Causes of Soil Boundaries in an Arid Region: I. Age and Parent Materials[1]

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ABSTRACT

Studies of soil distribution in arid regions show recurring similarities of many soil boundaries. This paper illustrates some of the boundaries caused by differences in soil age and parent materials. The relations are shown by small-scale diagrams of landscapes and by large-scale diagrams of the soil boundaries, diagnostic horizons, and other morphological features.

A major cause of difference in age is the deposition of new parent materials in some places but not in others. As a result, soils of the younger deposits are adjacent to unburied soils that are more complex. Particularly prominent changes in soils occur across the boundary between soils of Holocene and Pleistocene age, with taxonomic differences ranging from soil family to order. Magnitude of the morphological change between soils of these two ages and occurrence of the boundary over vast areas of the Southwest indicate the pedogenic significance of the boundary.

Other boundaries are caused by changes in parent materials. Differences in content of coarse fragments can cause category changes ranging from soil family to great group. High-carbonate parent materials can cause taxonomic differences on the level of suborder or order. Some soil boundaries have no expression at the land surface, but others are marked by landforms such as terraces, scarps, and fans.

Additional Index Words: **soil classification, soil morphology, argillic horizon, cambic horizon, calcic horizon, petrocalcic horizon, buried soils.**

RECURRING SIMILARITIES of many soil boundaries were observed in an arid area of southern New Mexico. Observations elsewhere in the Southwest and in the desert regions of northern Mexico indicate that these similarities are regional in extent. This paper illustrates some of the soil boundaries in the study area and discusses the principles responsible for their formation.

The area is in the basin-and-range topography of southern New Mexico (Fig. 1). Precipitation is about 20 cm annually in the arid part of the study area (between the mountains) where most of the illustrative soils occur.

Geology and geomorphology of the area have been discussed by Dunham (1935), Ruhe (1964, 1967), Hawley and Kottlowski (1969), and Gile, Hawley, and Grossman (1970). Extensive areas of both high- and low-carbonate parent materials[3] occur in the study area. Limestone bedrock in the mountains is the major source of carbonate in the former. Rhyolite and monzonite in the mountains are sources of alluvium with little or no carbonate. Because of atmospheric additions of Ca (from both dry dustfall and precipitation) soils formed in rhyolite and monzonite alluvium may have weak to prominent horizons of carbonate accumulation depending upon soil age (Gile, Peterson, and Grossman, 1966).

The main causes for soil differences that result in boundaries between these arid-land soils are differences in soil age, parent materials, degree of landscape dissection, soil moisture, and biotic activity. Soil boundaries caused by changes in soil age and parent materials are discussed in this paper. Soil boundaries caused by other factors are presented in a subsequent paper (Gile, 1975).

The landscapes, soils, and boundaries are presented diagrammatically. Classification changes across the boundaries to be illustrated range from soil family to order. In each of the three areas of illustration (Fig. 1), a small-scale diagram of the general area is presented first. This is followed by one or more large-scale diagrams giving closeup views of the soils, boundaries, diagnostic horizons and other morphological features. Although the diagrams are generalized for purposes of illustration, the soils shown represent specific polypedons and most are dominant ones in the areas concerned. The separation of Holocene and Pleistocene[4] alluviums has been made by radiocarbon dating of buried charcoal (Gile and Hawley, 1968). Soil classification is based on Soil Taxonomy (Soil Survey Staff, 1975, in press). Landform terminology used in this paper is summarized in Table 1.

SITE I. BOUNDARIES CAUSED BY DIFFERENCES IN SOIL AGE AND PARTICLE SIZE (HIGH-CARBONATE PARENT MATERIALS)

The soil parent materials at Site I (Fig. 2) are high-carbonate sediments derived from the San Andres Mountains, which consist mainly of calcareous sedimentary rocks. All soils are calcareous throughout because of the high-carbonate parent materials.

The Holocene soils occur both in topographic lows and on topographic highs (Fig. 2–4). Two large, partly dissected Pleistocene fans are the topographic highs near the mountains; a Holocene valley fill occurs in a topographic low between the fans. In places, Holocene colluvium derived from steep slopes of the dissected fan to the north occurs along the margin of the valley fill. In some areas downslope the Holocene materials partly bury toes of the Pleistocene fans and form the topographic highs.

Difference in Age: Younger Soils in Topographic Lows (Fig. 3); Boundary between Torrifluvents and Paleorthids—Typic Torrifluvents are dominant in the Holocene valley

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[3] "High-carbonate" designates parent materials with more than about 15% $CaCO_3$ equivalent; "low-carbonate" designates parent materials with less than about 2% $CaCO_3$ equivalent.

[4] The suggested time for the Holocene-Pleistocene boundary varies from one place to another but most national groups consider it to be about 10,500-10,000 years B.P. (Fairbridge, 1968). In the study area a boundary of about 7,500 B.P. seems to fit best.

Table 1—Landform terminology used in this paper and in a companion paper (Gile, 1975)

Major physiographic features	Large components of major features	Smaller landforms and parts of landforms
Valley	valley border	fans, terraces, ridges, ridge crests, ridge shoulders, ridge sides, saddles
	flood plain*	
Basin floor†	slight ridges, depressions	playas, dunes, scarps
Piedmont slope†	fans	fan toes, terraces, interfan valleys, ridges, ridge crests, ridge shoulders, ridge sides
	coalescent fan-piedmont‡	fans, dunes, terraces, ridges, ridge crests, ridge shoulders, ridge sides, drainageways, fan-piedmont toeslopes, scarps

* Not discussed in this paper.
† Basin floor and piedmont slope are the two basic landscape components of intermontane basins.
‡ Designated "fan-piedmont" for brevity.

fill; they show irregular decrease in organic C with depth (Gile and Hawley, 1968). Textures in the control section range from sandy loam to silty clay loam; some soils are gravelly. Ustollic Paleorthids occur on the Pleistocene fans. These soils are gravelly or very gravelly and most have cambic horizons with texture of sandy loam or loam. They also have petrocalcic horizons, which are thicker and have thicker laminar horizons on ridge crests (late-mid-Pleistocene age) than on ridge sides (late-Pleistocene age). The soil boundaries are apparent (Fig. 3) and occur at the contact of the Pleistocene fan and the Holocene valley fill. The latter is inset against the fan as a terrace (Fig. 3).

Initial Development of the Calcic Horizon; Boundary between Torrifluvents and Calciorthids—A few Calciorthids also occur in the Holocene valley fill (Fig. 3) but only in some areas of the oldest alluvium (Organ I; Gile and Hawley, 1968). In the developmental scheme for soils of the study area, the calcic horizon and the Calciorthids first appear in high-carbonate parent materials. This is because some of the 15% $CaCO_3$ equivalent (required for many calcic horizons; Soil Survey Staff, 1975, in press) is supplied by the parent materials. In these materials and in textures such as clay loam or silty clay loam, the initial stage of the calcic horizon is indicated by common carbonate filaments on ped faces. The gradation from the Calciorthids to the bordering Torrifluvents is indicated by a lateral change to only a few, or no carbonate filaments. The gradation occurs in the same deposit and in soils of the same age. This boundary is not illustrated.

Thus in high-carbonate parent materials, a calcic horizon can form in several thousand years. In these parent materials there is no place for the Camborthids in the developmental scheme for soils of this area. If the parent materials contain carbonate, the cambic horizon must be underlain by a horizon with much more carbonate (Soil Survey Staff, 1975, in press). By the time such a horizon has formed in

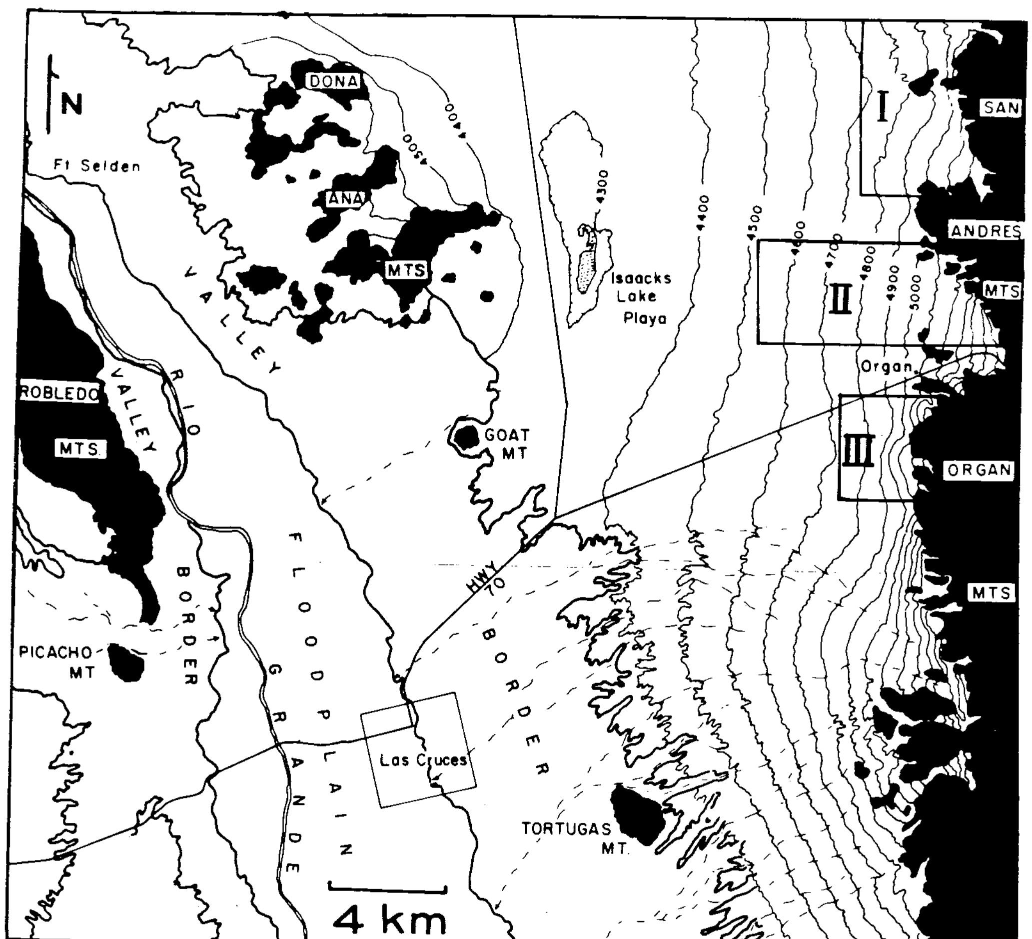

Fig. 1—Major physiographic features of the study area in southern New Mexico. Location of Sites I-III indicated.

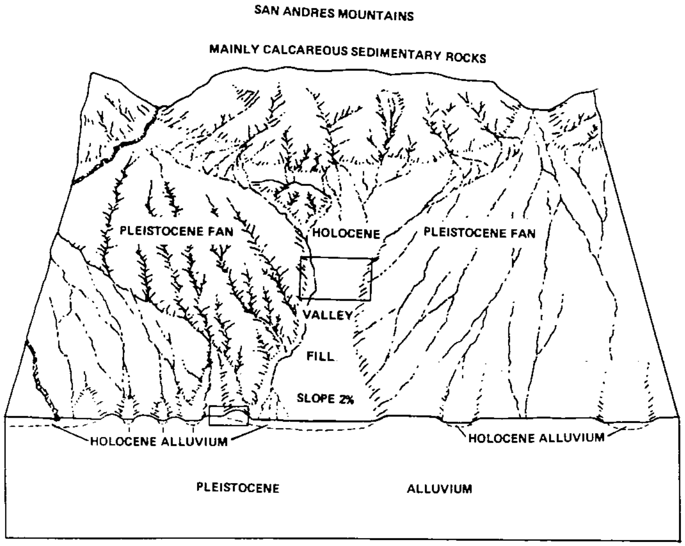

Fig. 2—Site I. San Andres Mountains and the downslope fans, valley fill and ridges. Soil parent materials were derived from the San Andres Mountains, which consist largely of calcareous sedimentary rocks. Location of large-scale diagrams (Fig. 3 and 4) indicated by rectangles.

high-carbonate parent materials, the soil has a calcic horizon and is a Calciorthid. A cambic horizon could also be present but the soil would not be a Camborthid because the calcic horizon takes precedence in classification.

Difference in Age: Younger Soils on Topographic Highs (Fig. 4); boundary between Torrifluvents and Paleorthids—Downslope in some areas the Holocene soils occur on topographic highs such as the ridge shown in Fig. 4. Typic Torrifluvents occur on the Holocene ridge; dominant texture of the control section is sandy loam. Slight carbonate accumulation is the most apparent feature of soil development. Ustollic Paleorthids occur in the Pleistocene alluvium; they have petrocalcic horizons. The soil boundaries are apparent and occur along the margin of the ridge.

Difference in Particle Size: Age and Topographic Setting the Same (Fig. 5); Boundary between Paleorthids and Calciorthids—Downslope from the area shown in Fig. 2, slopes are gentler and low-gravel materials are common. Very gravelly materials still occur, however, and in many places there are abrupt facies changes from low- to high-gravel materials in alluvium of the same age (late-Pleistocene). This is due to difference in position with respect to the streams that deposited the sediments; sediments deposited in the main channel zones are coarser than those in areas away from these zones. A petrocalcic horizon has formed in the very gravelly materials because of the relatively low total pore space of these materials as compared to nongravelly materials (Gile, Peterson, and Grossman, 1966). These soils are Typic Paleorthids. Typic Calciorthids, which have calcic instead of petrocalcic horizons, occur in the nongravelly materials (soils in the study area must be of mid-Pleistocene age for a petrocalcic horizon to form in nongravelly materials; Gile et al., 1966). The boundary between the Calciorthids and the Paleorthids cannot be observed at the land surface.

SOIL BOUNDARIES AND DEVELOPMENT OF THE ARGILLIC HORIZON

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

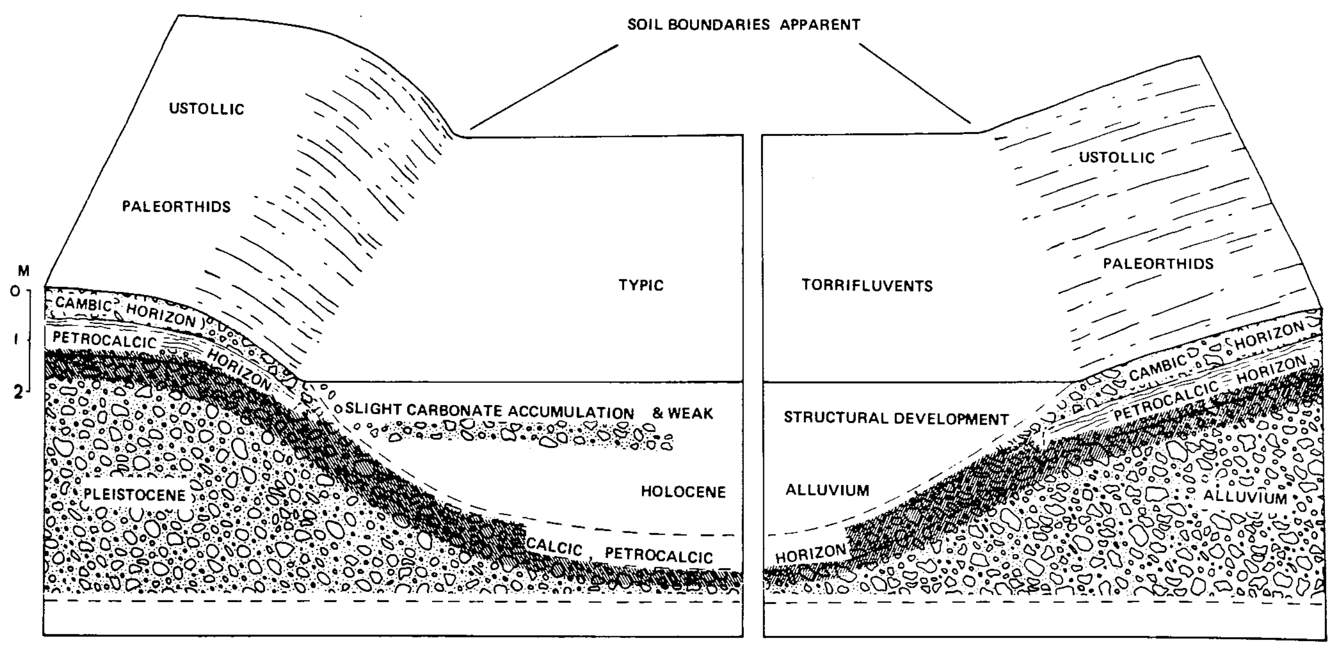

Fig. 3—Boundaries between soils of different ages and formed in high-carbonate parent materials. Typic Torrifluvents are dominant in the Holocene valley fill whereas Ustollic Paleorthids are dominant on the Pleistocene fans. The soil boundaries occur along the contact of the Pleistocene fan and the Holocene valley fill.

It should be stressed that many argillic horizons have prominent morphologies and are not difficult to identify. It is in the transitional stages between argillic horizons and other horizons in the B position that identification is less certain.

Some of the clay in the argillic horizon must be illuvial and it must also have more clay than the overlying eluvial horizon, depending upon clay content of the latter (Soil Survey Staff, 1975, in press). The major criterion for recognition of the argillic horizon in this arid region is the presence of oriented clay on sand grains (and on pebbles if present), and maximum expression of the oriented clay in the horizon of maximum clay (Gile and Grossman, 1968). Thin-section studies have shown that most argillic horizons in this area easily meet the requirement of at least 1% of oriented clay (Soil Survey Staff, 1975, in press). 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. In some soils argillic horizons have not developed because of high carbonate content of the parent materials, and in other soils because they are too young. 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. Soil boundaries associated with presence or absence of an argillic horizon may thus be considered under two headings: (i) boundaries caused by development of the argillic horizon, discussed in this paper, and (ii) boundaries caused by its obliteration (Gile, 1975).

Soil age and carbonate content of the parent materials are important factors in development of the argillic horizon. In the developmental scheme for soils of the area, the argillic horizon first appears in Holocene soils that have formed in low-carbonate parent materials. In these materials, slow illuviation of clay appears to start soon after deposition of the parent materials has ceased. Progressive clay accumulation is accompanied by gradual reddening of the B horizon. By the time the clay increase from A to B is enough for an argillic horizon, it is commonly noncalcareous and has 5YR hue in sandy loams. In finer textured horizons (such as loam or sandy clay loam) colors tend to be somewhat less red in Holocene soils and the argillic horizon may have hue of 7.5YR. Not all B horizons with these hues have enough clay increase for an argillic horizon, though most do.

Carbonate content of the parent materials is also important. The argillic horizon has not developed at all in sediments with abundant fragments of high-carbonate rocks such as limestone. This is true even in soils of Pleistocene age, that must have developed partly in times of greater effective moisture. Although clay may increase with depth in some of these soils, their high carbonate content precludes recognition of the required amount of oriented clay in thin section.

An argillic horizon *can* develop in soils of Pleistocene age

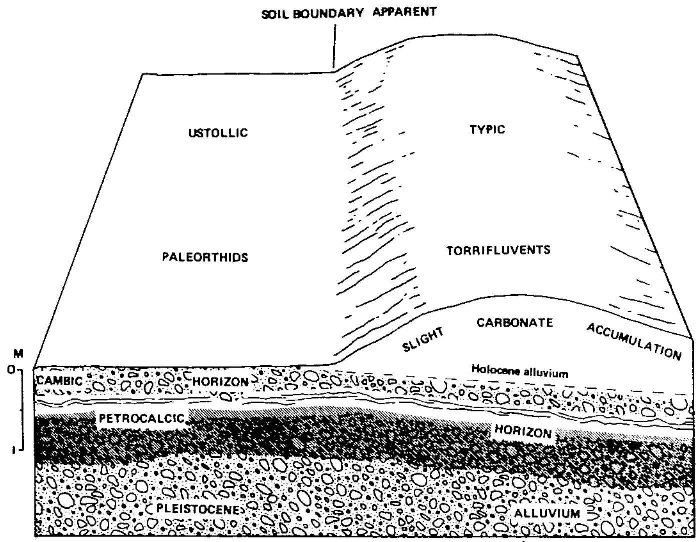

Fig. 4—Boundary between soils of different ages and developed in high-carbonate parent materials. Soils of the Holocene ridge are Typic Torrifluvents whereas adjacent soils of Pleistocene age are Ustollic Paleorthids. In contrast to the situation shown in Fig. 3 the Holocene soils occupy the topographic high. The soil boundary occurs along the edge of the ridge, where the Paleorthids emerge from beneath Holocene alluvium.

(though not of Holocene age) if the parent materials contain only moderate amounts of carbonate, as discussed later at Site II. In these materials enough oriented clay for an argillic horizon is indicated if the parent materials (of 10YR hue) have reddened to 5YR hue. If the reddening has proceeded only to 7.5YR there is usually so much carbonate that the required amount of oriented clay cannot be identified in thin section. Even where the B horizons have 5YR hues and are argillic horizons, they are usually calcareous. Carbonate additions causing the calcareous state of the argillic horizon are thought to have been emplaced in the Holocene since noncalcareous argillic horizons have been observed in places beneath Holocene deposits.

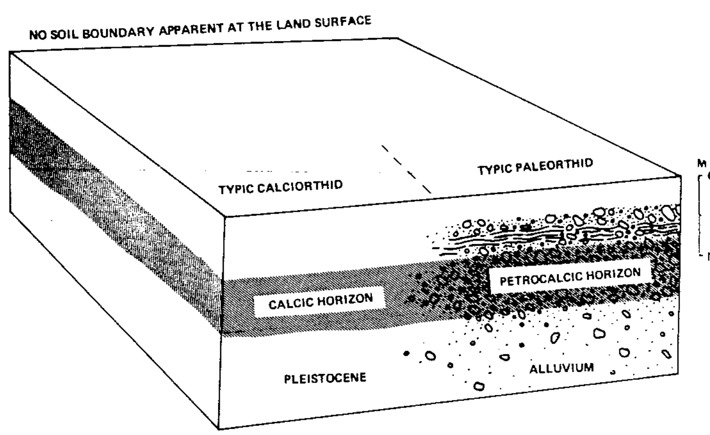

Fig. 5—Boundary between soils formed in high-carbonate parent materials of the same age but with markedly different content of coarse fragments (this area is downslope from the area shown in Fig. 4). Typic Paleorthids have developed in the very gravelly materials whereas Typic Calciorthids have formed in the nongravelly materials. The soil boundary is not visible at the land surface.

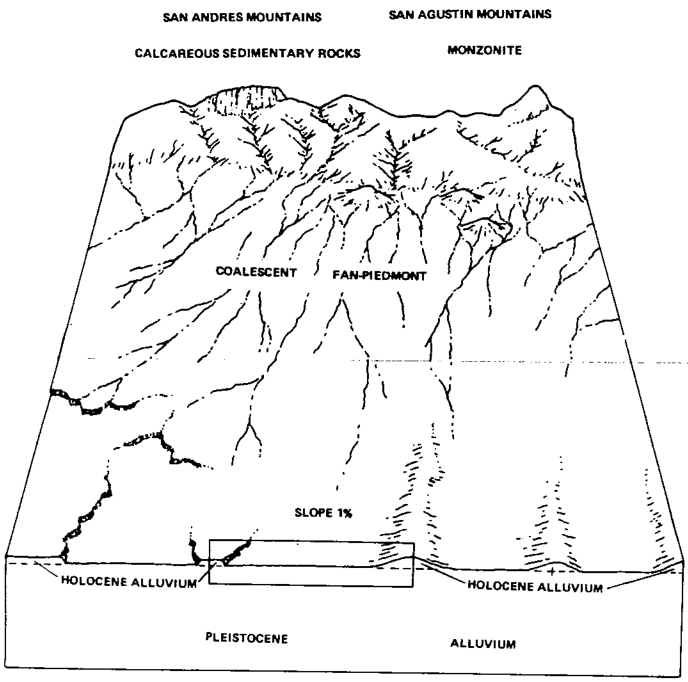

Fig. 6—Site II. San Andres and San Agustin Mountains, and the coalescent fan-piedmont downslope. High-carbonate parent materials occur downslope from the San Andres Mountains and low-carbonate parent materials occur downslope from the San Agustin Mountains. Location of large-scale diagram (Fig. 7) shown.

SITE II. BOUNDARIES CAUSED BY DIFFERENCES IN SOIL AGE AND CARBONATE CONTENT OF PARENT MATERIALS

South of Site I (Fig. 1, 6) there is a change from high-carbonate materials derived from the San Andres Mountains to low-carbonate materials (monzonite alluvium) derived from the San Agustin Mountains. On lower slopes of the fan-piedmont, the area of monzonite materials has little transverse relief except for occasional gullies and slight ridges. In contrast, the landscape in the high-carbonate materials commonly has a distinctive terrain with vertical or near-vertical scarps up to 1 m in height.

Site II (Fig. 6) illustrates soil boundaries caused by differences in age and carbonate content of the parent materials. In places, Holocene alluvium has buried soils of Pleistocene age (Fig. 6).

Difference in Age (High-Carbonate Parent Materials, Fig. 7); Boundary between Torrifluvents and Calciorthids—Torrifluvents are dominant in high-carbonate alluvium of Holocene age (Fig. 7). These soils have 10YR hue and are strongly calcareous throughout; no reddish-brown B horizons have formed because of the high carbonate content of the parent materials. Textures are silt loam, clay loam or silty clay loam. These soils have structural B horizons but not cambic horizons since there is very little or no visible pedogenic carbonate (Soil Survey Staff, 1975, in press). A Bca horizon (with common carbonate filaments on ped faces) is present in a few places and illustrates incipient development of the calcic horizon in high-carbonate parent materials.

The boundary between the Holocene soils and soils of

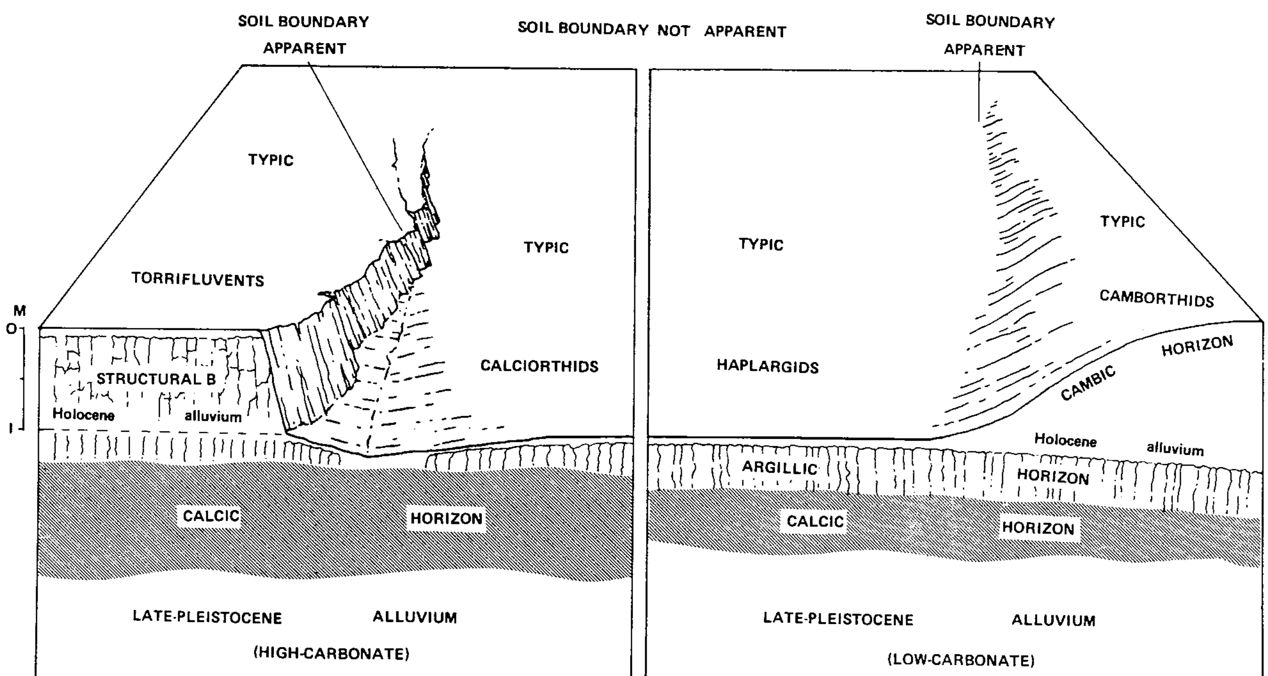

Fig. 7—Boundaries between soils of different ages and parent materials. In high-carbonate parent materials, Typic Torrifluvents are dominant in Holocene alluvium and Typic Calciorthids are dominant in Pleistocene alluvium. The boundary is marked by the scarp, where the Calciorthids emerge from beneath the Holocene alluvium. In low-carbonate parent materials, Typic Camborthids are dominant in Holocene alluvium and Typic Haplargids are dominant in Pleistocene alluvium. The soil boundary occurs along the margin of the ridge, where the Haplargids emerge from beneath the Holocene alluvium.

late-Pleistocene age is marked in many places by scarps (Fig. 7) that are cut mainly in the Holocene soils. The scarps are currently eroding headward and are thought to have been initiated by erosion. Perpetuation of the vertical scarps is promoted by the silty texture, the vertical faces of prisms in the soil, and by the thick grass cover that is usually present along the top of the scarp.

The soils of late-Pleistocene age, buried in many places by the Holocene deposits, commonly emerge at the surface below the scarps. These soils have thick calcic horizons (Fig. 7) and are Calciorthids. They usually have brown cambic horizons with 7.5YR hue (where not truncated) and thus illustrate a reddening in the B horizon not found in Holocene soils formed in similar materials. This reddening is thought to have been caused by the increased effective moisture of the late-Pleistocene pluvial. However, there is still so much carbonate that insufficient oriented clay for the argillic horizon (Soil Survey Staff, 1975, in press) can be seen in thin section.

Difference in Age (Low-Carbonate Parent Materials, Fig. 7); Boundary between Camborthids and Haplargids—The Holocene soils have noncalcareous, reddish-brown B horizons not found in high-carbonate parent materials of the same age (Fig. 7). Typic Camborthids are dominant in the area shown in Fig. 7. The cambic horizon is a sandy loam and is underlain by a weak horizon of carbonate accumulation.

The boundary between the Holocene soils and the soils of late-Pleistocene age occurs at the margin of the slight Holocene ridges, where the latter soils emerge at the surface (Fig. 6, 7). All the soils of late-Pleistocene age have reddish-brown and red argillic horizons and prominent calcic horizons, and are fine-loamy, Typic Haplargids. The distinct differences in morphology are attributed to the greater age of these soils and to their development partly during a Pleistocene pluvial.

Difference in Carbonate Content of the Parent Materials: Soil Age the Same (Holocene); Boundary between Camborthids and Torrifluvents—Holocene soils formed in low- and high-carbonate parent materials are illustrated in Fig. 7 and discussed in the two previous sections. With increasing carbonate content of the parent materials, the zone of transition (not shown in Fig. 7) between these soils is characterized by a change from Camborthids with reddish-brown B horizons (low-carbonate parent materials) to coarse-loamy Torrifluvents lacking these horizons. Parent materials of the Torrifluvents are still dominated by monzonite but enough carbonate is present to prevent development of the reddish-brown B horizon. The exact amount of carbonate required to prevent this development is not known but is probably somewhere between 2 and 15% for Holocene soils.

Difference in Carbonate Content of the Parent Materials: Soil Age the Same (late-Pleistocene); Boundary between Haplargids and Calciorthids—The transition from the prominent Argids in low-carbonate (monzonite) alluvium to the Orthids in high-carbonate alluvium (Fig. 7) corresponds to bedrock differences in the mountains upslope (Gile and Hawley, 1972). With increasing carbonate in the parent materials, the boundary zone from Argids to Orthids is marked by these changes, commonly in the following order: the argillic horizon becomes calcareous throughout; macroscopic carbonate appears in all subhorizons of the argillic horizon; colors become less red, finally reaching the 7.5YR or 10YR hues characteristic of the cambic horizon in Calciorthids of the area. The precise location of the boundary between the Argids and Orthids is not well marked on the landscape except that it usually occurs near the border of the scarped terrain that characterizes much of the area of high-carbonate materials.

The strong influence of carbonate content on development of the argillic horizon is also shown in places in the dominantly high-carbonate area west of the San Andres Mountains (Fig. 1, 6, 7). In these places the B horizons are reddish brown, have 5YR hue, and have enough oriented clay for an argillic horizon. It developed in parent materials that had less carbonate due to additions of sediment from igneous rocks that occur in places in the San Andres Mountains.

Initial Development of the Argillic Horizon; Boundary between Camborthids and Haplargids—Some of the Holocene soils in the vicinity of the area shown in Fig. 7 have incipient argillic horizons and are Haplargids; in these soils the clay content of the B horizon increases enough for an argillic horizon. These places occur in landscape positions (such as broad ridges that are level transversely) favoring maximum infiltration of moisture, in landscape positions (such as drainageways) that receive extra moisture for illuviation, and in sediments that may date from slightly earlier in the Holocene.

The effect of increased precipitation is shown mountainward, where most Holocene soils formed in low-carbonate parent materials have argillic horizons, as discussed in the following section.

SITE III. BOUNDARIES CAUSED BY DIFFERENCES IN SOIL AGE AND PARTICLE SIZE (LOW-CARBONATE PARENT MATERIALS)

Site III (Fig. 8) illustrates soil boundaries caused by differences in soil age and particle size in low-carbonate materials (monzonite alluvium). Large Pleistocene fans are major topographic features. The fans represent several stages of fan development during late- to mid-Pleistocene, with only minor areas of Holocene age. A Holocene fan-piedmont is downslope from the Pleistocene fans (Fig. 8, 9). In this area the Holocene alluvium overlies fan-piedmont deposits of late-Pleistocene age, which emerge further downslope (in places, the Holocene alluvium rests on an alluvium intermediate in age between the units shown in Fig. 9). While this area illustrates boundaries due to soil age and particle size, slight increases in moisture have also affected soils nearest the mountains. This is indicated by a thickening of B horizons and an increasing depth to carbonates towards the mountains in Holocene soils.

Difference in Soil Age (Fig. 9); Boundary between Coarse-Loamy and Fine-Loamy Haplargids—Coarse-loamy Haplargids have formed in the Holocene alluvium, which occurs as slight ridges in the coalescent fan-piedmont. These

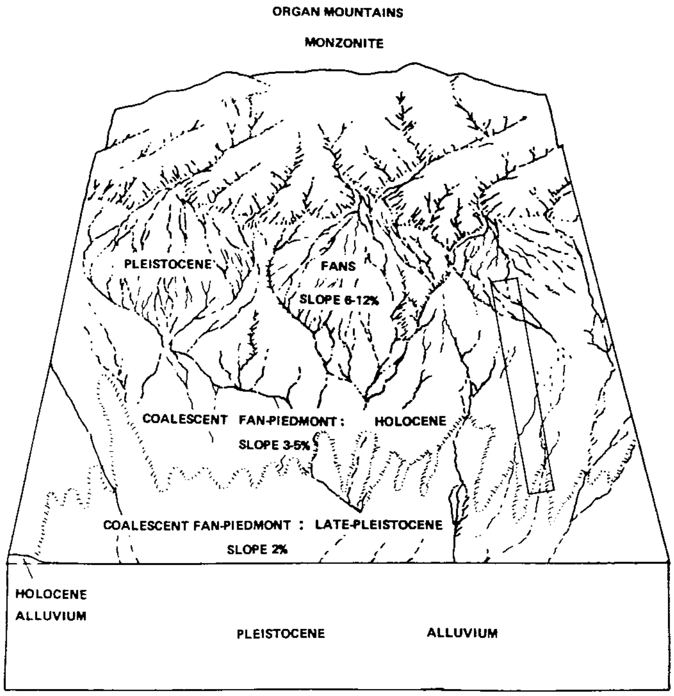

Fig. 8—Site III. Organ Mountains and the downslope fans and coalescent fan-piedmont. The parent materials are low-carbonate sediments derived from monzonite. The mountains are higher and canyons are larger than the area shown in Fig. 6, and the Pleistocene fans below are therefore more prominent. Location of large-scale diagram (Fig. 9) indicated by rectangle at right.

soils have sandy loam argillic horizons and weak horizons of carbonate accumulation. The argillic horizons tend to be slightly more prominent here than at lower elevations. This is thought to be largely due to slightly greater precipitation in this area. Also, some of these soils may have started their development somewhat earlier in the Holocene, thus would have had a longer time for clay illuviation.

The fine-loamy Haplargids of late-Pleistocene age emerge along the downslope margins of the Holocene ridges; these Haplargids have calcic horizons and reddish-brown and red argillic horizons with an average texture of sandy clay loam. The differences in morphology are attributed to the substantially greater age of these soils and the fact that they developed partly during a Pleistocene pluvial.

Difference in Particle Size and Age (Fig. 9); Boundary between Coarse-Loamy and Loamy-Skeletal Haplargids—The soil patterns on the Pleistocene fans (Fig. 9) are complicated because of wide variations in soil age and degree of landscape dissection. Major soils are loamy-skeletal, Ustollic Haplargids of Pleistocene age, with thick argillic horizons and calcic horizons. Depending upon soil age, the Argids on these fans may have calcic or petrocalcic horizons, or only weak horizons of carbonate accumulation.

The boundary between the coarse-loamy and loamy-skeletal Haplargids is apparent because of the distinct fan form and differences in slope (Fig. 8). The location of such a boundary, between soils that are skeletal and soils that are not, depends upon the character of the rock in the alluvium. Monzonite has the property of rapid comminution

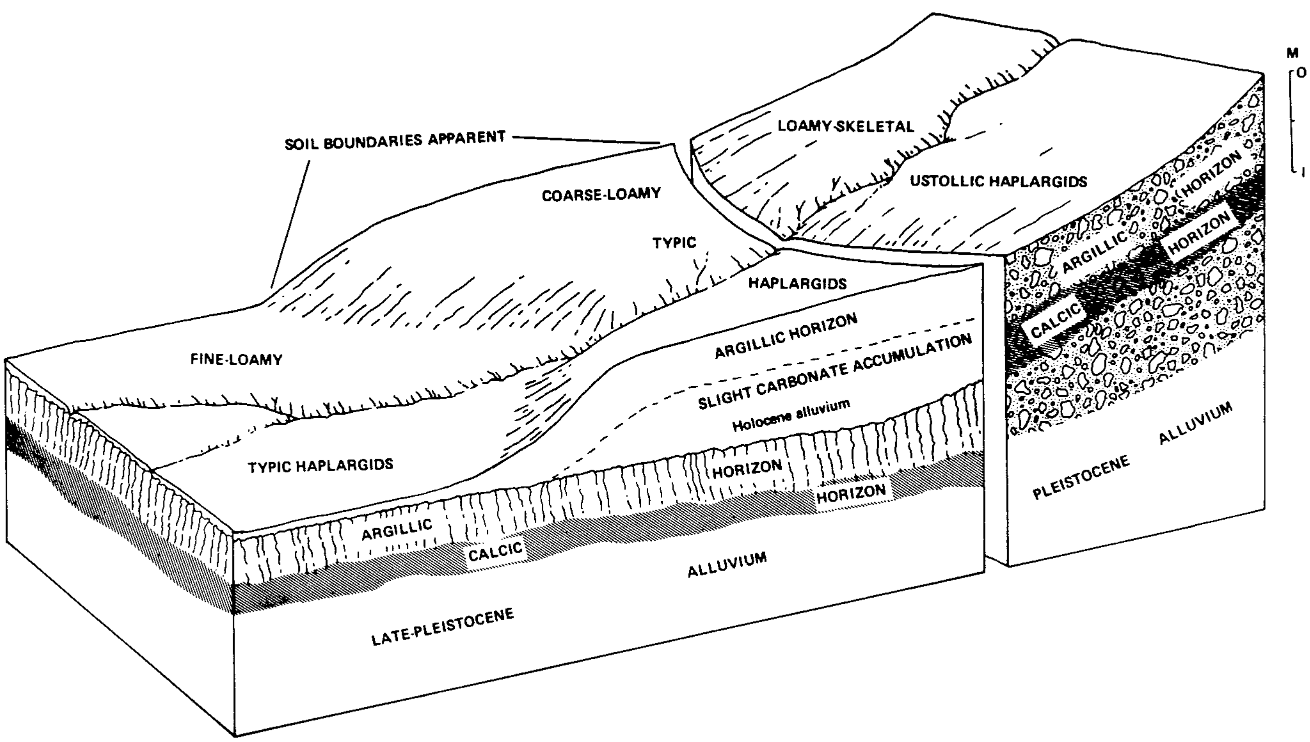

Fig. 9—Boundaries between soils differing in age and content of coarse fragments but formed in the same low-carbonate parent materials (monzonite alluvium). Fine-loamy Typic Haplargids with calcic horizons dominate the Pleistocene fan-piedmont. Coarse-loamy Typic Haplargids without calcic horizons dominate the Holocene fan-piedmont. The boundary between these soils is marked by the downslope margins of the slight Holocene ridges (cf. Fig. 8), where the soils of Pleistocene age emerge from beneath Holocene alluvium. Loamy-skeletal, Ustollic Haplargids dominate the Pleistocene fans. The boundary between these Haplargids and the coarse-loamy Haplargids downslope is apparent because of the steeper slopes and prominent fans on which the former soils occur (cf. Fig. 8).

in transport and weathering. Hence, the skeletal soils are confined largely to the steeper slopes along the mountain fronts.

DISCUSSION AND CONCLUSIONS

Differences in soil age were caused by deposition of new parent materials in some places but not in others (Fig. 3, 4, 7, 9). This can be a major cause for soil boundaries because the resultant differences in soil age may range from hundreds to hundreds of thousands of years. Soil boundaries caused by differences in soil age occur in five ways with respect to the character of the soil boundary: by sedimentation against older, higher materials, forming a terrace (Fig. 3); by soil burial, with the younger materials constituting a topographic high (Fig. 4); by erosion of younger materials and associated exhumation of buried soils, forming a scarp (Fig. 7); by deposition against older materials at the same elevation; and by backfilling of former channels to the level of the adjacent surface. Soil boundaries in the first three cases are readily apparent at the land surface, but not in the last two.

The deposition of new parent materials is episodic (Butler, 1959; Gile and Hawley, 1966). That is, there are times of unstable landscapes (during which erosion and deposition are active) separated by intervals of stability with little or no sedimentation. The intervals of stability have been recorded by buried soils. Evidence for Holocene sedimentation is widespread in the Southwest (Haynes, 1968). Apparently the sedimentation was initiated by changes in climate (Antevs, 1955; Haynes, 1968). After sedimentation stops, soil development begins in the new materials. Where the new material was deposited in the Holocene and the older material in the Pleistocene, there are commonly morphological differences that would separate soils at levels ranging from family to order. The magnitude of morphological change and the occurrence of this boundary over extensive areas of the Southwest indicate the pedogenic significance of the boundary.

Changes in content of coarse fragments and carbonate of the parent materials also cause significant boundaries. In late-Pleistocene, high-carbonate alluvium, Paleorthids (with petrocalcic horizons) occur in high-gravel materials but change abruptly to Calciorthids (with calcic horizons) in low-gravel materials. This boundary is not apparent at the surface. In late-Pleistocene alluvium, a change from low- to high-carbonate alluvium causes a change from Haplargids to Calciorthids in low-gravel materials and from Paleargids to Paleorthids in high-gravel materials. Boundaries between the Argids and the Orthids are marked by a shift from a noncalcareous, reddish-brown or red argillic horizon in the Argids to a calcareous, brown cambic horizon in the Orthids. The distance over which the change occurs depends on the degree of increase of carbonate in the parent materials. If the change from low- to high-carbonate parent materials occurs over a few meters then the change from Argids to Orthids takes place within this distance.

In Holocene alluvium a shift from low- to high-carbonate alluvium results in a change from Camborthids or Haplargids (in low-carbonate material) to mainly Torrifluvents with a few Calciorthids (in high-carbonate material). Morphologically the change is marked by a shift from a noncalcareous reddish-brown B horizon to highly calcareous materials with no reddish-brown B horizon. Observations suggest that less carbonate is required to prevent development of reddish-brown B horizons in soils of Holocene age than in soils of Pleistocene age. The exact amount required in either case is unknown.

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