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A Quantitative Comparison of Soil Development in Four Climatic Regimes

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A new quantitative Soil Development Index based on field data has been applied to chronosequences formed under different climatic regimes. The four soil chronosequences, developed primarily on sandy deposits, have some numeric age control and are located in xeric-inland (Merced, Calif.), xeric-coastal (Ventura, Calif.), aridic (Las Cruces, N. Mex.), and udic (Susquehanna Valley, Pa.) soil-moisture regimes. To quantify field properties, points are assigned for developmental increases in soil properties in comparison to the parent material. Currently ten soil-field properties are quantified and normalized for each horizon in a given chronosequence, including two new properties for carbonate-rich soils in addition to the eight properties previously defined. When individual properties or the combined indexes are plotted as a function of numeric age, rates of soil development can be compared in different climates. The results demonstrate that (1) the Soil Development Index can be applied to very different soil types, (2) many field properties develop systematically in different climatic regimes, (3) certain properties appear to have similar rates of development in different climates, and (4) the Profile Index that combines different field properties increases significantly with age and appears to develop at similar rates in different climates. The Soil Development Index can serve as a preliminary guide to soil age where other age control is lacking and can be used to correlate deposits of different geographical and climatic regions.

INTRODUCTION

The Soil Development Index (Harden, 1982a) is a useful tool in quantifying and comparing soil field properties. The purpose of this paper is to apply the index to soils developed on similar parent materials in Mediterranean, arid, and humid climates and to compare rates and characteristics of the development of soils and their individual properties.

Jenny (1941) defined a soil chronosequence as a series of related soils developed when all factors of soil formation except time (climate, flora and fauna, parent material, topography, and time) are held more or less constant. Four chronosequences in different climatic zones were selected for this study on the basis of available age control and soil descriptions in order to represent areas of different soil-moisture regimes and climates.

GEOLOGIC SETTING AND SITE SELECTION

The soil-moisture regimes represented in this study include xeric-inland and xeric-coastal (both in mediterranean climates), aridic (arid climate), and udic (humid climate). Soil-moisture regimes are important to soil development because they are distinguished on the basis of the amount of water available for leaching (Soil Survey Staff, 1975). In general, the amount of available leaching water is greatest in udic and least in aridic. Xeric-coastal soils are separated from xeric-inland because of the possible influence of sodium on the rate of soil development (Clayton, 1972; Yaalon and Lomas, 1970; Hingston and Gailitis, 1976).

The soil-forming factors of the four chronosequences are generally similar except for the differences in soil-moisture re-

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gimes and vegetation. Factors of parent material were controlled by selecting study areas and sites with unconsolidated deposits of sandy to sandy loam textures of granitic or arkosic lithologies. Relief (topography) at sites was generally flat to gently rolling with slopes of 0 to 5%. All soils are internally well drained and occur as surface soils that have formed since deposition of the parent material. Although climatic and vegetation fluctuations may have occurred in the past, the differences in leaching patterns (soil-moisture regimes) that exist today among the four areas probably also existed in the past: The xeric-inland area in the Central Valley of California has been separated from coastal influence since the Miocene; the xeric-coastal area near Ventura, California, has been adjacent to the coast throughout the Pleistocene; in the udic area in central Pennsylvania precipitation may have fluctuated with glacial cycles, but there is no strong evidence for dramatically different rainfall patterns or amounts; the aridic area in southern New Mexico demonstrates carbonate accumulation with increasing age, suggesting that leaching has not been sufficient to remove much carbonate from the soil.

Merced Area

The xeric-inland chronosequence consists of soils formed on a sequence of nine alluvial units of the Merced River in the eastern San Joaquin Valley, California. The alluvium is derived primarily from granitic rocks of the Sierra Nevada and has minor amounts of metamorphic and volcanic debris from the Sierran foothills. Vegetation is composed mainly of annual grasses and scattered oaks. All of the sites have been grazed by livestock and some sites were formerly under light cultivation. Quaternary units occur as nested or westward-prograding alluvial fans that were constructed during late Pleistocene glacial events (Marchand, 1977; Marchand and Allwardt, 1981). Harden (1982a) described the soils of this sequence and used the soils to develop the Soil Development Index.

Nine Quaternary units in the Merced chronosequence are from 200 yr to 3 myr old (Table 1). The oldest of all units in this study is the China Hat Gravel Member of the Laguna Formation, which is believed to be about 3 to 4 myr old (Marchand and Allwardt, 1981, p. 19). The second oldest unit within the Merced chronosequence is the upper unit of the Turlock Lake Formation, about 600,000 yr old as determined by radiometric dates on the Friant Pumice Member (Janda, 1965, 1966; Janda and Croft, 1967), which occurs at or near the base of the upper unit. The next younger soils of the Merced area are developed in three units of the Riverbank Formation. Marchand (1977) and Marchand and Allwardt (1981) assigned the following ages to the surfaces of the units: 330,000 yr for the lower unit based on age constraints of other units and tentative correlation to oxygen-isotope stage 10 (and/or 12); 250,000 yr for the middle unit based on uranium-trend ages of J. N. Rosholt (written communication, 1981), tentative correlation to isotope stage 8, and age constraints of the upper unit; and 130,000 yr for the upper unit based on uranium-series dates of bone, uranium-trend ages of Rosholt, and correlation with isotope stage 6 (Table 1). The next younger unit is the Modesto Formation, which is divided into lower and upper members (Marchand and Allwardt, 1981). An age of 40,000 yr was used for the top of the lower member, based on the recent uranium-trend ages of 31,000 ± 21,000 and 42,000 ± 16,000 yr (J. N. Rosholt, written communication, 1982). The unit could be as young as about 14,000 yr based on a ^{14}C age of wood within the upper member and as old as 70,000 yr if the unit was deposited during oxygen-isotope stage 4 as Marchand (1977) has proposed. The surface of the upper member of the Modesto Formation is about 9000 to 10,000 yr old based on ^{14}C ages of wood in glacial outwash along the Kern River (Croft, 1968), correlation of the lower section with the late Wisconsin deposits in the Sierra Nevada (Adam, 1967; Janda and Croft, 1967), correlation to sub-

TABLE 1. Geologic Age Control and Soil Profile Characteristics of Chronosequences

Stratigraphic Unit	Dating Information (see key) Age (10^3 yr B.P.)	Isotope Stage[1]	Profile Characteristics and Other Comments	Number of Soils This Report	Assumed Soil Age In Years
			Xeric-inland Moisture Regime, Merced, California Chronosequence[2]		
Post-Modesto deposits					
IV	Modern		Fresh deposits in active stream channel	0	
III	Modern tree rings, .01		A/C profile; little or no oxidation	2	200
II	Cb, 3; Ub, 4.4	1	A/Cox/Cn profile	6	3,000
I	Cc, 4-9		Cox or weak B horizon	0	
Modesto Formation					
upper member	Cw, 14		AC or weak B horizon	2	10,000
lower member	Ub, 29; Cw, 27; Ut, 42-43; Cw, 27; Ut, 42 and 43	4	Weak argillic B horizon 1 m thick	1	40,000
Riverbank Formation					
upper unit	Ub, 120 and 103; Ut, 140-150	6	Moderate to strong argillic B horizon 1-2 m thick	2	130,000
middle unit	Ut, 260	8		2	250,000
lower unit	-- --	10/12		1	330,000
Turlock Lake Formation					
upper unit	Ut, 560 $\pm$ 80 and 540 $\pm$ 50; KAa, 600	16	Very strong argillic B horizon 1-2 m thick; formation divided by well-developed buried soil, basal deposit contains glacial flour	2	600,000
lower unit	KAa, 730; PMr, 770	20		0	
Laguna Formation					
China Hat Gravel Member	KAb, $<$ 3700		Maximum argillic B horizon 2-4 m thick; gravels very disintegrated	3	3,000,000
			Xeric-coastal Moisture Regime, Ventura, California Chronosequence[3]		
latest Holocene deposits	Cc		Shallow A/C profile	1	1,000
late Holocene alluvium	Cs, 2; Us, 5		A/C profile	2	2,000
Punta Gorda terrace alluvium	AA, 45; Us, 50; Cwf	3	Weak argillic B horizon 1 m thick	2	40,000
Ventura terrace alluvium	AA, 85; Cwf, $<$ 105	5	Very strong argillic B horizon, 1-2 m thick	2	85,000
			Udic Moisture Regime, Susquehanna River Valley, Pennsylvania Chronosequence[4]		
Holocene deposits	-- --		A/C may have thin color B horizon; channel, point-bar, levee, and flood-plain alluvial deposits	1	11,000
Kent till	Cw, 15-16; Cl, 12.5-14.2; Cw, 12.5	2	Weak cambic or textural B horizon	2	16,000
Altonian deposits	-- --	4	Weak to moderate argillic B horizon 50 cm thick,	2	60,000
Laurelton deposits	-- --	8	Strong argillic B horizon 1-2 m thick	1	260,000
Penny Hill deposits	-- --	10	Very strong argillic B, more than 2 m thick	1	330,000
			Aridic Moisture Regime, Las Cruces, New Mexico Chronosequence[5]		
Organ alluvium					
Organ III	Cc, 1.1	1	A/Cca, Stage I carbonate	0	
Organ II	Cc, 2.1-2.2		"	0	
Organ I	Cc, 4-6.4		Cambic and Cca horizons	3	4,000
Isaack's Ranch alluvium	Cc, 7.4; Ur, 22 $\pm$ 15; Cs[7], 25-31; Ca, 24 and 43;	1/2	A/Bt/Cca/Cox, weak argillic horizons, Stage II carbonate	3	20,000
Jornada II alluvium	Ut, 98 $\pm$ 15; Cs, 62-96; Ca, 32-79	3-7	A/Bt/K, Stage III and IV carbonate	3	120,000
Jornada I alluvium	Ut, 290; Cs, 306-388	8	A/Bt/K, Stage III and IV carbonate	2	290,000
Camp Rice formation	KAa, 600 and 700 Vp, 1500	10/12			
Lower La Mesa surface	Cs, 500, estimated		A/Bt/K Stage IV carbonate	1	500,000
Upper La Mesa surface	Cs, 560-705		A/Bt/K Stage IV and V carbonate	1	750,000

Key. AA, amino acid techniques; Ca, $CaCO_3$ accumulation (R. J. Arkley, 1982 written communication); Cb, ^{14}C on bone; Cc, ^{14}C on charcoal; Cwf, cool-water fauna; Cl, ^{14}C on lake and bog sediments; Cs, $CaCO_3$ accumulation (Machette, 1982); Cw, ^{14}C on wood; KAa, K–Ar on ash; KAb, K–Ar on basalt; PM, paleomagnetic reversal; Ub, Uranium series (U–Th) on bone; Us, uranium series (U–Th) on shell; Ut, uranium trend (J. N. Rosholt, 1981; 1982 written communication; VP, vertebrate paleontology.

[1] Shackleton and Opdyke, 1972.
[2] Merced dates from Marchand and Allwardt, 1981.
[3] Ventura dates from Lajoie *et al.*, 1979 and Sarna-Wojcicki *et al.*, 1976.
[4] Pennsylvania dates from Marchand *et al.*, 1978.
[5] Las Cruces dates from Gile *et al.*, 1981.

surface A-clay (Janda and Croft, 1967), and age constraints of the next youngest alluvial unit.

Deposits of two late Holocene units were included in the Merced chronosequence. Post-Modesto II and post-Modesto III alluvial units are about 3000 and 200 yr old, respectively, based on data from tree rings as well as wood and charcoal samples dated by ^{14}C and uranium-series methods.

Ventura Area

The surfaces of the xeric-coastal chronosequence are located near Ventura in Southern California and recently have been studied by Lajoie *et al.* (1982) and Sarna-Wojcicki *et al.* (1976). Vegetation consists of annual grasses and coastal scrub. Marine terraces consist of wave-cut platforms cut into marine Cenozoic rocks that are overlain by seaward-thinning wedges of alluvium and colluvium. The terrestrial deposits are arkosic in composition and constitute the parent material of the soils. Deposition of alluvial sediments over the marine terraces probably closely followed marine regression and terrace emergence as a result of uplift and stream incision; sampling sites are located away from the back edge of the terraces in order to minimize the thickness of colluvium in the soil parent materials.

The oldest unit of the Ventura chronosequence, the Ventura Terrace, is about 85,000 to 125,000 yr old (Table 1) based on amino acid analysis of marine mollusks (Wehmiller *et al.*, 1978) collected at the contact of the terrestrial deposits and the wave-cut platform. The mollusk shells indicate a temperature regime that is slightly cooler than at present and considerably cooler than the temperature regime that existed about 120,000 to 130,000 yr ago (Lajoie *et al.*, 1979). The second oldest terrace, Punta Gorda, is estimated to be 40,000 yr old (Table 1) based on amino acid analysis of mollusk shells (Wehmiller *et al.*, 1977; Lajoie *et al.*, 1979), uranium-series ages of mollusks (Kaufman *et al.*, 1971), and presence of cool-water mollusks that limit the age to younger than about 130,000 yr. Two Holocene deposits were included in the Ventura chronosequence. Both deposits are slightly younger than the Sea Cliff Terrace that is between about 2500 and 5500 yr old, based on mollusk analyses by ^{14}C (K. Lajoie, written communication, 1982) and amino acid methods (Wehmiller *et al.*, 1978). The older of the two Holocene surfaces occurs in one site (sample V1) as a fluvial terrace that is graded to the Sea Cliff Terrace and is about 2000 yr old based on ^{14}C analysis of charcoal from a similar terrace in an adjacent canyon. The other site of this unit (sample V6), composed of stream deposits over a marine platform at the mouth of a canyon, is also about 2000 to 2500 yr old based on ^{14}C analysis of mollusk shells from an Indian midden found at the surface directly across the canyon from the sampling site (K. R. Lajoie and A. M. Sarna-Wojcicki, written communications, 1982). A 2000-yr age was used for the surface of both sites. The youngest unit of the chronosequence is composed of alluvial fans that overlie the Sea Cliff Terrace; based on Holocene uplift rates of the Sea Cliff Terrace, these sites were assigned an age of 1000 yr, which may be a maximum age for the surface and soil.

In all four units of the Ventura sequence, there is about a meter of silt and clay in the surface horizons of the soils. Muhs (1980) reported that eolian clays are a significant component of the soils of Santa Catalina Island to the southwest; we propose that the fine-grained cap in the Ventura soils may also be of eolian origin. For the quantification of total texture (see Methods) we assumed that the uppermost A horizons have a texture similar to that of the parent material of lower A and B1 horizons within the fine-grained cap. More studies are needed to determine if the caps are composed of pedogenic clay that has not yet moved into lower B horizons.

Pennsylvania Area

The Pennsylvania chronosequence occurs in a udic soil-moisture regime and is characterized by a humid high-leaching climate. The chronosequence consists of glacial deposits along the central Susquehanna River valley of central Pennsylvania. Soil data and geologic history used in this report were taken from Marchand *et al.* (1978), Marchand (1978), and E. J. Ciolkosz (written communication, 1980). The seven soils selected for this study are developed in till, outwash, or eolian sand (Table 1 and Appendix 3), and these deposits were derived primarily from middle Paleozoic sedimentary rocks. Age control for the deposits is minimal and many of Marchand's correlations and age estimates are based on weathering characteristics and soil development. The interdependence of age control and soil development make the age comparisons of this chronosequence quite tentative, but characterization of age trends are valid because relative age control is reliable. The oldest till, termed Penny Hill deposits, was formed by the first ice advance into the southern Susquehanna valley and were correlated by Marchand *et al.* (1978) with the later part of marine isotope stage 10 (ca. 330,000 yr B.P.). The next younger Laurelton deposits are older than the Altonian till and younger than Penny Hill deposits; Marchand tentatively correlated them with marine isotope stage 8 (ca. 260,000 yr B.P.). The next younger deposit is a till correlated with Altonian till of Illinois, which Marchand correlated with isotope stage 4 (ca. 60,000 yr B.P.). The Altonian till was derived from red sandstone and shale bordering the Appalachian Plateau, and we assigned redder parent-material colors to soils of this unit as compared to other soils of Pennsylvania (Appendix 3). The fourth youngest till, correlated and referred to by Marchand *et al.* (1978) as the Kent Till, is about 15,000 yr old based on ^{14}C ages from the organic lake and bog sediments bordering the drift boundary. The youngest sediments form stream terraces overlain by eolian sand. Marchand estimated an age of 11,000 yr B.P. for this youngest terrace, but the dunes could be considerably younger; possibly they are related to the middle hypsithermal about 7000 to 4000 yr B.P. (E. J. Ciolkosz, written communication, 1982).

Las Cruces Area

The aridic chronosequence, located near Las Cruces, New Mexico, consists of alluvial fans or fan piedmonts (bajadas) of the Organ Mountains and Rio Grande River. The parent material is fan sediment composed of monzonite and rhyolite derived from the Organ Mountains and a mixed assemblage of lithologies from the fluvial facies of the Plio–Pleistocene Camp Rice Formation (Strain, 1966; Gile *et al.*, 1981). Vegetation consists of creosote bush, snakeweed, tarbush, and other desert scrub. For this study, we used geologic and soil descriptions of Gile and Grossman (1979) and Gile *et al.* (1981).

The oldest of the five geomorphic surfaces is the La Mesa surface, part of a broad basin floor of the Rio Grande River valley (Gile *et al.*, 1981). It is subdivided into upper and lower surfaces, which are about 750,000 and 500,000 yr old, based on Irvingtonian and Blancan fauna (Gile *et al.*, 1981) and soil-carbonate accumulation (Machette, 1982) within the upper unit and on volcanic ashes within the lower unit to the north of the study area (Strain, 1966; Hawley *et al.*, 1976; Gile *et al.*, 1981). The four younger surfaces are fan piedmont deposits adjacent to the Organ Mountains. Minimum ages of the older three surfaces, the Jornada I, Jornada II and Isaacks' Ranch, were determined by ^{14}C dates of soil carbonate (Gile and Grossman, 1979), but rates of pedogenic carbonate accumulation (R. J. Arkley, written communication, 1982), thermoluminescence (R. D. May and M. N. Machette, written communications, 1982), and uranium-trend techniques (J. N. Rosholt, written communications, 1982) of pedogenic carbonate indicate significantly older ages, which we used for this study. The Jornada II deposits are probably about 120,000 yr old, and the Isaacks' Ranch deposits are probably about 20,000 yr, based on data of the above techniques. The youngest surface, underlain by Organ alluvium, consists of three separate units (Gile *et al.*, 1981), but only the oldest one was used in this study (J. Hawley, personal communication, 1981); it has an age of about 4000 yr based on ^{14}C ages of carbonate and wood within the deposit.

METHODS

Soil properties within each chronosequence were described in the field according to methods described by Soil Survey Staff (1951, 1975) and Birkeland (1974). Field properties were then quantified and compared according to the methods of Harden (1982a). Figure 1 outlines the steps for the Soil Development Index.

We encountered some new problems and situations when indexing these soils. Some of the Pennsylvania tills apparently had hard or firm consistences, and instead of using the loose class for parent materials of these soils, we used the loosest consistence class found within the profile (Appendix 3). In addition to the eight properties devised in 1982, we developed two new properties for soils of the Las Cruces area (Fig. 2). These soils contain abundant calcium carbonate which has a marked effect on hue, value, and chroma. *Color-paling* is an inverse scale of rubification, in which ten points are assigned for each hue decrease toward yellow and each chroma decrease. *Color-lightening* is the inverse of melanization and is quantified by assigning ten

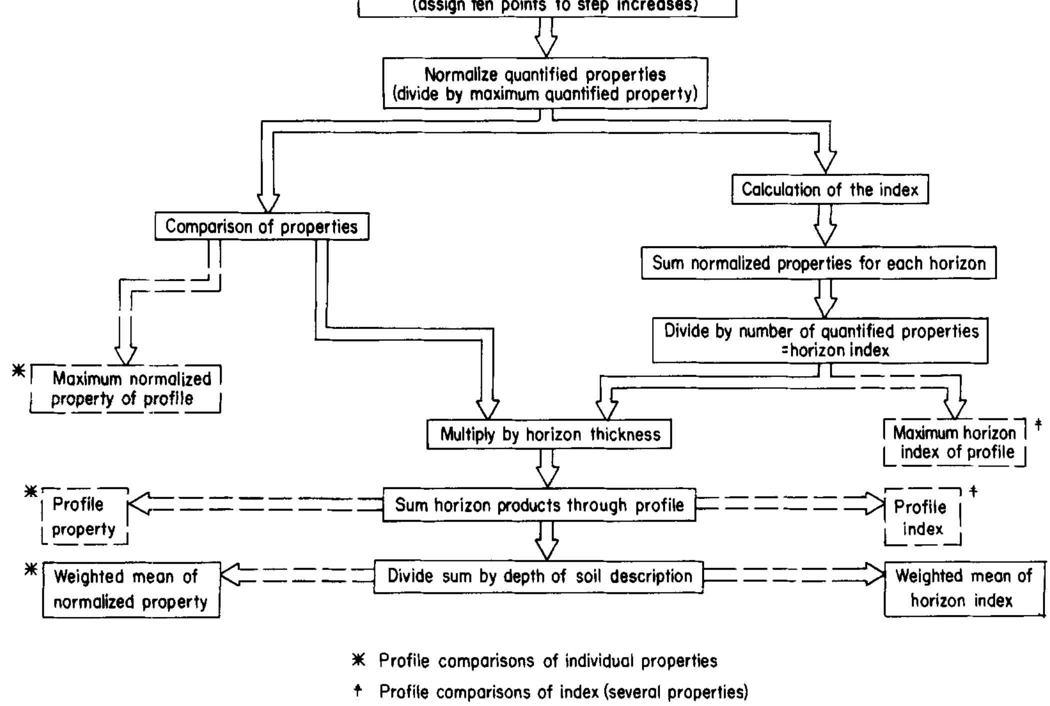

FIG. 1. Flow diagram for deriving comparative measures of the Soil Development Index (modified from Harden, 1982a).

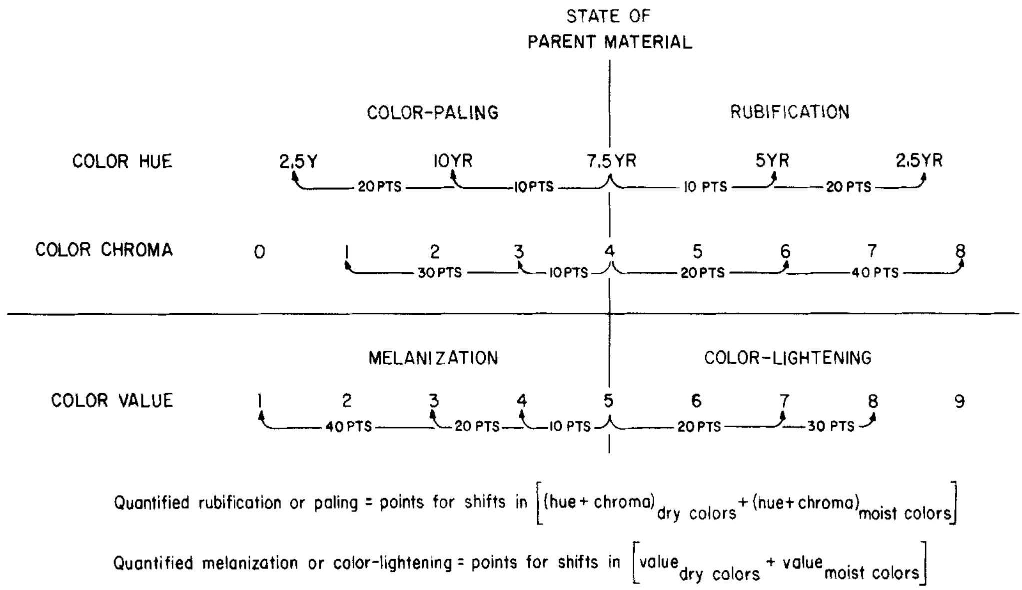

FIG. 2. Diagrammatic sketch for deriving properties of soil color for a soil horizon with a parent-material color of 7.5 YR 5/4 (moist). For a horizon with multiple colors, the minimum points are added to maximum points for a given color property, an the sum is divided by two.

points for each increase in color value. If more than one color is present within the horizon, the same procedure is used as in combining mixed colors for rubification. Points for moist and dry colors are added together for both cases. To normalize these quantified properties (Fig. 1, step 3), the maxima for color-paling and color-lightening were 60 and 80, respectively.

To study and compare individual properties, we compared normalized properties; to study overall soil development, we compared the horizon index or the profile index (Fig. 1).[1] Various calculations of normalized properties and the combined index were used for soil comparisons. One measure for comparing soils is the *maximum normalized property* or the *maximum Horizon Index* of a profile. A second type of profile comparison includes the *profile property* and *Profile Index,* in which the normalized property or Horizon Index is multiplied by horizon thickness and the products are summed through the profile (Fig. 1, step 8). A third type of profile comparison is the *weighted mean* of the normalized property or Horizon Index in which the profile property or Profile Index is divided by the depth of soil description (Fig. 1, step 9).

[1] The term index, as in horizon index and profile index, refers to a combination of two or more properties.

RESULTS

Comparative techniques of the Soil Development Index allow us to determine whether certain soil properties develop systematically with depth and age, and whether they develop similarly in different environments. Properties that develop systematically in different areas are compared in time plots to determine whether they develop at similar rates. When all properties are combined into Horizon and Profile indices, rates of overall soil development can be compared.

Many field properties are related to clay content, and most soils of this study appear to be characterized by clay formation and orientation. Las Cruces soils, with their high amounts of carbonate, have exceptional depth and age trends, but several properties display development with time. In soils of all chronosequences, the depth and age trends of total texture and clay films are highly correlated with clay content, and the maximum values of total texture and clay films occur in argillic horizons at depths of approximately 0.3–1.5 m (Fig. 3). Because the Las Cruces soils usually have argillic horizons overlying carbonate-rich (Cca and K) horizons, their maximum textures occur at shallower depths than soils of the three other areas (Fig. 3), which are generally noncalcareous. Rubification of most soils also corresponds to clay content but in a more general manner than clay films and total texture; maximum values are commonly at depths of about 0.5 to 2.0 m (Fig. 3). Las Cruces soils that are older than about 120,000 yr have very pronounced Cca or K horizons (carbonate stage III and greater; Gile and Grossman (1979)), and rubification is low or nil in B-horizon positions; however, color-paling increases systematically with age in the carbonate horizons. In all chronosequences, dry and moist consistence and soil structure are highest in A horizons of young soils, yet highest in B horizons of old soils. The depth position of the maximum consistence and structure changes when argillic or Cca or K horizons form. Melanization, limited to shallow depths by definition, is highest in surface A horizons and probably corresponds to organic carbon content. Color-lightening in Las Cruces soils is highest in carbonate horizons.

Plots of properties versus age are the best tests of whether a property develops systematically with age. Correlation coefficients of property versus age can be used to study the property–age relationship, but

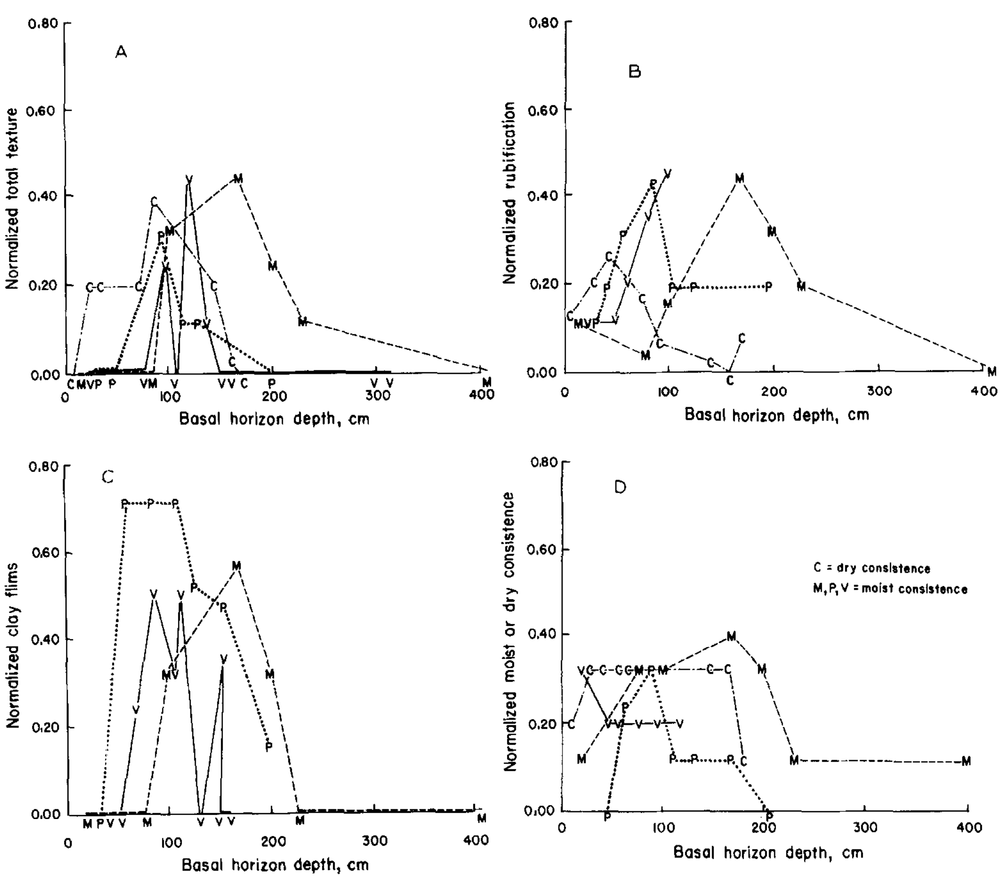

FIG. 3. Depth plots of four field properties for soils approximately 40,000 to 120,000 yr old. Normalized (a) total texture, (b) rubification, (c) clay films, and (d) moist consistence of soil horizons are plotted against basal horizon depth in centimeters from Appendices 1–4.

their reliability is limited because (1) the age range of a chronosequence can weight some soils more heavily in the statistical calculation, (2) the reliability of age assignments is limited and variable between age groups, and (3) the relationship may not be linear. We found that time curves were straightest when properties and indices or their logs are plotted against log time. Correlation coefficients of profile comparisons versus $\log_{10}$ age are included in Table 2.

Age Development of Individual Properties

Five properties, including total texture, rubification, clay films, dry consistence, and moist consistence, correlate most significantly with age in the four chronosequences (Table 2, Fig. 4). Merced and Ventura soils display systematic and similar age development of all four properties of Figure 4, and it appears that the coastal environment of Ventura has little effect on development rates of these four properties. Dembroff *et al.* (1982) concluded that gravelly soils along the Ventura River develop very rapidly compared to most areas, but this study suggests that the coastal climate has little or no effect on soil-development rates, at least in nongravelly deposits. For Pennsylvania soils, total texture, rubification, and clay films (Fig. 4) increase systematically with age, and these properties appear quite similar to Merced and Ventura soils for ages less than 60,000 yr. After about 60,000 yr, total texture and clay films of soils of Pennsylvania appear to decline, suggesting a steady state or declining state of development. ~~Harden (1982a)~~ proposed that steady-state analysis be judged by trends in the maxima of profiles rather than in profile properties in order to separate the properties from the factor of soil thickness. In Appendix 3, the maximum texture of Pennsylvania soils is highest in the oldest soil, and this property does not reach a steady state of development within the age range studied. The maximum of clay films, however, is found at an intermediate age (Appendix 3), suggesting that clay films reach a steady state of development at about 60,000 yr for Pennsylvania soils. Alternatively, the decline in profile texture and clay films may be due to the limited depth (<2 m) of the soil descriptions. Unlike total texture and clay films, rubification of Pennsylvania soils increases throughout the age range of the chronosequence and is similar to the xeric regime soils for any given age range (Fig. 4).

Several aspects of the development of

TABLE 2. CORRELATION COEFFICIENTS (r) FOR SOIL PROPERTIES VERSUS LOG AGE

	Total texture	Rubification	Clay films	Structure	Dry consistence	Moist consistence	Melanization	pH lowering	Color paling	Color lightening	Index of[1] 8 properties	Index of[2] 4 properties	n	r[3] at 5%
maximum normalized property in profile versus log age														
Merced	0.944*	0.905*	0.942*	0.483	0.916*	0.550	0.949	0.485	--	--	--	--	21	0.433
Ventura	0.948*	0.905*	0.989*	0.635	0.743*	0.846	-0.499	--	--	--	--	--	8	0.707
Pennsylvania	0.855*	0.899*	0.441*	0.422	--	0.271*	0.032	0.874	--	--	--	--	7	0.754
Las Cruces	0.198	-0.080	--	0.452*	0.732*	--	0.077	--	0.710*	0.949*	--	--	14	0.532
profile property divided by soil thickness (cm) versus log age														
Merced	0.809	0.737	0.823	-0.723	0.569	0.395	0.006	0.377	--	--	0.638	0.799	21	0.433
Ventura	0.792	0.782	0.938	0.551	0.636	0.480	-0.035	--	--	--	0.765	0.960	8	0.707
Pennsylvania	0.930	0.898	0.432	0.270	--	0.298	0.187	-0.103	--	--	0.758	0.881	7	0.754
Las Cruces	0.517	0.213	--	0.425	0.250	--	-0.059	--	0.818	0.880	0.312	0.856	14	0.532
log (profile property) versus log age														
Merced	0.934	0.974	0.940	0.740	0.919	0.917	0.208	0.605	--	--	0.962	0.981	21	0.433
Ventura	0.961	0.894	0.991	0.752	0.857	0.737	0 .659	--	--	--	0.876	0.957	8	0.707
Pennsylvania	0.881	0.723	0.400	0.224	--	0.294	0.276	0.228	--	--	0.546	0.723	7	0.754
Las Cruces	0.796	0.560	--	0.637	0.432	--	0.192	--	0.911	0.954	0.532	0.891	14	0.532

[1] Index for eight properties includes any properties available of first eight properties listed above from left to right.

[2] Index for four properties includes the four properties with best correlations with log age (indicated by * in first four rows).

[3] Correlation coefficient for 5% significance level, n-2 degrees of freedom; null hypothesis that slope of regression = 0.

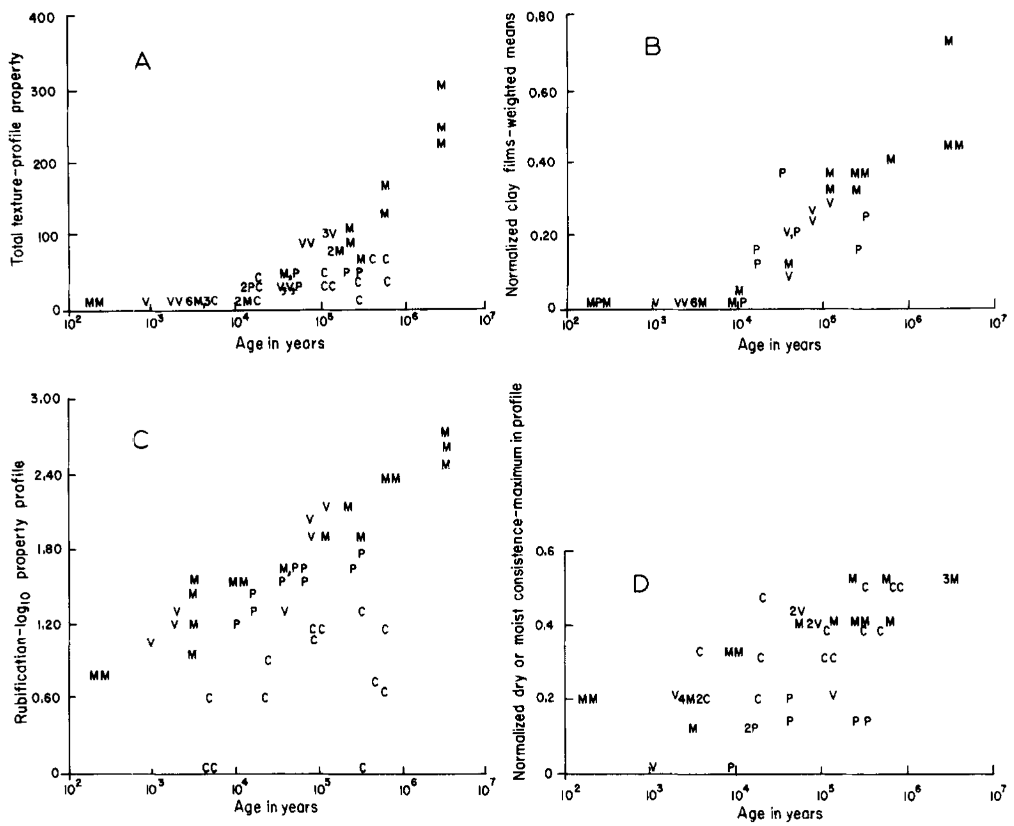

FIG. 4. Profile calculations of four selected properties versus age for soils of four chronosequences. Profile calculations, illustrated in Fig. 1, were applied to (a) total texture, (b) clay films, (c) rubification, and (d) dry consistence, if available, or moist consistence. Data plotted are in or calculated from Appendices 1–4. Correlation coefficients are in Table 2.

Las Cruces soils are somewhat exceptional to other chronosequences (Fig. 4). The correlation of total texture and rubification with age is much less significant (r values range from 0.080 to 0.196 for the various profile comparisons in Table 2), as compared to other chronosequences. The age plots suggest that rubification of Las Cruces soils develops very systematically for 100,000 yr, beyond which soils become variable and often have low values compared to younger soils. Rubification is notably lower than in other soils of similar ages, but the rate of development may be similar to other chronosequences. Perhaps the parent-material color that we assigned to Las Cruces alluvium was too high on the rubification scale; parent-material colors were difficult to determine because the sediments and their sources have very different colors. Development of total texture of Las Cruces soils also declines in older soils, but dry consistence appears to increase with considerable variability throughout the age range of Las Cruces soils.

Age plots suggest that total texture and rubification of aridic soils develop with age only as long as clay build-up and/or clay orientation are predominant over carbonate accretion. When carbonate content and morphology overwhelm clay morphology, which occurs in Las Cruces soils within about 100,000 yr, texture and rubification are poor indices of age development. The transformation of soil morphology appears to occur when carbonate morphology reaches stage II to stage III (Gile *et al.*, 1966), which occurs after about 100,000 yr in the Las Cruces area.[2] Unlike texture and rubification, dry consistence and structure of Las Cruces soils continues to develop even when carbonate morphology becomes predominant over clay morphology. Although structure is not always indicative of age for all chronosequences, it appears to develop regularly throughout the age range of Las Cruces soils. Structures of old Las Cruces soils are described as columnar and blocky (Gile and Grossman, 1979), and it appears that carbonate retains structures typical of clay-rich soils (calcium would act as a strong flocculent, thereby inducing well-defined structures).

With the exception of color-paling and color-lightening, properties other than those shown in Figure 4 generally do not develop significantly with age. Moist consistence often has lower r values than dry consistence (Table 2), and the authors believe this is due to the variable field-moisture state of the moist consistence. Lowering of pH has significant age correlation only in some profile calculations of Merced and Pennsylvania soils. The development of melanization is limited to young soils (Harden, 1982a), and the usefulness of both pH and melanization may be limited to specific age ranges (see Jenny (1941), Harden and Marchand (1977) and Harden (1982b) for discussion of age range of property development). Color-paling and color-lightening have high age correlations, and both indices emphasize the importance of complete field descriptions for the evaluation of soil development; they also demonstrate the versatility of the Soil Development Index and its ability to incorporate properties of different soil types.

Combining Properties into One Index

The Horizon and Profile indices incorporate several properties into one index. We calculated the indices using two methods: the first with as many of the eight properties used by Harden, in 1982, and the second with the four properties that correlated best with age for each chronosequence (indicated by asterisks in Table 2). As discussed under Methods, missing data are accounted for in the index calculation. When all eight properties are included in the index (Fig. 5a and b), Profile indices increase systematically with age, and indices of all four chronosequences appear to increase at similar rates (the Las Cruces soils have consistently lower values but generally have a similar slope or rate). The weighted mean of the eight-property index has considerable scatter, and the age correlations are much lower than for Profile indices. The correlation of both the Profile Index and its weighted mean (Fig. 5c) is much improved when only the "four best" properties are used for the index, and the indices appear to increase at similar rates for the four chronosequences.

For a closer examination of the index with four best properties, we plotted Horizon indices versus depth and time in a three-dimensional diagram (Fig. 6). We selected age groups that could be deciphered in the figure and chose one soil of those age groups that had the maximum Horizon Index or that were described to the greatest depth. The area shaded below the curve represents the Profile Index, which is a summation of the Horizon Index–depth product. The similarity in development rates of the Four Best Index (Fig. 5d) is apparent in the similarities in shaded areas for a given age group. Although the shaded areas often have different shapes, the total areas are not substantially different.

CONCLUSIONS AND DISCUSSION

This study demonstrates that the Soil Development Index is useful for comparing the development of different soils in a variety of environments; it can be adapted to various soil types and new properties can be incorporated into the index so that many

[2] The time that it takes for texture, clay films, and other properties to become obscured by carbonates probably corresponds to the rate of carbonate influx to the area, which varies significantly among different areas (Machette, 1982).

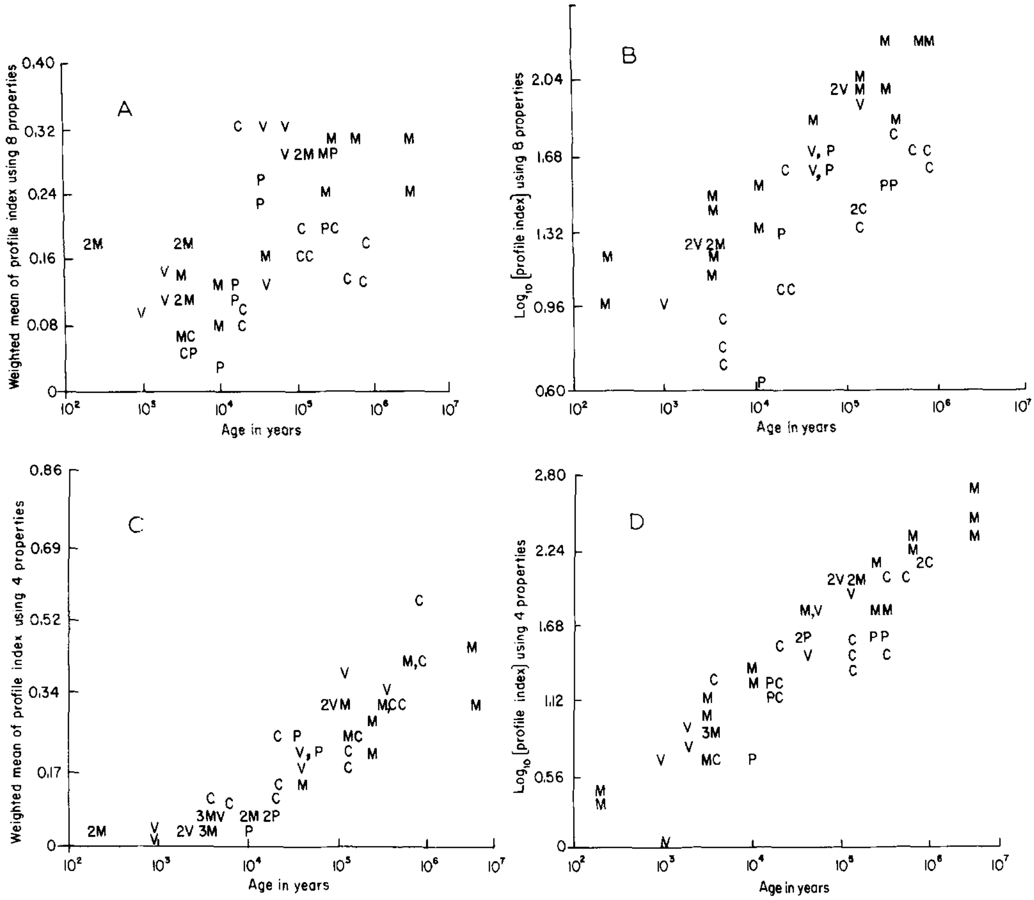

FIG. 5. Index calculations for soils of four chronosequences versus age. Profile comparisons are calculated according to Fig. 1. Data are in or calculated from Appendices 1–4. Correlation coefficients for each chronosequence are in Table 2.

aspects of pedogenesis are quantified. When several properties are combined into the index, a quantitative comparison can be made of overall soil development.

By studying soils with sandy, granite-like parent materials, we found that total texture, rubification, clay films, and dry and moist consistence develop systematically with age and appear to develop similarly in the four climatic regions studied. The other properties, including structure, melanization, pH lowering, color-lightening, and color-paling, develop systematically in some, but not all, climatic zones.

The overall development of soils, expressed as the profile index, appears to develop at similar rates among the four study areas. Before concluding that soil-development rates are similar among these areas, however, two important aspects of these data should be considered. First, the age control of these chronosequences is good, but soil ages have considerable ranges of uncertainty. For example, the older Pennsylvania soils have no radiometric age control; experimental dating techniques that were applied to soils in the Merced and Las Cruces areas must be studied further; slope processes in the Ventura area may have contributed sediment to the soils; and tectonism may have affected the stability of the surfaces and therefore the soils. As Yaalon (1975) emphasized, more precise and more closely spaced age control would improve the accuracy of the time function. For general age ranges (such as Holocene, Wisconsin, and Pleistocene), the development index does appear quite similar for

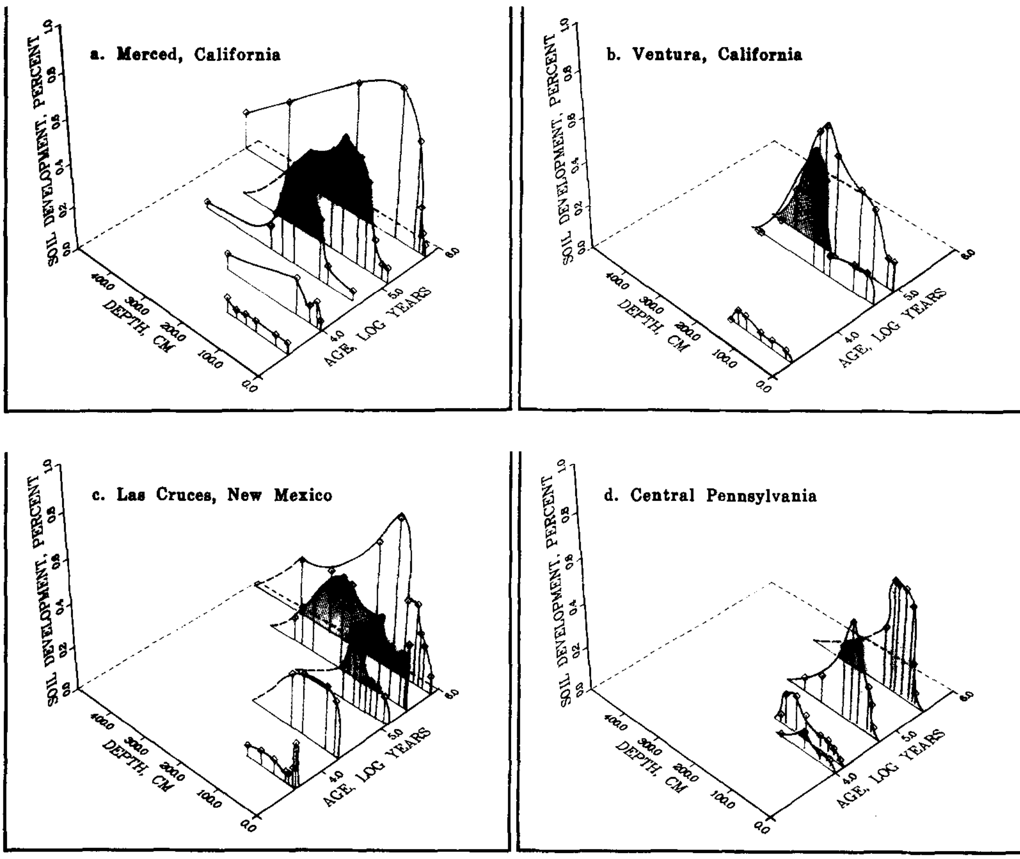

FIG. 6. A three-dimensional plot of soil development and depth versus age. Data are from selected soils in Appendices 1–4. Soil development is represented by the horizon index using "four best" properties of Table 2. Points represent Horizon Index; vertical lines are drawn from surface to depth of horizon. Shaded areas represent Profile Index of Fig. 1.

similar-aged soils of the different age groups, possibly emphasizing the minimum range of comparability of soil development. A second consideration in this comparison of soil development is that the index is a combination of several properties that may or may not develop at similar rates or for similar time spans. For example, in Merced soils dry consistence develops systematically for about 100,000 yr, then reaches a steady state of development, beyond which time consistence generally remains hard or very hard. In contrast, clay films in the Merced soils develop from about 40,000 yr to at least 3 myr. When the two (or more) properties are combined into one index, the resultant development rate appears to increase throughout the age span of the chronosequence. Although the index offers a single value for evaluating soil development, the soil properties in that case actually had different rates and age spans of development.

Others have reported on the significant effects of climate on soil properties (Jenny 1980) and their rates of development (Bockheim, 1980), and there are important morphological differences in the soils of this study: desert soils often appear to be concentrated within relatively shallow depths; soils of humid regions are notably deep; soils along the coast typically contain dark-colored clay tongues or films into very deep horizons, which is probably related to the dispersive effect of sodium on clays. To emphasize these soil differences, we compared depths, horizon thicknesses, and various calculations, but differences did not appear to be significant relative to variability within each chronosequence. When more data are compiled, other calculations, such as weighted means or maxima and minima values in profiles, or depths at which maxima occur, might resolve climatic differences. More data are needed to quantify soil factors such as parent-material mineralogy and grain size, to refine age control and to narrow the gaps between different-aged units, and to compile several sets of chronosequences in different climates in order to assess accurately the effects of climate on soil-development rates.

In conclusion, the Soil Development Index demonstrates that many properties of soils develop systematically with age. If samples are separated and grouped according to soil-forming factors and described carefully according to Soil Survey Staff procedures, the development of soil properties is found to be highly correlated with age, and quantitative comparisons of development rates can be made. In the four climatic zones of this study, certain properties and calculations of properties develop at similar rates, at least for general age categories. The Profile Index is especially useful for comparison of soil development, because it appears to develop most similarly in the differrent climates of this study. Soil field properties could be quantified into the ten properties described here and used to develop the relative geochronology of unmapped deposits where other methods are absent or need checking. These methods can also serve as a preliminary guide to soil age by correlating soil-development rates from areas of similar parent materials and slope but possibly of different climatic settings.

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APPENDIX 1

Maximum-Normalized and Profile Properties for Soils of the Xeric-Inland Chronosequence, Merced, California[1]

	Parent Material Properties						
Geomorphic surface: alluvial terraces and fans Vegetation: riparian and valley grassland MAP 35 cm MAT 15°C Relief: elevation 12 to 230 m, slope 0-5%	Dominant Lithology	Dry color	Moist color	Clay films	Structure	Consistence	pH
	arkosic alluvium	10YR7/2	10YR6/2	none	single grain	loose	5.7

Profile	Age (years)	Depth (cm)	Normalized Property maximum of profile: Total texture	Rubification	Clay films	Structure	Dry consistence	Moist consistence	Melanization	pH lowering
pm15	200	51	0.00	0.21	0.00	0.33	0.20	0.20	0.71	0.60
pm19	200	80	0.00	0.11	0.00	0.33	0.20	0.20	0.71	0.60
pm8	3,000	76	0.00	0.16	0.00	0.33	0.20	0.20	0.71	0.40
pm13	3,000	160	0.00	0.21	0.00	0.55	0.10	0.10	0.71	0.41
pm14	3,000	230	0.00	0.16	0.00	0.50	*	0.10	0.86	0.38
pm16	3,000	236	0.00	0.21	0.00	0.33	0.20	0.20	0.86	0.36
pm17	3,000	120	0.00	0.21	0.00	0.33	0.20	0.20	0.71	0.33
pm18	3,000	175	0.00	0.21	0.00	0.50	0.20	0.20	0.86	0.55
M31	10,000	254	0.00	0.16	0.00	0.50	0.30	0.20	0.71	0.07
M46	10,000	250	0.11	0.16	0.23	0.50	0.30	0.30	0.71	0.41
M12	40,000	413	0.44	0.42	0.54	0.50	0.40	0.30	0.71	0.37
R9	130,000	400	0.67	0.32	0.50	0.33	*	1.00	0.86	0.55
R33	130,000	300	0.56	*	0.69	0.50	0.40	1.00	*	0.50
R10	250,000	500	0.56	0.55	0.65	0.67	0.50	0.40	0.57	0.44
R32	250,000	360	0.44	0.37	0.69	0.33	0.40	1.00	0.57	0.44
R30	330,000	220	0.56	0.58	0.62	0.50	0.40	0.40	0.57	0.55
T6	600,000	190	0.78	0.74	0.73	0.67	0.50	0.40	0.86	0.49
T11	600,000	500	0.89	0.63	0.88	0.50	0.40	0.40	0.86	0.33
CH1	3,000,000	350	1.00	0.95	1.00	0.50	0.50	1.00	0.43	1.00
CH2	3,000,000	1000	1.00	0.89	0.81	0.50	0.50	0.30	0.43	*
CH3	3,000,000	1000	1.00	1.00	0.81	0.50	0.50	0.30	0.57	*

Profile	Profile Property: Total texture	Rubification	Clay films	Structure	Dry consistence	Moist consistence	Melanization	pH lowering	Index[2] 8 properties	Index[2] 4 properties
pm15	0.00	7.17	0.00	1.32	3.00	3.50	14.75	29.71	9.15	2.54
pm19	0.00	6.22	0.00	6.56	*	10.80	25.09	26.78	14.06	2.30
pm8	0.00	8.92	0.00	16.83	9.60	11.30	23.61	18.53	13.10	4.45
pm13	0.00	21.30	0.00	20.69	11.20	11.20	31.03	21.70	16.97	8.21
pm14	0.00	24.25	0.00	23.09	*	20.00	42.11	47.37	26.38	8.09
pm16	0.00	23.46	0.00	11.37	15.10	15.10	34.23	30.87	16.28	9.29
pm17	0.00	17.75	0.00	13.54	19.40	19.40	39.21	15.11	16.48	8.57
pm18	0.00	34.94	0.00	21.53	18.00	18.00	38.32	86.22	30.17	14.25
M31	0.00	36.94	0.00	10.00	38.70	43.00	44.90	1.40	19.89	18.87
M46	0.99	36.85	9.18	13.59	34.50	54.80	73.36	58.18	33.73	20.39
M12	46.97	53.04	52.84	96.30	85.00	43.80	30.44	49.83	67.05	59.47
R9	85.45	91.45	126.00	59.40	*	*	32.55	191.00	115.85	100.97
R33	74.42	*	113.89	85.53	81.30	72.00	999.00	*	87.85	92.83
R10	99.08	152.84	168.02	226.68	160.80	*	33.08	96.12	146.74	141.21
R32	74.03	*	123.12	61.40	118.50	103.20	33.45	*	89.07	68.74
R30	55.52	89.70	76.23	*	55.70	*	21.34	76.66	65.79	70.16
T6	119.80	222.20	199.50	108.50	109.00	117.00	87.30	131.90	148.10	161.98
T11	166.70	276.85	208.00	*	86.40	85.80	57.08	133.89	148.78	212.66
CH1	247.28	292.64	258.87	146.27	110.60	*	47.70	320.87	244.39	249.67
CH2	303.52	382.91	444.44	21.60	161.70	126.80	23.10	*	232.94	317.53
CH3	227.16	585.78	458.08	28.39	108.10	76.90	27.09	*	306.93	439.92

[1] From Harden (1982).

[2] Profile Index as in Fig. 1. Index of four properties includes texture, rubification, clay films, and dry consistence.

* Missing data.

APPENDIX 2

Maximum-Normalized and Profile Properties for Soils of the Xeric-Coastal Chronosequence, Ventura, California[1]

Geomorphic surface: marine terraces covered by terrestrial alluvium
Vegetation: coastal chaparral and scrub
MAP 35 cm MAT 15°C
Relief: elevation 7 to 170 m, slope 5-10%

Parent Material Properties						
Dominant Lithology	Dry color	Moist color	Clay films	Structure	Consistence	pH
sedimentary alluvium	2.5YR7/2	2.5YR6/2	none	single grain	loose	5.7

Normalized Property
maximum of profile

profile	Age (years)	Depth (cm)	Total texture	Rubification	Clay films	Structure	Dry consistence	Moist consistence	Melanization
vent 2	1,000	100	0.00	0.21	0.00	0.33	*	0.20	0.47
vent 7	1,000	100	0.00	*	0.00	0.00	0.00	0.00	*
vent 1	2,000	160	0.00	0.21	0.00	0.67	*	0.10	0.47
vent 6	2,000	120	0.00	0.21	0.00	0.67	0.20	0.00	0.71
vent 4	40,000	310	0.56	*	0.50	0.67	0.40	0.40	*
vent 5	40,000	155	0.42	0.30	0.50	0.67	0.40	0.30	0.47
vent 8	85,000	300	0.78	0.47	0.69	0.67	0.40	0.40	0.47
vent 9	85,000	311	1.00	0.42	0.57	0.67	0.40	0.30	0.35

Profile Property

Profile	Depth cm	Total texture	Rubification	Clay films	Structure	Dry consistence	Moist consistence	Melanization	INDEX[1/] all properties	INDEX[1/] 4 properties
vent 2	100	0.00	12.63	0.00	1.67	*	20.00	14.35	9.64	4.20
vent 7	100	0.00	*	0.00	0.00	0.00	*	0.00	*	0.00
vent 1	160	0.00	21.61	0.00	40.16	*	5.30	34.77	17.08	7.26
vent 6	120	0.00	14.73	0.00	33.33	10.00	0.00	51.76	16.38	6.18
vent 4	310	17.66	*	25.12	47.75	*	44.60	*	39.58	61.45
vent 5	155	10.11	22.27	28.11	46.16	*	25.30	28.23	49.79	26.69
vent 8	300	114.45	91.31	73.80	120.50	95.20	92.50	69.83	94.75	93.72
vent 9	311	127.78	102.61	80.19	136.67	51.40	55.90	40.09	91.91	97.61

[1] Unpublished soil descriptions, USGS.
[2] Profile Index calculation as in Fig. 1. Index of four properties includes total texture, rubification, clay films, and dry consistence.
* Missing data.

APPENDIX 3

Maximum-Normalized and Profile Properties for Soils of the Udic Chronosequence, Susquehanna River Valley, Central Pennsylvania[1,2]

Geomorphic surface: glacial moraines, outwash; sand dune
Vegetation: mixed hardwoods, conifers
MAP 254 cm MAT 10°C
Relief: elevation 265 to 330 m, slope 0-5%

Parent Material Properties						
Dominant Lithology	Profiles	Moist color	Clay films	Structure	Dry Moist consistence	pH
wind-blown sands	p1	10YR6/4	none	single grain	loose	5.7
brown glacial tills	p3,4,5	2.5Y5/4	"	"	"	"
red glacial tills	p2,6,7	7.5YR5/3	"	"	"	"

NORMALIZED PROPERTY
maximum of profile

Profile [2/]	Age (years)	Depth (cm)	Total texture	Rubification	Clay films	Structure	Moist consistence	Melanization	pH lowering
p1-S74 49-13	11,000	147	0.00	0.32	0.00	0.33	0.00	0.29	0.03
p2-S71 45-79	15,000	200	0.00	0.32	0.35	0.67	0.10	0.29	0.05
p3-S71 45-80	15,000	175	0.00	0.32	0.23	0.67	0.10	0.29	0.13
p4-S75 41-39	40,000	160	0.56	0.42	0.73	0.58	0.20	0.57	0.23
p5-S75 41-40	40,000	195	0.33	0.42	0.73	0.67	0.10	0.29	0.23
p6-S69 55-2	250,000	172	0.44	0.53	0.46	1.00	0.10	0.29	0.28
p7-S57 13-7	330,000	109	0.67	0.84	0.46	0.50	0.10	0.29	*

Profile Property

Profile	Depth (cm)	Total texture	Rubification	Clay films	Structure	Moist consistence	Melanization	pH lowering	INDEX[3/] all properties	INDEX[3/] 4 properties
p1-S74 49-13	147	0.00	17.64	0.00	6.77	0.00	5.80	0.52	4.25	4.41
p2-S71 45-79	200	0.00	23.53	25.98	79.57	10.82	7.26	49.80	21.81	15.11
p3-S71 45-80	175	0.00	25.86	25.98	79.57	9.14	7.26	49.80	22.61	13.98
p4-S75 41-39	160	36.13	41.19	34.28	64.77	20.08	60.22	23.25	41.32	37.89
p5-S75 41-40	195	22.30	47.05	71.20	83.39	9.91	45.01	31.30	44.52	39.92
p6-S69 55-2	172	44.58	54.55	29.13	60.37	8.64	9.10	22.45	33.40	37.11
p7-S57 13-7	109	32.46	65.77	24.89	41.58	7.38	*	*	32.12	36.22

[1] From Marchand and others (1978) and unpublished data of E. Ciolkosz.
[2] Profile numbers after hyphen are from Marchand and others (1978).
[3] Profile Index calculation as in Fig. 1. Index of four properties includes total texture, rubification, clay films, and moist consistence.
* Missing data.

APPENDIX 4

Maximum-Normalized and Profile Properties for Soils of the Aridic Chronosequence,[1] Las Cruces, New Mexico

Geomorphic surface: coalescent-fan piedmont
Vegetation: desert scrub
MAP 16 cm MAT 16°C
Relief: elevation 1300 m, slope 0–5%

Parent Material Properties

Dominant Lithology	Dry Color	Moist Color	Clay Films	Structure	Dry consistence	Moist consistence	pH
monzonite and rhyolite alluvium	7.5YR5/4	7.5YR4/4	none	single grain		loose	--

Normalized Property maximum of profile

Profile[1/]	Age (years)	Depth (cm)	Total texture	Rubification	Structure	Dry consistence	Melanization	Color paling	Color lightening
S59NM7-5	4,000	160	0.00	0.53	0.42	0.20	0.12	0.17	0.00
S62NM7-3	4,000	76	0.00	0.11	0.25	0.30	0.12	0.33	0.06
S67NM7-3	4,000	127	0.00	0.05	0.25	0.20	0.06	0.42	0.06
S59NM7-7	20,000	127	0.60	0.11	0.33	0.50	0.24	0.67	0.19
S70NM7-6	20,000	109	0.00	0.11	0.67	0.30	0.00	0.00	0.25
S81NM	20,000	141	0.20	0.00	0.83	0.20	0.24	0.00	0.13
S60NM7-6 1	20,000	142	0.20	0.16	0.83	0.40	0.12	0.25	0.50
S60NM7-7	120,000	165	0.40	0.29	0.50	0.30	0.24	0.33	0.38
S60NM7-13	120,000	114	0.20	0.26	0.00	0.30	0.29	0.42	0.38
S60NM7-10	290,000	127	0.20	0.00	0.67	0.50	0.00	0.83	0.88
S60NM7-21	290,000	305	0.20	0.21	0.67	0.40	0.12	0.67	0.81
S61NM7-8	500,000	340	0.40	0.11	0.67	0.40	0.00	0.83	0.88
S61NM7-7	800,000	353	0.40	0.16	0.67	0.50	0.29	0.92	0.81
S66NM7-12	800,000	251	0.40	0.21	0.67	0.50	0.12	1.00	1.00

Profile Property

Profile	Depth (cm)	Total texture	Rubification	Structure	Dry consistence	Melanization	Color paling	Color lightening	Index[2/] 8 properties	Index[2/] 4 properties
S59NM7-5	160	0.00	0.84	12.67	21.80	3.35	0.67	0.00	7.85	18.94
S62NM7-3	76	0.00	3.65	1.58	14.15	3.76	1.67	1.25	4.62	4.66
S67NM7-3	127	0.00	0.95	0.77	25.10	1.06	2.42	4.13	5.57	8.10
S59NM7-7	127	37.40	9.74	42.75	57.50	7.47	20.92	7.31	40.97	32.12
S70NM7-6	109	0.00	4.32	22.54	24.05	0.00	0.00	18.75	10.18	16.34
S81NM	141	10.80	0.00	17.83	20.40	2.59	0.00	12.14	10.32	12.60
S60NM7-6.	142	22.80	11.30	36.32	38.90	1.77	21.41	42.25	22.72	34.73
S60NM7-7	165	30.40	15.14	25.49	45.60	10.53	20.58	25.01	26.48	30.87
S60NM7-13	114	11.20	15.23	40.50	28.60	13.29	12.92	14.76	21.78	24.20
S60NM7-10	127	4.00	0.00	0.00	3.50	0.00	67.00	75.71	1.50	29.07
S60NM7-21	305	41.60	19.16	126.85	79.85	6.82	58.25	103.08	56.15	94.77
S61NM7-8	340	56.80	6.48	89.41	73.60	0.00	113.33	162.58	45.20	109.81
S61NM7-7	353	37.60	5.00	72.42	104.80	10.17	229.41	143.01	47.64	146.27
S66NM7-6	251	52.00	17.24	*	96.90	3.71	113.33	143.14	42.81	139.19

[1] From Gile and Grossman, 1979.

[2] Profile Index as in Fig. 1. Index of eight properties is after Harden (1982) which includes total texture, rubification, clay films, structure, dry and moist consistences, melanization and pH lowering. Index of four properties includes dry consistence, structure, color-lightening, and color-paling.

* Missing data.

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