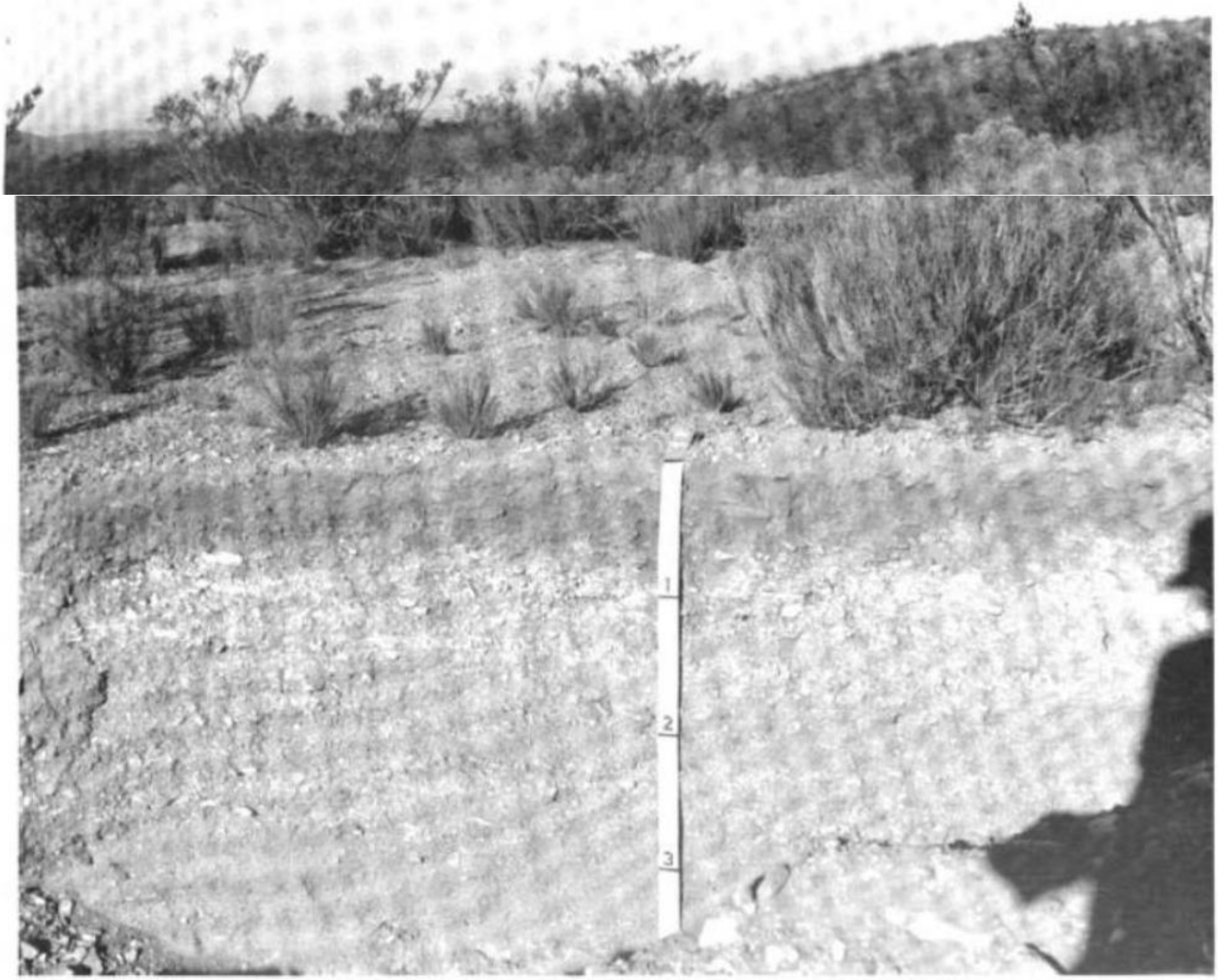

FIGURE 2—The Typic Haplocambid, Tugas, in Fillmore alluvium at area 3a. Vegetation consists of snakeweed and creosotebush. Scale is in feet. Photographed October 1981.

TABLE 2—Classification of soils discussed in this report, according to the Soil Survey Staff, 1994. a = argillic horizon; c = calcic horizon; cam = cambic horizon; d = duripan; g = gypsic horizon; pc = petrocalcic horizon; pg = petrogypsic horizon; s = salic horizon; n = natric horizon. See Soil Survey Staff, 1994, for details of definitions. All soils are thermic and have mixed mineralogy unless otherwise stated.

Classification and study area	**Comparison of subgroup classification**	
Aridisols	**new system**	**old system**
Argids—have a or n, but no d, g, pc or within 100 cm		
Calciargids—have c within 150 cm		
Ustic	Ustic Calciargids	Ustollic Haplargids
fine-loamy		
Headquarters, 27		
fine		
Stellar, 17		
Typic	Typic Calciargids	Typic Haplargids
loamy-skeletal		
Pinaleno, 4a, 20b, 23, 24		
fine-loamy		
Berino, 6b, 8		
coarse-loamy		
Yucca, 10b		
fine-loamy		
Doña Ana, 27		
Haplargids—no c, d, g, pc, pg, or n within 150 cm		
Ustic	Ustic Haplargids	Ustollic Haplargids
loamy-skeletal		
Monza, near 11a		
Caralampi, 25		
clayey-skeletal		
Eloma, clayey substratum analog, 25		
coarse-loamy		
Summerford, 11c		
fine		
Eloma, fine analog, 25		
Lithic Ustic	Lithic Ustic Haplargids	Lithic Ustollic Haplargids
loamy-skeletal		
Lemitar, noncalcareous analog, 25		
Typic	Typic Haplargids	Typic Haplargids
loamy-skeletal		

Typic	Typic Haplargids	Typic Haplargids
loamy-skeletal		
Soledad, 23a, 24		
coarse-loamy		
Sonoita, 26		
fine-loamy		
Bucklebar, 9c		
Petroargids—have d, pc or pg between 100 and 150 cm		
Typic	Typic Petroargids	Typic Haplargids
coarse-loamy		
Rotura, 26		
Calcids—have c or pc within 100 cm; no a or n within 100 cm unless pc is within 100 cm		
Haplocalcids—c within 100 cm; no a, d, n, or pc within 100 cm		
Ustic	Ustic Haplocalcids	Ustollic Calciorthids
Fine-silty		
Reagan, 16, 27		
Reagan, buried soil analog, 27		
Typic	Typic Haplocalcids	Typic Calciorthids
coarse-loamy		
Algerita, 23, 24		
unnamed, 26		
coarse-loamy, carbonatic		
Jal, 26, 27		
fine-silty		
Reakor, 27		
Reakor, buried soil analog, 27		
Petrocalcids—have pc within 100 cm		
Argic—have a within 100 cm	Argic Petrocalcids	Petrocalcic Paleargids
loamy-skeletal, shallow		
Casito, 3d, 23, 24		
Hachita, 4b, 23b, 24		
loamy, shallow		
Cruces, 6a		
coarse-loamy		
Hueco, 26		

TABLE 2 (*continued*)

Classification and study area in Supplement	Comparison of subgroup classification	
Aridisols, continued	**New system**	**Old system**
Petrocalcids, continued		
Argic Ustic—have a within 100 cm	Argic Ustic Petrocalcids	Petrocalcic Ustollic Paleargids
clayey-skeletal		
Hayner, 25		
clayey--skeletal, shallow		
Terino, clayey-skeletal analog, 25		
clayey, shallow		
Terino, clayey analog, 25		
fine		
Hayner, fine analog, 25		
Typic	Typic Petrocalcids	Typic Paleorthids
loamy-skeletal, shallow		
Delnorte, 23, 24		
loamy-skeletal, shallow, carbonatic		
Tencee, 26		
coarse-loamy, shallow		
Simona, 26		
Cambids—have cam within 100 cm; no a, c, d, g, pc, pg, n, or s, within 100 cm		
Haplocambids—no d, pc, or pg within 150 cm		
Typic	Typic Haplocambids	Typic Camborthids
sandy-skeletal		
Tugas, 3a, 23, 24		
coarse-loamy		
Pajarito, 10a		
Ustic		
loamy-skeletal		
Gallegos, 25		

Classification and study area in Supplement

Entisols

- Torrifluvents
  - Ustic
    - sandy-skeletal
      - Minneosa, sandy-skeletal analog 25
    - fine-silty
      - Glendale, Ustic analog, 27
  - Typic
    - fine-silty
      - Glendale, 27
- Torriorthents
  - Ustic
    - fine-silty
      - Lacita, buried soil analog, 27
  - Lithic Ustic
    - loamy-skeletal
      - Coyanosa, 25
  - Typic
    - sandy-skeletal
      - Kokan, 26
      - Arizo, 23, 24
    - sandy
      - Yturbide, 26
    - fine-silty
      - Tome, buried soil analog, 27
- Torripsamments
  - Typic
    - Bluepoint, 26
    - Bluepoint, thin analog, 26
    - University, 19

Classification and study area in Supplement

Mollisols

- Argiustolls
  - Aridic
    - clayey-skeletal
      - Earp, clayey-skeletal analog, 25
      - Earp, clayey-skeletal, calcic analog, 25
    - fine
      - Earp, fine analog, 25
  - Pachic
    - clayey-skeletal
      - Limpia, 25
- Haplustolls
  - Cumulic
    - loamy-skeletal
      - Santo Tomas, Cumulic analog, 25
  - Pachic
    - loamy-skeletal
      - Santo Tomas, 25
- Paleustolls
  - Petrocalcic
    - clayey-skeletal
      - Hayner, mollic analog, 25

TABLE 3—Physiographic location and estimated age of 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)
The valley border	
Arroyo channels	Historical (since 1850)
Coppice dunes[1]	Historical
Fillmore	100–7,000
Leasburg	Earliest Holocene- latest Pleistocene (8,000-15,000)
Fort Selden	(Fillmore and Leasburg—undifferentiated)
Picacho	Late Pleistocene (25,000–150,000)
Tortugas	Late to middle Pleistocene (150,000–250,000)
Jornada I[2]	Late middle Pleistocene (250,000–400,000)
Lower La Mesa[2]	Middle to early Pleistocene (500,000–900,000)
Upper La Mesa[2]	Late Pliocene (2,000,000–2,500,000)

Geomorphic surface	Physiographic location and soil age (yrs B.P. or epoch)
The piedmont slope	
Arroyo channels	Historical
Coppice dunes[1]	Historical
Whitebottom[3]	Historical
Organ	100–7,000
III	100(?)–1,100
II	1,100–2,100
I	2,200–7,000
Isaacks' Ranch	Earliest Holocene– latest Pleistocene (8,000–15,000)
Jornada II	Late Pleistocene (25,000–150,000)
Jornada I	Late middle Pleistocene (250,000–400,000)
Jornada	(Jornada I or Jornada II, undifferentiated)
Doña Ana	Middle to early Pleistocene (> 400,000)
Mountain slopes and summits (undifferentiated)	

Basin floor north of US–70	
Lake Tank	Present to Late Pleistocene
Petts Tank	Late Pleistocene (25,000–150,000)
Jornada I	Late middle Pleistocene (250,000–400,000)
La Mesa	Middle to early Pleistocene (500,000–900,000)
Jornada I–La Mesa	(Jornada I or La Mesa, undifferentiated)

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

[2] 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.

[3] 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.

book pp. 108). A feature not discussed in the Guidebook is the low-gravel horizon beneath the plugged horizon (Fig. 3; table 45, Guidebook). In places this low-gravel horizon, which has scattered carbonate nodules and occurs continuously across the exposure, has noncalcareous zones in the upper few cm. These noncalcareous zones and the carbonate nodules beneath them are thought to have formed during pluvial times of deep leaching, because the low-gravel horizon is relatively close to the surface and must have been within reach of wetting during moist times. During drier times, and particularly after the K horizon formed, the marked change in particle size would have caused soil moisture to hang along the sedimentary contact, slowing the wetting fronts so that carbonate would tend to accumulate along or above the contact.

Study area 4—Calciargids and Petrocalcids of the Picacho and Jornada I surfaces

Refer to pages 109–111, Guidebook, for discussion of study area 4 as a whole. New study areas 4a and 4b (Figs. 4, 5) replace 3b and 3c. The Typic Petrocalcid of the Jornada I surface (study area 4 of the Guidebook, pp. 109, 110) is now designated study area 4c.

New areas 4a and 4b—Typic Calciargid (Pinaleno) and Argic Petrocalcid (Hachita) in Picacho alluvium

The Picacho surface occurs as a terrace inset against sediments of the Jornada I surface just south. Presence of a small arroyo between the Picacho and Jornada I surfaces shows that this Picacho remnant could not have been

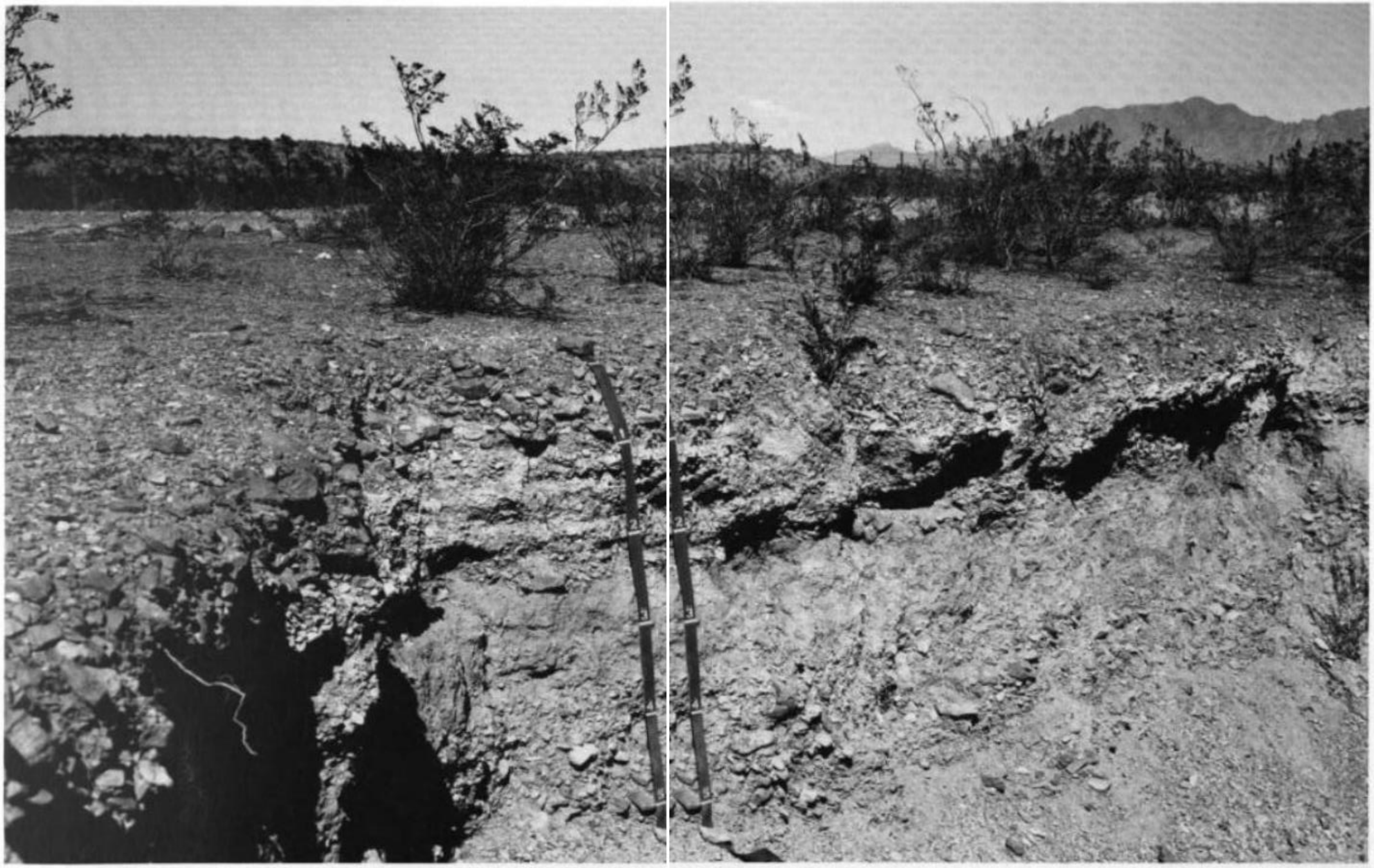

FIGURE 3—Landscape of the Argic Petrocalcid, Casito 60–1, on the Picacho surface at area 3d. This is the site selected to illustrate the stage III plugged horizon (see text). Note the low-gravel horizon with its upper boundary at a depth of about 2½ ft. The Organ Mountains are on the skyline. Scale is in feet. Photographed April 1960.

TABLE 4—Particle size distribution for upper horizons of the Argic Petrocalcid at study area 4b. $CaCO_3$ and organic carbon removed.

Horizon	Depth (cm)	Sand 2.0–0.05 mm	Silt 0.05–0.002 mm	Clay <0.002 mm	>2 mm (vol)
		percent			
E	0–5	69	24	7	30
BEt	5–12	66	21	13	55
Bt1	12–21	52	22	26	50
Bt2	21–34	60	22	19	55

affected by runoff from the Jornada I surface for a very long period of time. The surface is stable, and maximum penetration of soil moisture would be expected. The Bt horizon at this stable site has substantially more clay (Table 4) than at the less stable area 3d (table 45, Guidebook).

Micromorphology of the Bt horizon (Plate 2) differs markedly from that of the late Holocene Bt horizon at study area 3a. This is illustrated by a thin section from a Bt horizon near the west end of the trench (Plate 2). Argillans on the sands and pebbles are much thicker than at area 3a, and a clay-rich matrix occurs between the argillans.

The volume of rock fragments (>2mm material) in the soil prominently affects morphology of the accumulating carbonate and silicate clay (Guidebook, pp. 67, 72). This exposure of the Picacho alluvium and its soils illustrates initial and sporadic development of both the stage IV carbonate horizon and a petrocalcic horizon in skeletal material[1] of late Pleistocene age (Fig. 5). In the pedon just to the left (west) of the tape, carbonate cementation is not continuous enough for a petrocalcic horizon; this pedon is the Typic Calciargid Pinaleno. A petrocalcic horizon occurs at right (east) of the tape; this is the Argic Petrocalcid Hachita.

The volume of rock fragments is similar on both sides of the tape; thus, development of the petrocalcic instead of a calcic horizon cannot be attributed to the volume of rock fragments as it could be at areas 3b and 3c (see Guidebook, p. 107). Development of the petrocalcic horizon at

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[1] A term used informally in this volume to designate materials of any texture and thickness that contain 35% or more, by volume, of rock fragments.

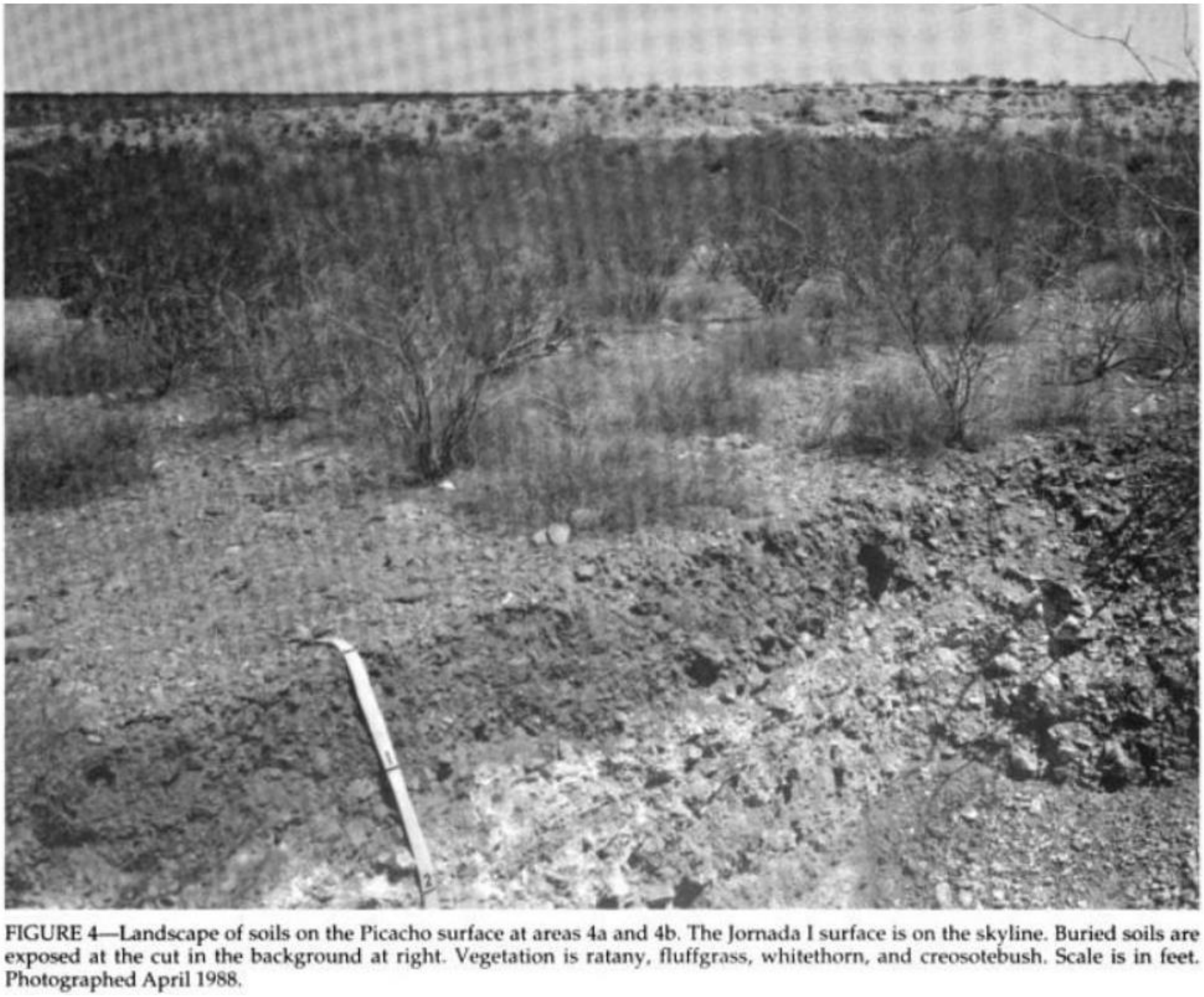


FIGURE 4—Landscape of soils on the Picacho surface at areas 4a and 4b. The Jornada I surface is on the skyline. Buried soils are exposed at the cut in the background at right. Vegetation is ratany, fluffgrass, whitethorn, and creosotebush. Scale is in feet. Photographed April 1988.

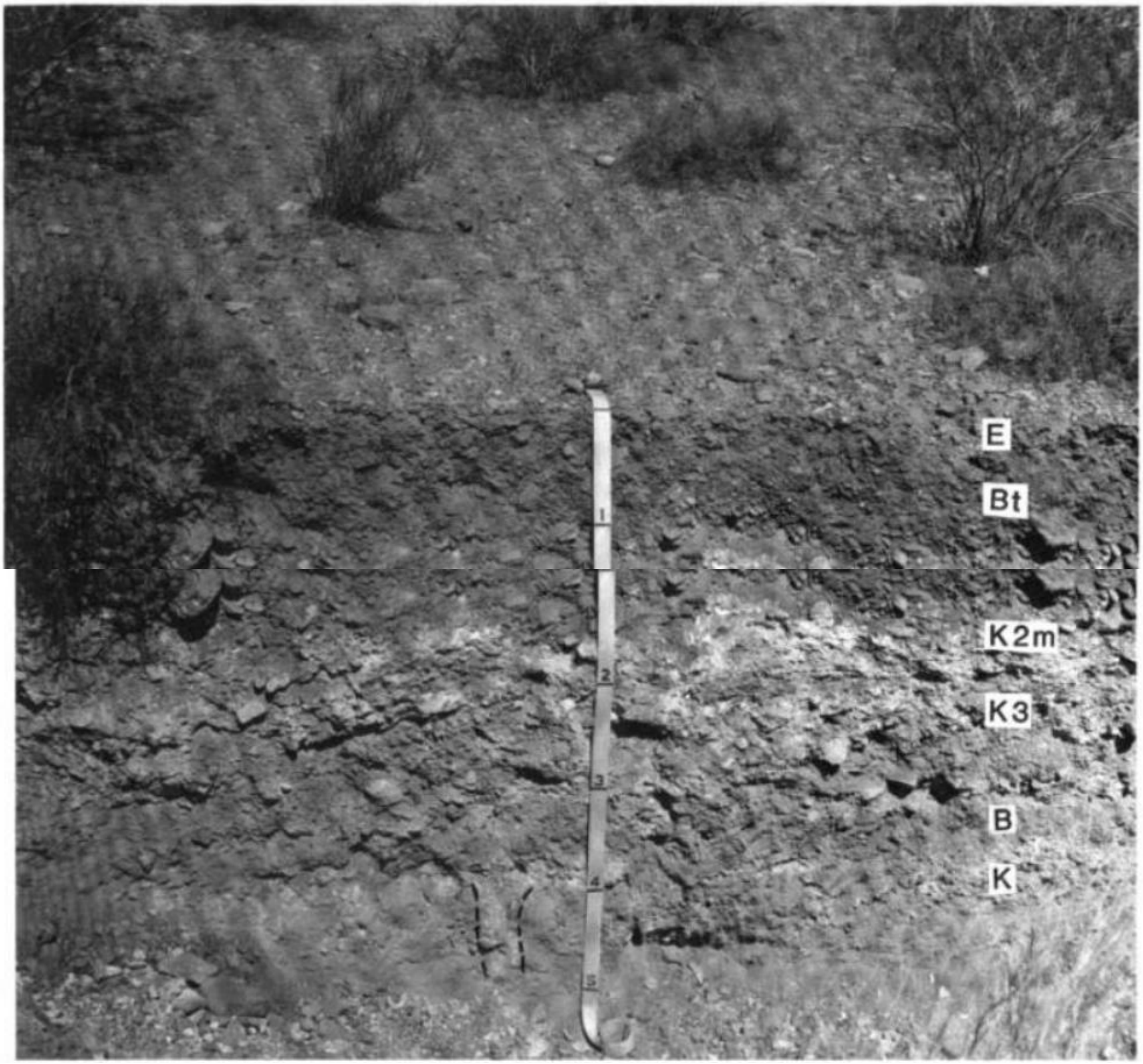

E
Bt
K2m
K3
B
K
1
2
3
4
5

FIGURE 5—Picacho surface and soils at areas 4a and 4b. Profiles of the Typic Calciargid, Pinaleno, at left of the tape (4a) and the Argic Petrocalcid, Hachita, at right of the tape (4b). These soils of Picacho age illustrate isolated zones of K-fabric that are common in skeletal materials of Late-Pleistocene age. Such isolated zones of K-fabric are largely masked by later carbonate accumulations in the thick K horizons of pre-Picacho soils. Occasional tongues of carbonate nodules occur below a depth of about 4 ft (1.2 m); one of these is outlined at left of tape. Generalized horizon designations are shown for a pedon at right. Vegetation is ratany, fluffgrass, whitethorn, and creosotebush. Scale is in feet. Photographed April 1988.

the right of the tape may be related to the more gravelly zones at a depth of about 4 ft (1.2 m, Fig. 5), as compared to carbonate tongues, discussed later, in less gravelly materials at the left of the tape.

Soils of the Picacho surface are instructive in studying carbonate accumulation because they are less complex than older soils of Pleistocene age, in which more prominent carbonate horizons have largely masked patterns of carbonate accumulation that could be related to movement of soil water during soil development in the Pleistocene. Soils of the Picacho surface must have formed in part during pluvials of the late Pleistocene. During such times, moisture penetration would have been substantially deeper than now, and this could be responsible for the carbonate accumulation below a depth of about 4 ft (1.2 m, Fig. 5).

A number of workers have shown the effects of changes in particle size on water movement in soils, and their work suggests possible patterns of water movement and associated carbonate accumulation in deeper layers of these soils. Strata that differ markedly in particle size retard downward movement of the wetting front (Taylor, 1957; Miller and Gardner, 1962), and tend to increase the amount of water retained above the contact. Thus, early in soil history and before the petrocalcic horizon formed, at times of deeply penetrating moisture, the gravelly layer at about 4 ft (1.2 m) depth could cause soil water to "hang" along the sedimentary contact. As a result, carbonate could accumulate along the contact and such carbonate could have formed the zones of K-fabric in these materials (e. g., the zone designated K at the right side of Fig. 5).

When the soil above the contact becomes wet enough, water enters the soil beneath it in a few points and moves downward as in a drain (Taylor, 1957, p. 62). In these soils, such points of water entry may be marked by the downward-extending tongues of carbonate nodules outlined in Figure 5. In contrast to the carbonate tongues, some of

the zones between them are noncalcareous or effervesce weakly. These zones may be similar in origin to the "bypass zones" in stratified tuff at Kilbourne Hole (Gile, 1987), in that they represent material bypassed by tongues of deep moisture penetration.

In addition to roughly vertical movement of soil moisture, lateral movement of water above gravelly layers has been reported (Miller, 1963, 1973). Such lateral movement would also contribute moisture to the tongues of moisture penetration (Fig. 5).

During this period of early leaching, the deep B horizon (Fig. 5) would have been in cambic position, above the zone of carbonate accumulation (Soil Survey Staff, 1975, p. 36). But changes to drier climates would cause carbonate to accumulate at shallower depths. With continued carbonate accumulation above the deep B horizon, wetting fronts could not penetrate as deeply; the base of the gravelly layer just above the deep B horizon would tend to hold up these shallower wetting fronts, thus largely preserving the noncalcareous state. Similarly, abrupt changes in particle size could also be responsible for some of the remarkably abrupt boundaries between high-carbonate horizons and underlying noncalcareous horizons observed in other areas: the situation shown in Figure 5 would be an earlier stage of the phenomenon.

Study area 6—Calciargids and Petrocalcids of upper La Mesa surface

Work on the magnetostratigraphy by Mack et al. (1993) indicates that upper La Mesa dates from late Pliocene time. Age of its soils is tentatively estimated to be about 2.0–2.5 Ma (Table 3).

when moistened, and do not slake in water. Lower subhorizons of the deep Btk horizon have very little clay and high ratios of 15-bar water to clay (App. Part 1). These characteristics are attributed to resistance of the materials to the dispersion pretreatment of mechanical analysis, as suggested by Flach et al. (1969) for materials cemented by silica. Thin sections of the lowest (Btk) subhorizon show part of a silica nodule (Plates 5, 6), and silica is thought to be largely responsible for hardness of the horizon, for its nonslaking property, and for cementation of the prisms. Tight packing, grain-to-grain contacts and well-developed grain argillans may be contributing factors.

Both margins and interiors of weatherable grains in the Btk horizon are sharp and lack evidence of weathering, even in this pipe which must have been quite moist at times in the past. This agrees with the abundance of weatherable minerals found in other Bt horizons and is further evidence that little of the clay in Bt horizons of the arid part of the Desert Project formed by weathering in place. As noted in the Guidebook (p. 118) for adjacent Cruces 61–7, "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."

Study area 8—Calciargids of the Jornada II surface

Refer to pages 134–139 of the Guidebook for discussion of study area 8.

Typic Calciargid (Berino 60–7) in Jornada II alluvium

The photomicrograph (Plate 7) of the Bt horizon in Berino illustrates a ped face that is typical of fine-loamy argillic

Refer to pages 118–124 of the Guidebook for discussion of study area 6, where the Petrocalcid Cruces 61–7 and the Calciargid Berino 68–8 were sampled in the well-known airport trench (Guidebook, fig. 37).

Area 6a—Argic Petrocalcid (Cruces 61-7) in upper Camp Rice sediments

Plate 3, a photomicrograph of the K21m horizon, shows a feldspar grain that has been partly dissolved and replaced by micrite (calcite crystals <4 µm, Bullock et al., 1985). See study areas 24a and 26 for additional evidence of dissolution of primary grains and replacement by micrite.

Area 6b—Typic Calciargid (Berino 68–8) in upper Camp Rice sediments

Upper horizons of a large pipe near Cruces 61–7 were sampled in 1968 (Guidebook, p. 121). The trench was deepened in 1987 and deeper horizons were sampled. A thick Btk horizon in the lower part of the pipe extends to 284 cm depth, where it overlies a deep Km horizon (App. Part 1). This thick Btk horizon and the Km horizon occur only beneath the pipe and clearly must have formed as a result of deep leaching by water that funneled into the pipe from the top of the adjacent petrocalcic horizon. Prisms in the Btk horizon are commonly coated with carbonate, but prism interiors are mostly noncalcareous (App. Part 1).

Thin sections of the deep Btk horizon show the thickest grain argillans found in the study area (Plate 4). The horizon also has common grain-to-grain contacts, which contrast with the "floating grains" of certain other Bt horizons (see study area 3a).

Prisms in the deep Btk horizon in the pipe are very and extremely hard (App. Part 1), do not soften noticeably horizons of the area. Although hand specimens show smooth and reflective ped surfaces suggestive of argillans, thin sections show none to be present on ped faces. Instead, prominent argillans occur on sand grains in ped interiors. A clay-rich matrix occurs between the argillans.

Study area 9—Haplargid in Isaacks' Ranch alluvium

Refer to pages 139–145 of the Guidebook for discussion of study area 9, and page 144 for area 9c.

Area 9c—Typic Haplargid (Bucklebar 88–1) in Isaacks' Ranch alluvium

The Bucklebar pedon (Figs. 6, 7; App. Part 2) has formed in two different sedimentary environments and textures. The lower, coarser-textured materials represent a gully fill. The upper material contains less sand, more silt, and more clay, and reflects decreased energy of the Isaacks' Ranch streams as they spread out over the whole broad drainageway landscape instead of being confined to the gully.

No A or E horizon is present at the sampled pedon because of erosion along the gully. Silicate clay increases with depth in the Bt horizon (App. Part 2), and thin sections show the characteristic grain argillans in the argillic horizon (Plate 8). Some argillans have been obliterated by carbonate (Plate 9).

The pedon illustrates the typical stage II carbonate that is characteristic of Isaacks' Ranch soils. The Btk3 horizon contains barely enough carbonate (15%) for a calcic horizon, but does not meet the minimum thickness requirement (15 cm) of the calcic horizon. This pedon was one of a group of pedons in a study of pedogenic carbonate in soils of Isaacks' Ranch age (Gile, 1995). The study indicated that the amount of pedogenic carbonate in soils of

FIGURE 6—Landscape of the Typic Haplargid, Bucklebar 88–1, on the Isaacks' Ranch surface at area 9c. The area at the tape is barren. Pole lines along U.S. Highway 70 may be seen in the background. Scale is in feet. Photographed November 1981.

Isaacks' Ranch age may range up to five-fold, that landscape position is an important factor in this range, and that texture of the parent materials can have a major effect on the amount of carbonate in soils of a given age regardless of landscape position.

The range in age of Isaacks' Ranch surface and the associated alluvium and soils is from 8,000 to 15,000 yr B.P. (Table 3). Harden and Taylor (1983, page 346) believe the Isaacks' Ranch deposits to be about 20,000 yrs old; however, there is evidence for an age of about 11,000 yr for the bulk of this alluvium (Gile, 1987, p. 755; Gile, 1995).

Study area 10—Haplocambids of the Organ surface; Calciargids of the Late Jornada II surface; the Isaacks' radiocarbon site

Refer to pages 144–149 of the Guidebook for a discussion of study area 10.

Area 10a—Typic Haplocambid (Pajarito 67–3) in Organ alluvium

The north bank of the arroyo just south of Pajarito 67–3 (Guidebook, p. 147) has been used for area 10a instead of Pajarito 67-3 because the soils are very similar, because the same dated charcoal bed occurs in both soils, and because such use would help to preserve the original sample site. However, the arroyo bank site must be carefully filled each time that it is excavated because erosion of the bank has nearly penetrated to the sampled pedon.

Thin sections (Plate 10) show the Bt horizon at area 10a. Nearly all of the clay occurs as grain argillans. In the Ck horizon (Plate 11), thin carbonate coatings on sand grains and pebbles are termed grain calcitans (Douglas and Thompson, 1985).

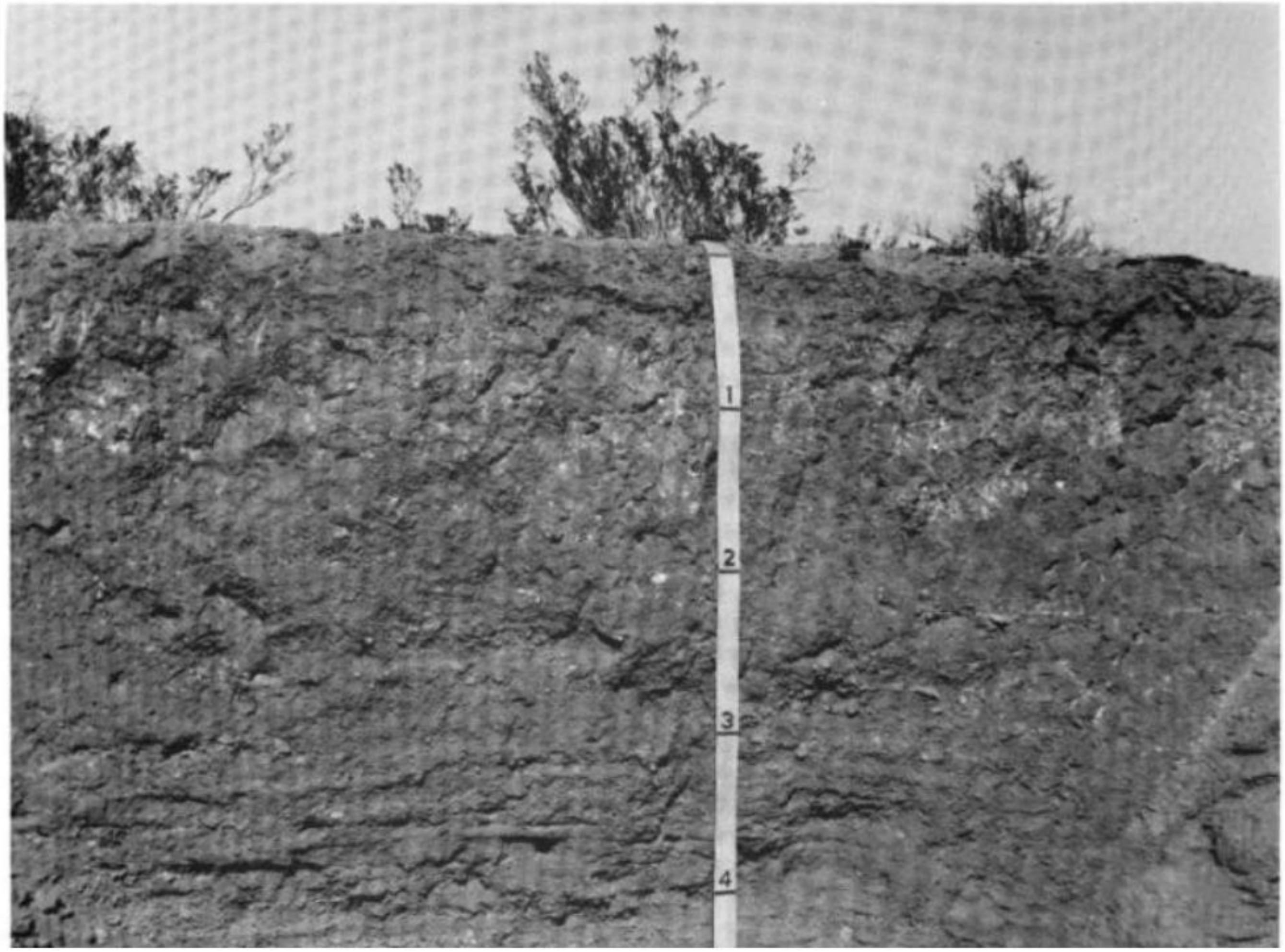
Area 10b—Typic Calciargid (Yucca 88–2) in late Jornada II alluvium

The deposit and soil at study area 10b have been considered to be of earliest Isaacks' Ranch age (15,000 yr B.P.) or possibly slightly older (Guidebook, p. 149). Carbonate morphology and data (Table 5, App. Part 3) indicate that this soil is older than Isaacks' Ranch. Over the ridge crest as a whole, the horizon of carbonate accumulation commonly qualifies as a K horizon (as it does for the sampled pedon); this is not usual for soils of an Isaacks' Ranch ridge. Pedogenic carbonate totals 126 kg/m^2 (Table 5), which is intermediate between Isaacks' Ranch and Jornada II soils (Gile et al., 1981, table 27). On the basis of the foregoing evidence, the surface and soil at Yucca 88–2 are considered to be older than Isaacks' Ranch, and are designated late Jornada II.

Thin sections of the Bt horizon (Plate 12) show the grain argillans to be thicker than for the Haplocambid at area 10a. In addition, less void space is evident, and more clay—rich material occurs in the matrix between the grain argillans. Carbonate in the Btk horizon (Plate 13) is in the process of engulfing formerly continuous Bt material. As for many other soils of the area, the bulk of the carbonate in the underlying K horizon must have been emplaced before the accumulation of carbonate in the Btk horizon.

Study area 11—Haplargids of a monzonite pediment and the Organ surface

Refer to pages 151–156 of the Guidebook for discussion of study area 11.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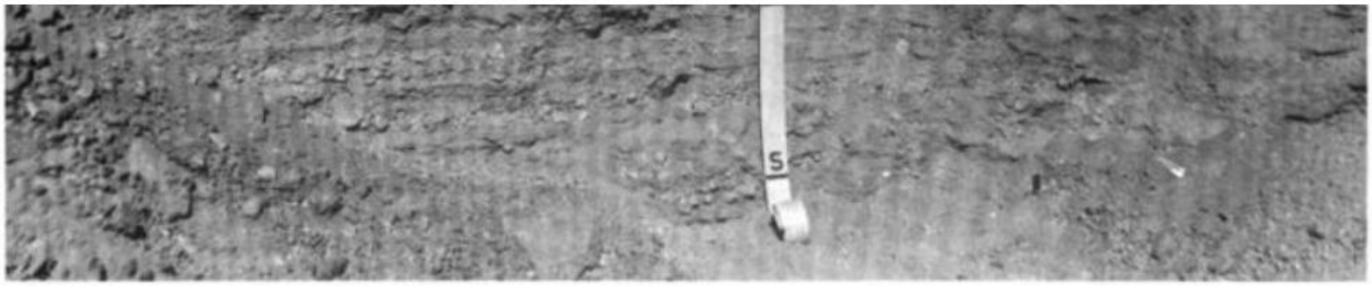

FIGURE 7—The Typic Haplargid, Bucklebar 88–1, in Isaacks' Ranch alluvium at area 9c. The stage II nodular carbonate is distinct. Scale is in feet.

Near area 11a—Ustic Haplargid in monzonite pediment

A thin section (Plate 14) of an Rt horizon from a pedon between Monza 70–1 (at study area 11a) and the road just west shows clay of two origins. Plate 13 shows *illuvial* clay in a grain fracture (at left) and clay formation by *weathering* from exfoliated biotite (at right).

Area 11c—Ustic Haplargid (Summerford)

In the arid part of the Desert Project, Bt horizons in Holocene soils commonly are reddish brown. But in semiarid areas in and near the mountains, illuvial clay and Bt horizons can be masked by dark organic carbon, especially in younger soils with only slight clay accumulation. This is illustrated by the soil at study area 11c (Plate 15, Table 6). Clay increases enough from E to Bt, and the Bt horizon has grain argillans (Plate 15) that are typical of the argillic horizon in this area.

Although this soil is easily dark enough for a mollic epipedon (Table 6), organic carbon at 25 cm depth is too low (Table 6; the mollic epipedon must be at least 25 cm thick in these soils). Organic carbon is high enough for a mollic epipedon in some soils, however, especially mountainward, and these soils are Aridic Argiustolls if they have an argillic horizon. Pedon 59–1, formerly classified as a Haplustoll, illustrates (see table 62, Guidebook). Coatings of oriented clay have been found in the B position for Pedon 59–1, and silicate clay increases sufficiently from A to B for an argillic horizon.

Study area 12—Torrifluvents and Haplocalcids of the Organ surface; the Gardner Spring radiocarbon site

Refer to pages 157–164 in the Guidebook for discussion of study area 12.

Preservation of study areas

Attempts have been made to preserve many of the Desert Project study areas that are in the public domain (Gile and Grossman, 1979, p. 10). A number of them have already been lost due to rapid urban expansion; however, some study areas appear to have a good chance for

TABLE 5—Calculated total of pedogenic carbonate for Yucca 88–2 at study area 10b. Bulk densities estimated from previous work (Gile and Grossman, 1979), using soil texture, consistence, and carbonate content.

Horizon	Depth (cm)	$CaCO_3$ %	Pedogenic $CaCO_3$[1] kg/m²	Estimated bulk density g/cm³	>2 mm (vol.) %
E	0–5	TR			
Bt	5–18	TR			
Btk1	18–29	2	1.4	1.4	10
Btk2	29–43	5	6.3	1.4	20
Btk3	43–53	5	1.5	1.5	75
K1	53–60	23	20.9	1.7	20
K21	60–74	21	35.2	1.8	30
K22	74–88	13	22.7	1.8	25
Bk	88–99	5	5.6	1.6	20
K	99–110	10	12.5	1.8	30
C1	110–130	2	2.6	1.5	15
C2	130–143	3	3.3	1.5	15
Ck	143–153	12	14.0	1.5	15

[1] The calculation is for a volume element 1 m in horizontal cross section and of variable thickness, according to the formula

$$CaCO_3(kg/m^2) = \frac{\left[L \times Db \times \frac{1 - >2\ mm\ vol.\ \%}{100} \times CaCO_3\ \%\right]}{10}$$

where L is the thickness of the horizon in cm, Db is the bulk density of the fine-earth fabric, (1 − >2 mm vol.%)/100 is a correction for the volume occupied by the >2 mm material, and $CaCO_3$ is carbonate content of the horizon minus the carbonate content of the parent materials.

TABLE 6—Characteristics of the soil at study area 11c. Organic carbon is 0.62% for the 0–5 cm zone.

Horizon	Depth (cm)	Sand 2.0–0.05 (mm)	Silt 0.05–0.002 (mm)	Clay < 0.002 (mm)	Organic C	Hue	Value/Chroma dry	moist

must be removed for an argillic horizon to form (see study area 27).

Study area 17—Calciargids of the Jornada I surface

Refer to pages 185–189 of the Guidebook for discussion of study area 17.

Ustic Calciargid (Stellar 60–21) in Jornada I alluvium

In contrast to Reagan at study area 16, Stellar 60–21 has formed in low-carbonate parent materials derived primarily from monzonite, rhyolite, and andesite of the Doña Ana Mountains. Also in contrast to Reagan, the Bt horizon of Stellar 60–21 has prominent grain argillans (Plate 17).

Study area 19—Torripsamments of the Fort Selden surface

Refer to pages 192–197 of the Guidebook for a discussion of study area 19.

Typic Torripsamment (University 59–10) in Fort Selden colluvium

University 59–10 has formed in colluvium derived from upslope deposits of the ancestral Rio Grande. Thin sections (Plate 18) illustrate that coatings of oriented clay can also occur on sand grains in B horizons of Torripsamments.

Study area 20—Argids of the Organ and Jornada II surfaces

Refer to pages 197–205 of the Guidebook for discussion of study area 20.

Area 20b—Typic Calciargid (Pinaleno 59-15) in

$$CaCO_3(kg/m^2) = \frac{\left\lfloor L \times Db \times \frac{1 - >2\ mm\ vol.\ \%}{100} \times CaCO_3\ \% \right\rfloor}{10}$$

where L is the thickness of the horizon in cm, Db is the bulk density of the fine-earth fabric, (1 − >2 mm vol.%)/100 is a correction for the volume occupied by the >2 mm material, and $CaCO_3$ is carbonate content of the horizon minus the carbonate content of the parent materials.

TABLE 6—Characteristics of the soil at study area 11c. Organic carbon is 0.62% for the 0–5 cm zone.

Horizon	Depth (cm)	Sand 2.0–0.05 (mm)	Silt 0.05–0.002 (mm)	Clay < 0.002 (mm)	Organic C	Hue	Value /Chroma dry	moist
			percent					
E	0–2	74.7	16.0	9.6	0.62	7.5YR	5/2.5	3/2
BAt1	2–5	74.1	14.7	11.2		7.5YR	4/2	2.5/2
Bat2	5–12	73.5	15.2	11.3	0.73	7.5YR	4/2	2/2
Bt1	12–20	73.2	14.9	11.9	0.55	7.5YR	4/2	2.5/2
Bt2	20–36	70.9	15.4	13.7	0.36	7.5YR	4.5/2	3/2
Bt3	36–52	75.0	12.0	13.0	0.33	7.5YR	4.5/2.5	3/2

preservation, and five of them are located at Gardner Spring. Thanks to a cooperative effort in 1980, these areas have been fenced for permanent protection. Study areas 12a and 12b (Guidebook) illustrate two of these protected areas.

Study area 16—Haplocalcids of the Petts Tank Surface: effects of parent material carbonate on micromorphology

Refer to pages 182–185 of the Guidebook for discussion of study area 16.

Area 16—Ustic Haplocalcid (Reagan 60–17) in Petts Tank sediments

The Ustic Haplocalcid Reagan 60–17 has formed in high-carbonate parent materials derived from the San

Study area 16—Haplocalcids of the Petts Tank Surface: effects of parent material carbonate on micromorphology

Refer to pages 182–185 of the Guidebook for discussion of study area 16.

Area 16—Ustic Haplocalcid (Reagan 60–17) in Petts Tank sediments

The Ustic Haplocalcid Reagan 60–17 has formed in high-carbonate parent materials derived from the San

Andres Mountains. Plate 16 is a photomicrograph of the Reagan Bk3 horizon. No grain argillans are present despite a considerable increase in clay from A to B. Carbonate in soil parent materials tends to flocculate silicate clay, reducing clay movement in the soil (Jenny, 1941, p. 71). Thus the oriented clay required for the argillic horizon cannot form in high-carbonate parent materials; however, not all of the primary carbonate in the parent materials

Fort Selden colluvium

University 59–10 has formed in colluvium derived from upslope deposits of the ancestral Rio Grande. Thin sections (Plate 18) illustrate that coatings of oriented clay can also occur on sand grains in B horizons of Torripsamments.

Study area 20—Argids of the Organ and Jornada II surfaces

Refer to pages 197–205 of the Guidebook for discussion of study area 20.

Area 20b—Typic Calciargid (Pinaleno 59-15) in Jornada II alluvium

Pinaleno 59–15 has formed in Jornada II alluvial fan sediments derived from rhyolite. Prominent argillans occur on sand grains and pebbles (Plate 19), and a clay–rich matrix occurs between the argillans.

Study area 23—Haplargids and Haplocambids of the Fillmore surface; Petrocalcids of the Picacho and Jornada I surfaces

Summary of pedogenic features

Soils ranging in age from late Holocene to late middle Pleistocene; side-by-side occurrence of weak Haplargids and Haplocambids of late Holocene age, in high-gravel and low-gravel materials respectively; morphology and relative ages of carbonate as evidence for the developmental chronology of the stage IV carbonate horizon; obliteration of the argillic horizon and partial disintegration of the stage IV carbonate horizon in Jornada I soils due to landscape dissection and associated soil truncation; radiocarbon age of 19.7 kyr for carbonate coatings in the plugged horizon of a Petrocalcid as evidence of deep penetration of moisture in shallow petrocalcic ho-

Pleistocene; side-by-side occurrence of weak Haplargids and Haplocambids of late Holocene age, in high-gravel and low-gravel materials respectively; morphology and relative ages of carbonate as evidence for the developmental chronology of the stage IV carbonate horizon; obliteration of the argillic horizon and partial disintegration of the stage IV carbonate horizon in Jornada I soils due to landscape dissection and associated soil truncation; radiocarbon age of 19.7 kyr for carbonate coatings in the plugged horizon of a Petrocalcid as evidence of deep penetration of moisture in shallow petrocalcic ho-

rizons during pluvials.

Setting

The geomorphic map for study area 23 is in the Guidebook (fig. 25, southwest corner). With increasing elevation the geomorphic surfaces are arroyo channel–Fillmore–Picacho–Tortugas–Jornada I. Small areas of a post-Picacho and younger surfaces). Other features are 1 = exposure of buried soils in west track of road down the side of the Jornada I ridge; 2 = deep drainageway in Tortugas ridge (see text); 3 = exposures of Argic Petrocalcids of the Picacho surface, in north bank of arroyo; 4 = exposures of Bt horizons and stage I carbonate horizons in soils of Fillmore age, in arroyo banks; 5 = exposure of Jornada I K horizon, beveled by a drainageway that crosses the road; 6 = exposure of Petrocalcids in north-facing side of Jornada I ridge, on west side of road; 7 = exposure of the transition between Argic and Typic Petrocalcids on the margin of a Tortugas terrace, on west side of road. Aerial photograph taken in 1974.

the Fillmore, with the Haplargids occurring only in some of the very gravelly sediments.

Map unit B is dominated by the Argic Petrocalcid Hachita soils. Smaller areas of Typic Petrocalcids and Haplocalcids are also present, occurring mainly in or near drainageways, where the argillic horizon has been truncated and/or engulfed by carbonate accumulation. Minor areas of the Typic Calciargids, Pinaleno soils, occur where the carbonate horizon is not continuously cemented and a calcic instead of a petrocalcic horizon is present.

Many soils of map unit C have been strongly affected by dissection and former argillic horizons have now been obliterated. Unit C is dominated by Typic Petrocalcids (mostly Delnorte), Argic Petrocalcids (mostly Hachita), and Haplocalcids (mostly Algerita). The Argic Petrocalcids occur in stablest areas of the Jornada I and Tortugas ridge sides and ridge crests, and also are common on sides of drainageways that have penetrated below the petrocalcic and calcic horizons of the ridge-crest soils. Also in map unit C are small areas of the Argic Petrocalcid, Casito, which contains some macroscopic carbonate in all subhorizons of the Bt horizon. The Haplocalcids occur in facies changes to low-gravel materials, so that a calcic horizon has formed instead of a petrocalcic horizon. Narrow areas of arroyo channels and the adjacent Fillmore surface are dominated by Streamwash and Torriorthents respectively.

The landscape of unit D has been so strongly dissected that only a very few Argids are present, and the unit is dominated by Typic Petrocalcids and Haplocalcids. The Typic Petrocalcids occur in the more gravelly areas where a petrocalcic horizon has formed, and the Haplocalcids occur in less gravelly areas. Buried soils, beveled by dissection, are common beneath colluvium on sides of ridges, and in places are at or very near the surface (see #1, Fig. 8).

A deep drainageway in a Tortugas ridge

The west road crosses a Tortugas ridge at #2 (Fig. 8). A deep drainageway in the margin of the ridge crest occurs west of the road. The floor of the drainageway appears to be quite stable, and although deep has no incised channel. Bt and Km horizons have formed in the drainageway. The Bt horizon is usually noncalcareous in the upper few cm and appears to be currently forming. The top of the Km (petrocalcic) horizon ranges from about 15 to 40 cm from the surface. Argic Petrocalcids dominate the floor and sides of the drainageway; there are minor areas of Haplocalcids and Typic Petrocalcids.

The drainageway forks in its northern part, with one fork heading east of the road and the other west of it. West of the road, the fork deeply cuts the Tortugas sediments to a depth of about 10 ft (3 m) at a point only about 60 ft (18 m) south of the south edge of the ridge crest.