Soil Forming Factors, Morphology and Classification-Santa Cruz Island, California

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Abstract - The objective of this study was to describe on a preliminary basis the field characteristics of Santa Cruz Island soils and to identify environmental factors that have the greatest influence on soil genesis, morphology and erosion. Soils from 163 sites on the island were sampled according to combinations of geology, vegetation, slope and aspect. The most frequently occurring soil great groups were Haploxerolls, Argixerolls, Xerorthents, Xerumbrepts and Xerochrepts. Because of the large extent of grass cover (>80%) and volcanic or Monterey shale parent material (>50%), Haploxerolls cover nearly one-half the island. When not eroded, island soils are typically 30-90 cm thick, have fine loam texture, massive or blocky structure and pH values between 5.5-7.5. Soil development on Santa Cruz Island reflects the interaction of multiple soil forming factors rather than the domination of any single factor. Nevertheless, our data show that distinct geographical subunits exist on the island, as demonstrated by the relationship between soil great groups, geologic substrate and vegetation.

Introduction

The soils of Santa Cruz Island have never been mapped. The objective of this study was to determine the field characteristics of the island's soils as a preliminary step in a project to map them on a predictive basis using a geographic information system (GIS). Moreover, following the removal of grazing animals from the island, the dynamics of vegetation succession will clearly be influenced by the variation in soil characteristics and extent of erosion. Therefore, a second objective of this study was to identify environmental factors that have the greatest influence on soil genesis, morphology and erosion. Our knowledge of these factors will aid in more comprehensive analyses of edaphic effects on vegetation recovery, incorporating laboratory and remotely sensed data and the geographic information system being constructed for the island (Crippen *et al.* 1987).

The earliest documented description of Santa Cruz Island soils was conducted by the Soil Conservation Service (1950), but concerned only farmed valley soils. Brumbaug (1980) used the USDA *Soil Taxonomy* to describe and classify some hillslope soils including Chromoxererts, Haploxerolls and Xerorthents. According to Brumbaugh (1983), many island soil profiles were truncated in the late 1800's as a result of grazing by an estimated 150,000 feral sheep. Brumbaugh (1983) stated that the type and extent of erosion (*e.g.*, sheet, gully and piping) of different parts of the island were related to geologic substrate. On San Clemente Island, Muhs (1982) attributes soil genesis to topographic position. Johnson (1979, 1980, 1987) emphasized the effects of climatic change and aeolian deposition on San Miguel Island soil genesis. Work by W. Allardice and others (pers. comm.) suggests that high levels of gypsum and sodium carbonate present in Santa Barbara Island soils are due to Ca and Na aerosol deposition from dust and ocean fog.

The extreme heterogeneity of relief, geology and vegetation suggests that the island could

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contain a large number of soil types, requiring a formidably large number of field sampling sites to adequately assess soil spatial variability. Several sampling methods were considered during extensive field reconnaissance and study of existing geologic, topographic and vegetation maps. We chose to stratify our sampling design on an *a priori* basis, taking various combinations of parent material, vegetation, slope angle and aspect as the most influential soil forming factors.

Methods

Soil Sampling: Soils were sampled (and subsequently mapped) on an *a priori* predictive basis. Profiles were sampled in proportion to the area that we estimated was covered by each combination of parent material, vegetation, slope angle and aspect. Due to lack of data on the age of geomorphic surfaces, the influence of time on soil formation was treated as being synonomous with age of geologic substrate. Climate was not treated as an independent factor due to inadequate data. However, based on climatic data for the island's central valley (Yeaton 1974), soils have a xeric moisture regime and a thermic temperature regime (Soil Survey Staff 1975). We believe other soils may have an ustic moisture regime, depending on location, aspect and hillslope position.

Geologic substrate was divided into 10 classes according to Weaver & co-authors (1969), vegetation into 11 classes according to Jones & co-authors (1993), aspect into 4 classes (N, S, E and W) and slope into three classes (0-8%, 9-30% and >30%). Combination of these four factors results in 1320 potential soil map units of which 758 occur on the island. If only vegetation and geology are considered, there are 110 possible units of which only 54 occur on the island. We described 163 profiles covering all 54 combinations of vegetation and geology and nearly 25% of the 758 potential units. Sixty-six of the profiles were sampled by augering and 97 soil pits were dug.

Description and Analysis: Soils were described using standard soil survey procedures (Soil Survey Staff 1951). The following field characteristics were recorded: color; texture; structure; consistence; horizon boundaries; coarse fragments; reaction to 2% HCl and presence of roots, pores and clay skins. In addition, pH and organic carbon were analyzed in the laboratory to enable classification (Soil Survey Staff 1975). Soil pH was determined in water by glass electrode using a 2:1 soil:water paste with 20 g air dried soil. Organic carbon was determined for 70 samples by the Walkley-Black method (Walkley 1947). To date, soils have not been analyzed for exchangeable bases. However, for classification purposes, base saturation was inferred from pH, taking pH 5.8 or greater as indicative of base saturation of at least 50% (Buol *et al.* 1980).

Results

Almost all island soils appear to have formed *in situ*, except those in canyon bottoms, where multiple buried soils are common on alluvial terraces. When not eroded, island soils are typically 30-90 cm thick, with loam texture, massive or blocky structure and have pH values between 5.5-7.5. Because of the large extent of grass cover (>80%) and volcanic or Monterey shale parent material (>50%), Haploxerolls cover nearly one-half the island. Except those under pine forest, the majority of island soils have a fine loam subsoil horizon with redder color, a slight increase in translocated clay and/or carbonate removal (cambic horizon) that overlies a thick zone of weathered parent material. Some soils under pines (particularly those near Pelican Bay) seem to be sufficiently leached to contain albic and argillic horizons; such soils (classified as Haploxeralfs) were unusual of the island and merit further study.

Table 1 summarizes soil subgroups found under different combinations of parent material and vegetation on the island. The most frequently occurring soil great groups were Haploxerolls, Argixerolls, Xerorthents,

Table 1. Soil subgroups occurring under selected combinations of parent material and vegetation. The 10 original parent material classes are grouped into 3 general types, and only the 5 predominant vegetation types are given in the table. Numbers in parentheses indicate the number of profiles sampled.

Vegetation	Parent Material		
	Volcanics, Volcaniclastics	Plutonite, Diorite, Schist	Shale, Sandstone
Grassland	Lithic, Typic Pachic, Vertic Haploxerolls (12)	Lithic, Typic, Pachic Haploxerolls (5)	Typic, Pachic Ultic Haploxerolls (6)
	Typic, Calcic, Pachic Argixerolls (4)	Typic Xerochrept (3)	Pachic, Vertic Calcixerolls (2)
	Typic Xerumbrept (5)	Lithic Xerorthent (1)	Typic, Pachic Vertic Argixerolls (3)
	Typic, Calcixerollic Xerochrepts (6)	Typic Xerorthent (2)	Typic, Entic Xerumbrepts (6)
	Lithic Xerorthent (4)		Typic Xerochrept (3) Lithic, Typic Xerorthents (5)
			Lithic Haploxeralf (1)
Chaparral	Lithic Haploxeroll (1)	Entic Haploxeroll (1)	Typic, Entic, Lithic Xerumbrepts (3)
	Typic, Lithic Xerumbrepts (2)	Lithic, Typic, Dystric Xerochrepts (4)	Lithic Xerorthent (1)
		Typic, Dystric Xerorthents (2)	
Oak Woodland	Typic, Lithic Haploxerolls (3)	Typic Haploxeroll (1)	Typic, Entic Xerumbrepts (2)
	Typic Argixeroll (1)	Ultic Argixeroll (1)	Lithic Xerorthent (1)
	Lithic, Typic Xerumbrepts (3)	Typic, Dystric Xerochrepts (2)	
	Lithic Xerorthent (1)	Lithic Xerorthent (2)	
Coastal Sage Scrub	Typic, Entic Haploxerolls (2)	Typic Haploxeralf (1)	Typic Haploxeroll (1)
	Typic Calcixeroll (1)	Typic Xerorthent (1)	Calcic, Ultic Argixerolls (2)
	Pachic Argixeroll (1)		Typic Xerumbrept (1)
	Calcixerollic Xerumbrept (1)		Typic Xerochrept (1)
			Lithic Xerorthent (2)
Pine Forest	Lithic Haploxeralf (1)	Dystric, Typic, Lithic Xerorthents (3)	Entic Xerumbrept (1)
	Lithic Xerorthent (1)	Lithic Xerochrept (1)	

Xerumbrepts and Xerochrepts. Haploxerolls and Xerumbrepts were nearly two to three times more frequent than Xerochrepts and Xerorthents on volcanic, shale and sandstone parent materials and twice as frequent on diorite and schist. Haploxerolls and Xerumbrepts were twice as frequent as Xerochrepts and Xerorthents under grassland, oak woodland and coastal sage scrub but only one-eighth as frequent under pine forest.

Table 2 shows representative profile descriptions of common Santa Cruz Island soils. Island Haploxerolls are moderately developed with a mollic epipedon with a blocky structure, silt loam texture and pH values in the range of 6-7. Argixerolls are among the most developed soils on the island; they are relatively deep (>1m) but have weakly expressed argillic horizons. The mollic epipedon has a blocky structure, silty clay loam texture, and pH values in the range of 5-6; the argillic horizon is massive or has a blocky structure with clay loam or clay texture and pH values of 6.5-7.

Table 2. Representative profile descriptions of common Santa Cruz Island soils.

Horizon	Depth (cm)	Moist Color[1]	Texture	Structure	pH[2]
Typic Haploxeroll, fine-loamy, mixed, thermic					
A1	0-5	10YR 3/1	sl	ccr	6.4
A2	5-20	10YR 3/2	scl	msbk	6.6
Bw	20-98	10YR 2/2	scl	m	6.2
Cr	98+	7.5YR 4/4	scl	m	-
Vertic Haploxeroll, fine, mixed, thermic					
A1	0-8	10YR 2/1	sic	cabk	6.0
A2	8-71	10YR 2/1	c	cabk	7.5
AC	71+	10YR 3/3	c	cabk	-
Typic Argixeroll, fine, mixed, thermic					
A1	0-18	10YR 3/2	sil	mabk	5.8
A2	18-43	10YR 3/2	sicl	mabk	6.4
Bt	43-61	10YR 3/3	c	mabk	6.6
BC	61-79	5Y 5/4	scl	m	6.9
Cr	79-84	5Y 5/4	scl	m	6.8
R	84+	-	-	-	-
Typic Chromoxerert, fine, montmorillonitic, thermic					
A1	0-18	10YR 2/2	cl	msbk	6.1
A2	18-102	10YR 3/2	cl	cabk	6.5
Bw	102-117	2.5Y 4/4	c	mpr	8.1
Cr	117+	2.5Y 6/4	c	m	-
Lithic Xerorthent, loamy, mixed, thermic, shallow					
A1	0-1	10YR 3/4	l	mcr	-
A2	1-10	10YR 3/4	l	mabk	5.5
Cr	10-71	5YR 4/6	cl	m	6.1
R	71+	-	-	-	-
Typic Xerumbrept, fine-loamy, mixed, thermic					
O	5-0	-	-	-	-
A	0-13	10YR 3/2	sil	csbk	5.6
Bw	13-66	10YR 3/2	sicl	msbk	5.7
Cr	66+	10YR 6/4	scl	m	-
Typic Xerochrept, fine, mixed, thermic					
A1	0-5	5YR 3/3	sil	msbk	5.7
A2	5-24	2.5YR 3/6	sicl	mabk	6.8
Bw	24-79	2.5YR 3/6	sic	m	7.2
Cr	79+	2.5YR 5/6	sicl	m	-

[1]All abbreviations after Soil Survey Manual (1951:139-140).
[2]Determined using 2:1 soil:water paste.

In some cases, particularly on calcareous shale or basaltic parent materials, moderately fine- to fine-textured soils have formed with enough shrink-swell clays to create deep cracks in the soil profile during the dry summer. Soils with these cracks and intersecting slickensides are Typic Chromoxererts. They occupy gentle slopes. On moderate slopes, similar soils lacking slickensides are Vertic Haploxerolls.

Xerumbrepts and Xerochrepts are less developed than Haploxerolls, Argixerolls or Chromoxererts. Typically, island Xerumbrepts and Xerochrepts are <1 m deep and have umbric or ochric epipedons with blocky structure, silt loam to silty clay loam texture and pH values in the range of 5-6, underlain by a typically massive cambic horizon with a silty clay to silty clay loam texture and pH values of 5.5-7.5. Island Xerorthents are poorly developed, shallow (<60 cm), massive soils with an ochric epidedon, silt loam texture and pH values of 4.5-5.5.

Discussion

Two general problems were encountered in describing and classifying island soils. First, it was often difficult to identify translocated clay in subhorizons from field observation since clay skins are not obvious in the fine textured soils that form from certain island parent materials. Many of these parent materials are deeply weathered and those that have high clay content tend to shrink and swell appreciably, causing mixing of the soil. Both these factors make it difficult to discriminate soil horizons. Soil micromorphological examination is needed to clarify the extent of translocated clay.

A second problem concerned the eroded condition of many island soils, which further add to the high degree of spatial variability of soils over short distances. In particular, soil morphology could not be predicted on the basis of hillslope position because shallow, eroded soils frequently occurred adjacent to deep, less eroded soils. This made the selection of sites representative of certain hillslope positions a somewhat subjective procedure.

High soil spatial variability raises the question of cause and consequence of soil erosion. One hypothesis suggests that grazing by feral sheep has removed vegetation cover resulting in sheet erosion and profile truncation over wide areas. However, the island is extensively faulted, and an alternative hypothesis suggests that structural geologic processes may lead to changes in base level that cause the rapid development of soil piping and gully networks. Our detailed field observations lend support to both of these hypotheses, but on different parts of the island. Vegetation removal, sheet erosion and widespread profile truncation have occurred on Willows diorite and Santa Cruz Island schist, whereas grazing has had a much less severe impact on sheet erosion of Santa Cruz Island volcanics and Monterey shale. On the other hand, faulting may be related to gully networks, especially on Tertiary sandstones and shales in the southwest portion of the island.

A priori sampling provides a useful basis for initial investigations of soils on Santa Cruz Island, where a heterogeneous set of soil forming factors has resulted in high spatial variability of soils. Soil development reflects the interaction of multiple soil forming factors, rather than the domination of any single factor.

The results presented here do not permit discussion of specific soil nutrient and moisture constraints induced by local erosion, nor their influence on vegetation recovery. Nevertheless our data confirm that distinct geographical subunits exist on the island, as demonstrated by the relationship between soil great groups, geologic substrate and vegetation. Soil characteristics in these geographical subunits will clearly influence vegetation recovery; these relationships are being explored in ongoing research.

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A Computer-generated Soils Map of Santa Cruz Island, California

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Abstract - A soil map of Santa Cruz Island (249 km^2) was constructed based on a field soil survey and data in a geographic information system (GIS) of the island. Soil map units were determined from 138 classified soil profiles generalized using a dasymetric approach based on an overlay of the registered GIS image planes of geologic substrate and vegetation. Nearly 60% of the island is covered by the three largest mapped units, representing soils on volcanics and volcaniclastics under grass and oaks, and soils on the Monterey formation under grass. Eleven subgroups of the USDA Soil Taxonomy (Soil Survey Staff 1975) occur in the large area of island volcanics under grass (37% of the island) and soil spatial variability is high, with two or three subgroups occurring in a single 2.25 ha grid cell of the map. However, the southwest corner of the island has the most heterogeneous soils (14 subgroups) and the greatest soil spatial variability, with four or more subgroups occurring in a single grid cell. The use of a GIS permits rapid generalization of map units from sampled points, but the rules used for generalization were simplistic, based only on geologic substrate and vegetation, which in turn were mapped at a coarse spatial resolution (150 m). It is difficult to compare the accuracy of the technique to that of a standard soil survey, because no standard soil survey exists for the island. Soils not identified in map unit names are estimated to cover less than 25% of the area of any map unit. However, the gridded format means that soil unit boundaries are poorly defined and therefore the map has limited field utility. Nevertheless this map provides a broad overview of the nature and distribution of Santa Cruz Island soils while illustrating a method whereby computerized data could be utilized in soil mapping.

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Introduction

The purpose of this study was to construct a soil map of Santa Cruz Island, based on a field soil survey (Butterworth *et al.* 1993) and a geographic information system (GIS) of the island. No soils map currently exists for the island, but some soils have been described and classified by Brumbaugh (1980, 1983). Soil surveys have been completed for some of the other California Islands, notably San Nicolas and San Clemente (U.S. Department of Agriculture 1985a, b) and soils on Santa Barbara, San Miguel and San Clemente Islands have been described and analyzed by W. Allardice (pers. comm.), Johnson (1979, 1980) and Muhs (1982).

A computerized approach was selected for mapping because of the large size (249 km^2) and relative inaccessibility of the island, which has rugged relief and few roads. The project was a test of the utility of a dasymetric approach to mapping using computerized geographical data as a tool for soil map unit generalization in remote areas, similar to that suggested by Fisher (1988). Data for the GIS layers and the soil map were collected as part of a larger ongoing project to construct a GIS of the natural resources of Santa Cruz Island (see Butterworth *et al.* 1992; Jones *et al.* 1993).

Methods

Soil mapping is the process of extending point observations of soils to areas of the same