MAPPING SANTA CRUZ ISLAND, CALIFORNIA SOILS USING A GEOGRAPHIC INFORMATION SYSTEM AND FIELD SURVEY

by

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TABLE OF CONTENTS

Description of the Study Area

Review of the Literature

Methods

Results and Discussion

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LIST OF FIGURES AND TABLES

Figure

Table

MAPPING SANTA CRUZ ISLAND, CALIFORNIA SOILS USING A GEOGRAPHIC INFORMATION SYSTEM AND FIELD SURVEY

ABSTRACT: Soils of Santa Cruz Island, California were mapped at the subgroup taxonomic level using a Geographic Information System (GIS) and field survey. Lithologic substrate, vegetative cover, slope gradient and slope aspect comprised the GIS data layers; these correspond to the soil-forming factors that were hypothesized to exert the greatest influence on Santa Cruz Island soil genesis. The data were encoded according to map grid cells that correspond to 5.7 acre ground units. A total of 164 sites were randomly selected to observe soil properties representing each unique combination of pedogenic factors. Soils were described and classified according to the USDA Soil Taxonomy. The GIS was used to extend the 54 known soil types to all other grid cells having the same combination of pedogenic factors. An image map was created using the GIS to display the soils distributions.

DESCRIPTION OF THE STUDY AREA

Introduction

Santa Cruz Island is the largest and most geographically diverse among the California Channel Islands. The island is part of an east-west trending chain of four islands that lie approximately 25 miles south of Santa Barbara (Figure 1). Twenty four miles in length, and ranging from 2 to 7 miles in width, the island occupies an area of 91 square miles.

The island has complex geology, and its high relief

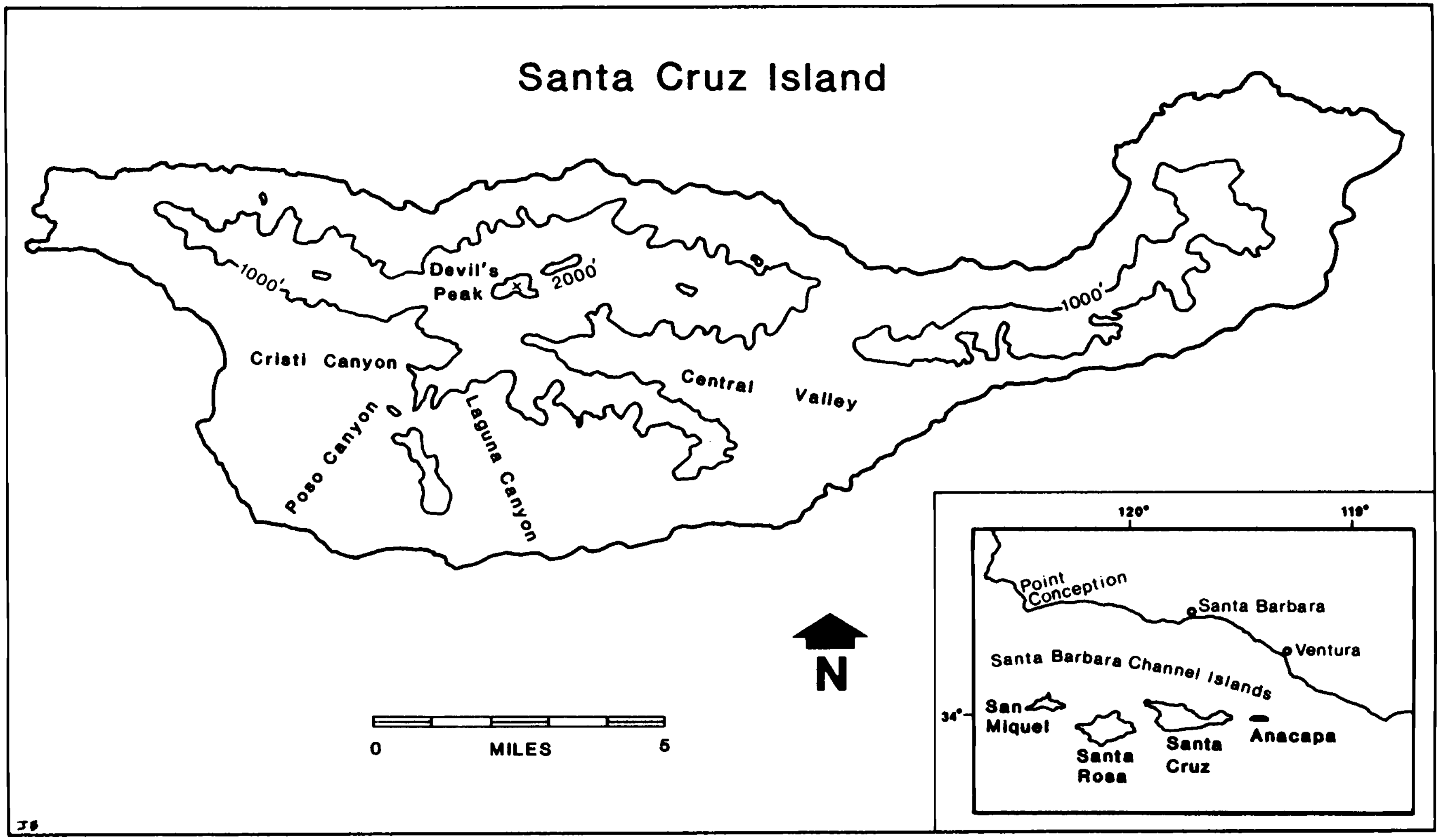

Figure 1. Map of Santa Cruz Island and vicinity.

varies from gently sloping, raised marine terraces to nearly vertical rocky cliffs. Its highest elevation is 2404 feet at Devil's Peak. A wide range of plant communities are found on the island, including grassland, coastal sage scrub, chaparral, oak woodland and pine forest. Most of the 22 inches mean annual precipitation occurs between November and April. The island is presently used for small-scale cattle ranching, and as a site for scientific research.

Climate

The climate is Mediterranean with generally warm, dry summers and cool, rainy winters. Mean annual precipitation ranges from less than 20 inches in the Central Valley, to more than 24 inches at the higher elevations in the western part of the island. Most of the summer season moisture is supplied to coastal areas from fog drip, which is caused by a shallow marine layer (Minnich 1980). Because the island's rainfall and temperatures are quite variable, and due to the short time period over which the soil sampling was conducted, soil moisture and temperature regimes were inferred from previously existing climatic data. The island's soils were determined to have a xeric moisture regime by inference based on two observations: 1) the xeric regime is indicative of Mediterranean climates (Soil Survey Staff 1975), and 2) nearly all the soils of nearby Santa Barbara County have a xeric moisture regime (Soil Survey Staff 1980a).

The soil temperature regime was inferred from mean annual air temperature (maT) data (Yeaton 1974). Two degrees Fahrenheit were added to the island's 62 degrees F maT to place the soils in a thermic temperature regime (Soil Survey Staff 1975). It is noteworthy that soils on the north- and south coasts of the island may have a mesic temperature regime (due to a stronger marine influence), however no long term data is available for these locations.

Geology and Geomorphology

A wide assortment of rock types of varying age are found on the island, and many inactive faults occur throughout. The oldest are Jurassic schistose rocks that are deeply weathered. The youngest are Quaternary marine terrace materials that are found at the east and west ends of the island. Most of the northern half of the island is composed of Tertiary volcanic rocks. Other soil parent materials are siliceous and calcareous shales and sandstones, quartz diorite, and recent alluvium in canyon bottoms (Weaver, et al. 1969).

The island's most prominent landform is the Central Valley, a graben-like erosional feature that is associated with the Santa Cruz Island Fault. Other areas of the island are extensively folded or faulted, especially in the southwest part.

Topographically, the island is moderately dissected, and slopes are generally steep and convex-shaped. Slopes commonly exceed 50 percent, and there are relatively few areas where slopes are less than 5 percent.

The majority of the island has been subjected to at least some form of erosion. Hillslope processes include rotational slumps, soil slips, and sheet, rill and gully erosion. Much of the southwestern portion has deep gullies that have cut to saprolite or bedrock; some are more than 30 ft deep at the base of hillslopes. This condition is particularly notable in the Canada Formation, where it is likely that soil pipes formed in shale have collapsed to form steep-sided, V-shaped gullies.

In many instances (particularly at summit hillslope positions) all or part of the solum has been truncated by erosion. Many areas that are presently rock outcrops probably have never supported a soil cover (Brumbaugh 1983); however in some parts of the island (e.g. the Central Valley, parts of the isthmus, and on marine terraces), little or no erosion is apparent.

Vegetation

The prevailing plant communities on the island are similar to those of the mainland coast ranges. These include valley grassland, coastal sage scrub, chaparral, oak woodland, and closed-cone pine forest, and can be roughly differentiated on the basis of their physiognomy.

Grasslands occupy a major proportion of the island; most grasses are introduced European annuals that have successfully competed with the native bunch grasses (Minnich 1980). Grasslands are found in all areas of the island, however the cover is sparse in some parts of heavily-grazed pastures.

Coastal sage scrub, mainly comprised of california sagebrush (Artemesia californica) and white sage (Salvia apiana), usually occurs on south-facing slopes; most of it is found in the isthmus area.

Chaparral takes three general forms on Santa Cruz Island. In the more wind exposed north- and west-facing coasts, it consists of prostrate mats of scrub oak (Quercus dumosa). The interior Central Valley form is characterized by a dense growth of mostly scrub oak, manzanita (Arctostaphylos spp.) and chamise (Adenostoma fasiculatum). In the eastern part of the island, chaparral is principally manzanita, with some scrub oak (Minnich 1980).

Oak woodlands occupy many of the north-facing slopes and canyons of the island. They consist mostly of coast live oak (Quercus agrifolia) with an annual grass herbaceous layer. Oak woodlands are commonly found in upper Canada Cervada, in the Central Valley, and in the gorge south of Prisoner's Harbor.

Closed-cone pine forests are found in three distinct areas: the north-facing slopes of the isthmus ridge, near Pelican Bay, and in the vicinity of the Christie Ranch in the southwest part. Bishop pine (Pinus muricata) is the dominant species.

Land Use History

Indigenous peoples occupied Santa Cruz Island from more than 7000 years before the present to the mid-1800's, when their last were removed to the mainland (Glassow 1980). Sheep ranching began in the early 1800's, and during the latter part of the century populations numbered more than 40,000 head. By this time the sheep had become feral, and much of the island's soils were severely eroded, partially because of overgrazing (Brumbaugh 1980). Few sheep roam the island today, their numbers reduced by eradication programs. Pastures in which sheep have been excluded for some time show evidence of vegetation recovery, however some areas (particularly at ridge tops and on steeper slopes) remain completely denuded. Presently the island is used for small-scale cattle ranching and scientific research, and most (88%) of it is managed by The Nature Conservency.

REVIEW OF THE LITERATURE

Automated Soil Mapping

Numerous workers (Singh and Dwevedi 1986; Wong, et al. 1977; and Weismiller, et al. 1977) have utilized remotely sensed and ancillary data to detect and map both soil types and soil boundaries with moderate success. For the most part methods have involved the integration of manually-interpreted or computer-classified multispectral scanner imagery with digital elevation or other environmental data; however these methods rely primarily on the spectral properties of vegetation and the soil background. The method of producing soil maps from digitized environmental data in a Geographic Information System (GIS) format appears to be most closely approximated by Singh and Dwevedi (1986). Their work involved the construction of a small-scale soil map by combining spectral, lithologic, and topographic data with ground truth verification to manually delineate soil types. Despite the reliance on various 'remote' data for mapping, field observation of soil properties is an integral part of all soil mapping.

To date, the application of GIS to soil survey has principally involved the display and analysis of interpretive soils data for land use planning (Burrough 1986; Rogoff 1982; and Rudeforth 1982). Apparently no work has been conducted that utilizes a GIS format <u>per se</u> to map soil types from digital data that correspond to the soil-forming factors.

Previous Soils Work on the Island

The earliest documented description of Santa Cruz Island soils was given by the Soil Conservation Service (SCS) (1950). The SCS examined soil characteristics in parts of the island's Central Valley, and provided a general inventory of the erosional condition of soils, but did not conduct a formal soil survey.

Several researchers have reported certain soil properties in particular locales and ecological environments, but only as these properties relate to plant growth and distribution (Hobbs 1980; Hochberg 1980; and Renwick, et al. 1982).

A more comprehensive study of island soils was made by Brumbaugh (1980), who described morphological characteristics, conducted laboratory analyses, and classified some soils according to the USDA Soil Taxonomy. Brumbaugh found Chromoxererts, Haploxerolls, and Xerorthents in similar soil landscape patterns as were observed in this study, but did not attempt to delineate soil types and soil boundaries.

Some knowledge of Santa Cruz Island soil genesis may be gained from soils investigations on nearby Channel Islands. Muhs (1982) found that topographic position and its effect on water flow on hillslopes exerts a significant influence on San Clemente Island soil genesis. Johnson (1979 and 1980) emphasised the effects of climatic change and aeolian deposition on San Miguel Island. Work by W. Allardice (pers. comm., 1987) suggests that soil genesis on Santa Barbara Island may be strongly affected by Na and Ca deposition, owing to high levels of carbonates in soil profiles.

METHODS

Logic of the Approach

Soil maps are ordinarily constructed from intensive ground survey and through the use of stereo aerial photographs. In field mapping, the pattern of soil types and soil boundaries in an area can be anticipated to some degree by observing the nature of certain environmental characteristics. Soils delineations therefore are made through a combination of predictions based on known soil patterns, and from actual observation of soil properties (Soil Survey Staff 1980b).

In the approach outlined in this paper, the predictive aspect to soil mapping is emphasized in an attempt to model pedogenesis using certain soil-forming factors. This work is based on the assumption that soils that have formed under the influence of a unique set of soil-forming factors in one area will be similar to soils formed elsewhere under the same set of conditions. Through these _a priori_ predictions, observed soil types for each combination of pedogenic conditions are extended to other areas having the same set of conditions. A GIS was used in this work to quickly and efficiently classify grid cells in which soil properties were not known, from the basis of cells in which soils _had_ been observed and classified.

Geographic Information System

The GIS data layers were selected according to the soil-forming factors that were hypothesized to exert the greatest influence on the genesis of Santa Cruz Island soils. Jenny (1941) listed these factors as parent material, topography, biota, climate and time. Climatic factors were not included (except indirectly through slope aspect) in the GIS due to the lack of data for the island, and because the island's high relief and variable marine influence results in a complex microclimate. Similarly, the pedogenic factor of time was omitted because no data were available as to the age of geomorphic surfaces. Moreover, the high spatial variability of erosional conditions would have been difficult to map with any degree of accuracy, and would have greatly increased the number of soil sites to sample.

To provide for consistency in encoding the variables of each data layer, a grid network of 1/4" square cells was drawn on a large sheet of acetate to subdivide the island's area into discrete units. Comprised of 88 rows and 250 columns, the grid contains precisely 10,839 cells to cover the entire area of the island. The grid was then overlain to a 1:24000 scale topographic map; at this scale, each grid cell corresponds to a 500' X 500' area (5.7 acres) on the ground; this is also the size of the minimum mapping unit. Registration marks were made on the topographic map at the four outside corners of the grid so that registry was retained when the grid was overlain to a different data layer map.

Following placement of the grid network, the elevation of the center of each grid cell was then recorded (to the nearest 5 ft), as was the corresponding row and column position. These data were then imput to a computer file for storage and manipulation. An algorithm was used to convert the elevations of each cell into slope gradient and slope aspect data. The computed slope gradients were grouped into three classes (0-3, 4-12, and greater than 12 degrees) to make the data more manageable. These slope classes were selected on the basis of hypothesized soil genetic conditions (Birkeland 1984), and were not intended to resemble standard SCS slope classes used as phases of mapping units. The resultant data layer for slope classes is shown in Figure 2.

The algorithm-derived slope aspects (originally 360) were then grouped into four classes that were hypothesized to most closely model soil formation as affected by variability in solar insolation (Buol, et al. 1980). Each slope aspect class was centered on the cardinal points, and included the area 45 degrees to either side of each. Thus the north slope aspect class, for example, was comprised of true compass bearings from 316 degrees to 045 degrees. This data layer is shown in Figure 3.

Data for geologic substrate (parent material) was derived from a 1:24000 scale geologic map (Weaver, et al. 1969) of

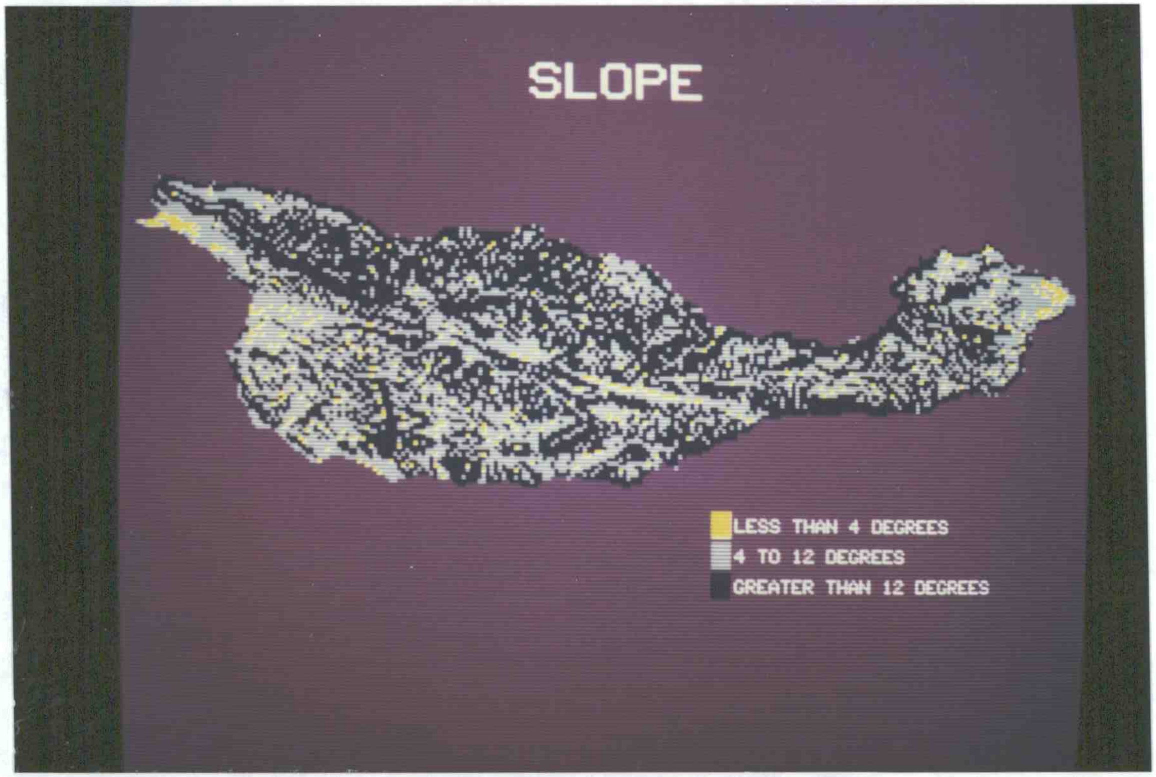

Figure 2. Slope gradient data layer of Santa Cruz Island GIS.

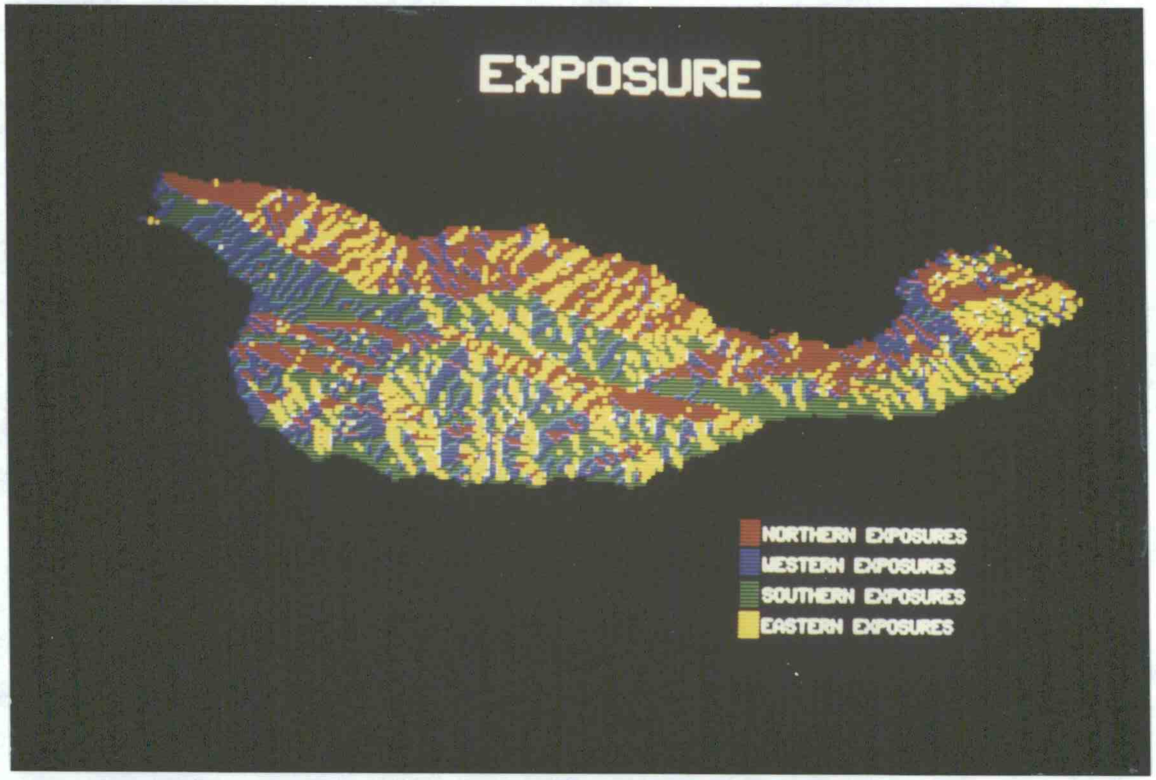

Figure 3. Slope aspect (exposure) data layer of Santa Cruz Island GIS.

the island. The acetate grid was overlain to this map, using the same registration marks that were used on the topographic map. Substrate types were recorded for each cell according to the symbols used for the geologic mapping units. When more than one mapping unit appeared in a given cell, the one occupying the greatest proportion of the cell was the one recorded. Some of the mapping units were identified only as "Quaternary terrace gravels" or "Quaternary landslide", for example, and therefore did not indicate the actual lithology of the unit. In these instances, the mapping unit designation for the area immediately upslope of these was used, for it was assumed that the unspecified materials originated from the rocks above.

Some geologic units were combined for soil mapping purposes. Groupings were made on the assumption that similar (in terms of original grain size, age, and minerology) parent materials will produce similar soils, given that the other pedogenic factors are held constant. Table 1 shows the various geologic units as found on the geologic map, and how some of these were combined to define a single variable for the parent material data layer (shown in Figure 4).

The vegetation data layer was constructed through the use of recent (1985) 1:24000 scale CIR aerial photographs. A Bausch and Lomb Zoom Transfer Scope was used to optically enlarge the photos, and to register each photo to its corresponding area on the topographic base map. The photos were then interpreted to delineate boundaries around the five

	GEOLOGIC MAPPING UNIT	PARENT MATERIAL CLASS
Jurassic	Santa Cruz Island Schist- chloritic schist	1
	Willows Diorite- quartz diorite	
	Alamos Plutonite- quartz diorite	
Tertiary	Santa Cruz Island Volcanics	2
	Members:	
	Prisoners's Harbor- andesite	
	Devil's Peak- andesite; breccia	
	Stanton Ranch- breccias; tuffs	
	Griffith's Canyon- basalt; breccia	
	Intrusive (undifferentiated)	
	Blanca Volcaniclastics	3
	Members:	
	Upper- tuff breccias with conglomerates	
	Middle- tuff breccias with volcanic sandstones	
	Lower- volcaniclastic and metamorphic conglomerates	
	Cozy Dell Shale- calcareous shale	4
	Vaqueros Sandstone- volcanic sandstone	5
	Jolla Vieja Formation- sandstone and volcanic conglomerate	
	Canada Formation- calcareous shales and siltstones	6
	Pozo Formation- calcareous sandy shales and siltstones	
	Rincon Shale- shales and mudstones	7
	San Onofre Breccia- conglomerate with sandstones and siltstones	8
	Monterey Formation- siliceous shales	9
Quaternary	Quaternary alluvium- mixed alluvium	10
	Quaternary fanglomerates	(texture and minerology inferred from surrounding material)
	Quaternary landslides	
	Quaternary terrace gravels	

Table 1. Groupings of geologic mapping units into parent material classes.

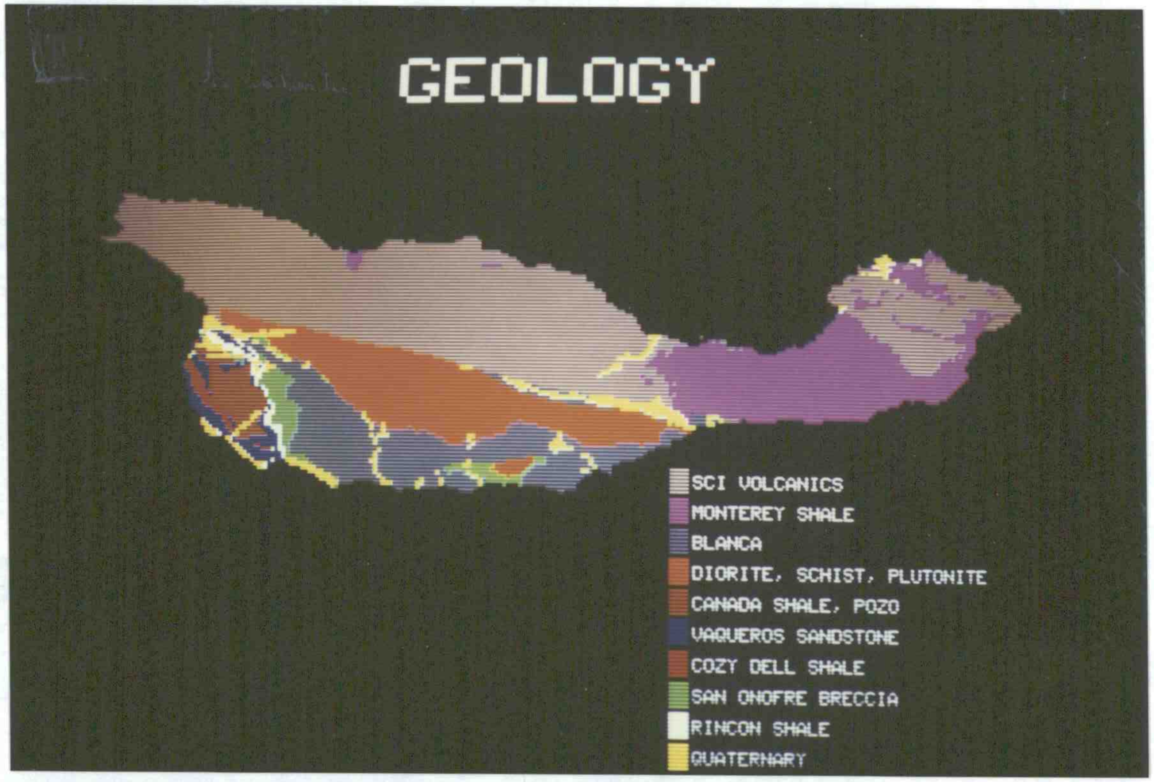

Figure 4. Geology (parent material) data layer of Santa Cruz Island GIS. (Note: 'Quaternary' refers to Quaternary alluvium).

physiognomic vegetation types. Additionally, a class for 'bare' was made for rock outcrops and other unvegetated areas. Many delineations were later ground truthed to insure interpretation accuracy.

Finally, the grid sheet was overlain to the vegetation map. The vegetation class was recorded for each cell, as were the associated line and column coordinates. Cells were encoded in same manner of the geology data layer when more than one vegetation type appeared in a given cell. This data layer is shown in Figure 5.

After all the geologic, topographic and vegetation data for each cell was recorded, they were converted to computer files in which each line in the file contained all the data for a given cell. This data was manipulated on the ERDAS GIS system. (See Appendix A for a brief description of the characteristics of ERDAS).

Field Survey

The locations for observing soil characteristics were determined according to the occurrance of unique combinations of pedogenic factors. Since in the GIS there are 10 parent material classes, 4 slope aspect classes, 3 slope gradient classes, and 6 vegetative cover classes, there are 10 X 4 X 3 X 6 = 720 potential soil units that could occur on the island. However, because not every vegetation class and

Figure 5. Vegetation data layer of Santa Cruz Island GIS. (Note: Vegetation types other than those of the described physiognomic types occupy only portions of a small number of grid cells, and are not significant to soil mapping).

topographic variable were found on all geologic substrates, the number of a priori soil types was drastically reduced to 54.

All possible combinations of (observed) pedogenic factors known to occur on the island were tabulated in order to determine specifically what soils were to be sampled. Sites for soil profile analysis were then randomly selected to sample one soil for each combination of factors. In choosing sites, some attempt was made to describe soil pedons in which the degree of erosion was observed to be representative for the area. Aerial photographs were used in conjunction with the geology map of the island as aids in finding locations that met the specific criteria for soil sampling sites.

Most soil pedons were observed after digging soil pits; some were observed from samples using a bucket auger. Pedons were described according to standard soil survey procedures (Soil Survey Staff 1951); soil samples were collected from each soil horizon for pH and organic carbon analysis at the U.C. Santa Barbara Soils Laboratory.

Soil pH was determined in water by glass electrode using a 1:2 soil:water paste with 20g of soil. pH was used to infer percent base saturation-- a soil chemical property central to distinguishing surface diagnostic horizons (epipedons), which influence soil classification at the order and suborder taxonomic levels. Base saturation is normally measured after cation exchange capacity (CEC) has been determined. However in this work, CEC was not calculated due to limited time and funding, and because it was likely that the CEC determination would have been inconclusive due to a probable high sodium content in soils (W. Allardice, pers. comm., 1986).

Inferring base saturation from pH is not nearly as precise as conventional measurements, but a general indication as to soil ion concentrations can be gained from pH (Buol, et al. 1980). For the epipedons, a pH of less than 5.8 was used to infer a base saturation of less than 50%, and a pH of 5.8 or more was taken for a base saturation of at least 50%.

The organic carbon analysis, determined by the Walkley-Black method (Walkley 1947), was performed on some soil samples to test for the organic carbon criterion for mollic epipedons.

RESULTS AND DISCUSSION

Soil Landscape Characteristics

Field observations indicate that the nature of Santa Cruz Island soils varies primarily due to the influence of the island's complex geology, its distinct vegetation patterns, and to a lesser extent, its high relief. Vegetation likely influences island soils not only through physicochemical properties, but perhaps more importantly, by affecting the current condition of soils by influencing susceptibility to erosion. Microclimatic variation appears to exert a less significant influence than the other pedogenic factors on the genesis of island soils, but this has not been closely examined due to lack of data.

In this work, similar soil landscape patterns and soil types were observed as those reported by Brumbaugh (1980). However there appears to be little correspondence with the pedogenic factors reported to predominate on other California islands. No soils were observed to have formed in aeolian sand on Santa Cruz Island (as is the case on San Miguel); nor does Ca and Na deposition appear to have a siginificant effect on soil morphology, as was reported for Santa Barbara Island. On Santa Cruz Island, it is likely that variable, accelerated erosion has had a major effect in controlling the present composition of many soil profiles.

Almost all island soils appear to have formed *in situ*, except those in canyon bottoms, where multiple buried soils are common on alluvial terraces. Although not observed directly, it is likely that some soils have formed in colluvium that has accumulated at the bases of steep slopes.

As might be expected from the variety of parent materials, vegetation, and geomorphic conditions on Santa Cruz Island, a range of soil types was observed. Soils vary considerably over short distances, a condition that may be partly due to the influence of site-specific erosional conditions.

At least six soil great groups (and 13 subgroups) occur on the island (see Appendix B for pedon descriptions for the most commonly occurring soils):

1) Haploxerolls (Typic, Lithic, Pachic, Vertic),
2) Argixerolls (Typic, Calcic),
3) Chromoxererts (Typic),
4) Xerorthents (Typic, Lithic),
5) Xerumbrepts (Typic, Lithic), and
6) Xerochrepts (Typic, Lithic).

Haploxerolls have the greatest areal representation (nearly 50%) on the island. They were found on all parent materials, but mostly under grassland vegetation. These soils have indistinct horizonation even at stable landscape positions. Island Haploxerolls have a thin to moderately thick mollic epipedon that has a blocky structure, silt loam texture, and high base saturation. Where the epipedon is underlain by a shallow lithic contact, they are Lithic Haploxerolls. Somewhat more developed Haploxerolls have a structureless cambic horizon that merges gradually with the underlying saprolite; such soils are usually Typic Haploxerolls and Pachic Haploxerolls. The latter soils are found mostly in volcaniclastic and calcareous shale parent materials.

Argixerolls show the greatest development on Santa Cruz Island; these soils usually occur in level to moderately sloping areas under grassland vegetation on basic volcanic rock parent materials. The A horizon is 8-20 inches thick, with blocky structure, silty clay loam texture, and moderate to high base saturation. The structure of the argillic horizon is massive to blocky, with clay loam or clay texture. In some pedons carbonates have accumulated in soft powdery forms at the contact with the weathered parent material; these soils are classified as Typic Argixerolls and Calcic Argixerolls. In some cases, particularly on calcareous shale and basaltic parent materials, sufficient shrink-swell clays have formed to create deep cracks in the soil profile during the dry island summers. Soils with these cracks are Typic Chromoxererts on gentle slopes, and Vertic Haploxerolls on moderate slopes.

Xerorthents are found primarily at summit hillslope positions and on actively eroding slopes on the island. In many instances Xerorthents are found intermixed with other soils in which the A and B horizons remain only in patches, so that the majority of the surface is exposed weathered or hard bedrock; this is particularly notable on certain geologic substrates, for example, Santa Cruz Island schist and Willows diorite. Island Typic Xerorthents characteristically have a bedrock contact greater than 20 inches depth, low organic matter content, silt loam texture, and low base saturation. The Lithic subgroup differs primarily in that depth to the R horizon is less than 20 inches.

Xerumbrepts and Xerochrepts occur mostly under chaparral and coastal sage vegetation on most island parent materials. In the chaparral a thin litter layer (Oe horizon) is underlain by an A horizon with blocky structure, loamy texture, and low to moderate base saturation. The subsoil consists of a moderately thick, massive-structured cambic horizon that has lost bases from leaching, but retains some of the original rock structure. Soils under coastal sage are like those under chaparral, except that they lack an O horizon, and the A horizon sometimes has a massive structure.

Though not a significant soil in terms of areal extent, it is noteworthy that a Haploxeralf was observed at one location on the island. This soil occurred on a north-facing slope under pine forest, where it is likely that the moist, acid conditions have favored the development of both an albic horizon and an argillic horizon.

The resultant image-map of GIS-classified soil types is shown in Figure 5.

Figure 6. Computer-generated soil map of Santa Cruz Island.

Two 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 clays and fine textured loams that form from island parent materials. Soil micromorphological examination is needed to clarify the extent of translocated clay. Additionally, the intrinsic high content of shrink-swell clays tends to favor pedoturbation, and many island parent materials are deeply weathered; these factors sometimes made it difficult to discriminate soil property variations with depth.

A second problem concerns the eroded condition of many island soils, which gives rise to a wide variability of soil types over short distances. In particular, the expected relationship between hillslope position and soil profile characteristics was not found: intact soil profiles (i.e. those in which soil formation is equal to or greater than rates of erosion) frequently occur adjacent to eroding soils at most hillslope positions. Soil morphological conditions therefore tend to be site-specific. High, often unpredictable soil spatial variability made the selection of sites representative of certain hillslope positions a somewhat arbitrary procedure.

In general, the deepest and most finely-textured soils on Santa Cruz Island have formed in volcanic bedrock and in the shales of the southwestern part of the island. Many of these soils have weakly-expressed horizonation due to the pedoturbative effects of shrink-swell clays. Soils on steeper slopes and on narrow summits are usually shallow to bedrock and have relatively coarse textures; and they tend to have a lower organic matter content than other island soils. Except those under pine forest, island soils frequently have a subsurface cambic horizon with redder color and a slight increase in clay and/or carbonate removal that overlies a thick zone of weathered parent material.

Accuracy Assessment of Soil Type Predictions

Because of time limitations, only seven soil pedons were used to test the accuracy of soil type predictions. These sampling sites were selected to duplicate two different sets of soil-forming factors in which soils had been previously sampled. Based on these two sets, a moderate degree of correspondence between soils in similar environmental conditions was observed.

In particular, three soil profiles (each about 1/2 mile apart) were found to be quite similar: all were classified as Lithic Xerochrepts. These soils formed in schist parent material, under pine forest, on a north aspect, and in the greater than 12 degrees slope class. One factor that may have led to their similarity is that each was eroded to about the same degree, and each was located at a backslope hillslope position.

In contrast, other duplicate soil profiles were sampled in several areas in the northern part of the island; these varied significantly in morphology. All of the soils had formed in Santa Cruz Island Volcanics parent material, under grassland vegetation, on an east aspect, and in the greater than 12 degrees slope class. Five were classified as Haploxerolls, but their subgroup classifications were Lithic, Typic, and Vertic. A sixth soil was a Typic Argixeroll-- a markedly different soil type than the Lithic Haploxeroll. Here, the variability among the soils may be explained by several factors: 1) The Santa Cruz Island Volcanics are comprised of rock types (see Figure 1) having different mineralogy. The basaltic member of the formation may have given rise to the shrink-swell clays to cause the Vertic intergrade soil, whereas the other formation members did not; 2) the six pedons were situated at hillslope positions ranging from summit to footslope-- this factor may have affected the amount of soil material either being lost or gained at a given point,as would have the concavity or convexity of the slope; and 3) site-specific erosional conditions could easily explain the difference in soil depth between the Lithic and Typic subgroups.

CONCLUSIONS AND POTENTIAL FOR FUTURE RESEARCH

The GIS-based, predictive approach to soil mapping is shown to be advantageous in that, once compiled and encoded, a large volume of spatial data corresponding to the soil forming factors can be quickly and efficiently manipulated and displayed. However, the accuracy of soil type predictions depends on a variety of factors; these perhaps can be grouped into four general categories: 1) the ability of the model to predict soil genesis and therefore soil morphological characteristics; 2) the resolution of the cells comprising the GIS (corresponding to the smallest unit on the ground that can be identified and mapped); 3) the heterogeneity of the soil landscape under study; and 4) the taxonomic level at which soil types are mapped. Taken separately, these factors are discussed in more detail:

1) The processes of soil genesis are complex, and are not fully understood. In some soils, certain of the five soil-forming factors may exert a greater influence than others to result in the unique physiochemical properties of a particular soil profile. In the context of modeling pedogenesis for predictive soil mapping, the intent is to identify which of these factors have the greatest influence on soil morphological variability, and to subdivide them in such a way so as to account for these variations. In theory, potential predictive accuracy is therefore a

function of: A) the number of pedogenic factors considered; and B) the degree that each factor is subdivided. For example, the soil-forming factor of parent material can affect both the minerology and texture of soils. If two parent materials in an area are different types of shale (e.g. siliceous and calcareous), the accuracy of soil type predictions is therefore potentially decreased because these materials often result in highly dissimilar soil types (given that the other soil-forming factors are held constant). Predictive accuracy is likely to be higher if both shales were treated as separate variables. In some environmental conditions, this differentiation may not explain soil differences, for other pedogenic factors may exert a stronger influence on the genesis of that soil. However, when the entire group of soil-forming factors are considered, and when each factor is subdivided into many types, more time is spent compiling and manipulating these data. Using the full set of soil-forming factors and many subdivisions for each will not neccessarily lead to a high predictive accuracy.

2) Similarly, grid cell size affects predictive accuracy in that with increasingly greater resolution, the spatial variability of soils can be mapped to more closely conform to the way soils are distributed on the landscape. A coarse grid network may require relatively less encoding and manipulation of data, but soils occupying small areas

may be lost in the generalization of large cells. In the case of Santa Cruz Island, the high relief requires that a small cell size be used in order to account for soil variability caused by slope aspect and gradient differences. With respect to the slope aspect and slope gradient data layers in the GIS, the grid cell size was likely too coarse. In many instances, a cell may have covered an area that included two steep, opposing slopes in a drainage, as well as the thalweg having only a gentle slope. Soils may vary considerably within such a cell.

3) The greater the complexity and variability of the soil landscape, the greater the difficulty in accurately predicting the characteristics of a soil at a given location. In the case of Santa Cruz Island, soils vary considerably according to parent material, vegetation, slope, aspect, hillslope position and degree of erosion. The latter two factors were not used as variables in the GIS, and it may be that had these been included, predictive accuracy may have increased significantly. However when the soil-forming factors were being selected as variables for the GIS, these were not thought to be important to island soil genesis; further, it would have been infeasible to map such factors. An additional problem is that given the resolution of the grid cells, in many areas slope position and erosional conditions may have varied greatly within a given cell.

4) The lower the taxonomic level at which soils are mapped, the greater the difficulty in predicting soil types. Had soils been mapped at the suborder level, soil type predictions largely would have entailed the identification of epipedons and subsurface diagnostic horizons. Given the resolution of the grid cells, and the number of pedogenic factors considered, the GIS in its present form is somewhat ill-suited to identify and map soils at the subgroup level.

Soil mapping using a cell-based GIS has an additional problem in that the final output contains soils delineations that have a blocky appearance; these do not conform exactly to the way in which soils are distributed on the landscape. With further work, soils delineations might be 'smoothed` by overlaying a transparency of the raster version of the map to an orthophoto quadrangle so that soil boundaries may be adjusted to coincide with topographic and vegetative variations.

This work was a first step in an attempt to predict pedogenesis on the basis of certain soil-forming factors, using a Geographic Information System. Despite the limitations of this method, its usefulness is promising in areas where soil variability is low, in inaccessible regions, and when only a general knowledge of soils distributions is desired.

Since the work is apparently the first of its kind, considerable research remains to be conducted that explores more fully methods to identify the dominant pedogenic factors in a study area. Stepwise multiple regression, principal components or discriminant analysis techniques would be indispensible to this process. A study area having low- to moderate soil variability would likely streamline the work. Moreover, further research would benefit if existing soil survey data were available for the study site, both to reduce the proportion of the work involving field sampling, and to use as a benchmark to assess the accuracy of soil type predictions.

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APPENDIX A

The ERDAS System

The ERDAS system is an interactive, free-standing, raster format, turnkey image processing and Geographic Information System. It is based on an IBM-AT microcomputer with high resolution display. ERDAS programs are available to perform image enhancement, classification, geometric correction of remotely sensed images, GIS merger and analysis, and hard copy output.

Appendix B

Representative pedon descriptions of frequently occurring Santa Cruz Island Soils

Horizon	Depth(in)	Moist Color[1]	Texture	Structure	pH[2]
		Typic Haploxeroll, loamy, mixed, thermic			
A1	0-2	10YR 3/1	sl	c,cr	6.4
A2	2-8	10YR 3/2	scl	m,cr	6.6
Bw	8-40	10YR 2/2	scl	m	6.2
Cr	40+	7.5YR 4/4	scl	m	-
		Typic Argixeroll, fine-silty, mixed, thermic			
A1	0-7	10YR 3/2	sil	m,abk	5.8
A2	7-17	10YR 3/2	sicl	m,abk	6.4
Bt	17-24	10YR 3/3	c	m,abk	6.6
BC	24-31	5Y 5/4	scl	m	6.9
Cr	31-36	5Y 5/4	scl	m	6.8
R	36+	-	-	-	-
		Typic Chromoxerert, fine, montmorillonitic, thermic			
A1	0-7	10YR 2/2	cl	m,sbk	6.1
A2	7-40	10YR 3/2	cl	c,abk	6.5
Bwk	40-46	2.5Y 4/4	c	m	8.1
Cr	46+	2.5Y 6/4	c	m	-

Vertic Haploxeroll, fine, mixed, thermic

A1	0-3	10YR 2/1	sic	c,abk	6.0
A2	3-28	10YR 2/1	c	c,abk	7.5
AC	28+	10YR 3/3	c	c,abk	-

Lithic Xerorthent, coarse-loamy, mixed, thermic

A1	0-1	10YR 3/4	l	m,cr	-
A2	1-4	10YR 3/4	l	m,abk	5.5
Cr	4-28	5YR 4/6	cl	m	6.1
R	28+	-	-	-	-

Typic Xerumbrept, fine-loamy, mixed, thermic

Oe	2-0	-	-	-	-
A	0-5	10YR 3/2	sil	c,sbk	5.6
Bw	5-26	10YR 3/2	sicl	m,sbk	5.7
Cr	26+	10YR 6/4	scl	m	-

Typic Xerochrept, fine-silty, mixed, thermic

A1	0-2	5YR 3/3	sil	m,pl	5.7
A2	2-10	2.5YR 3/6	sicl	m,abk	6.8
Bw	10-28	2.5YR 3/6	sic	m	7.2
Cr	28+	2.5YR 5/6	sicl	m	-

[1] All abbreviations after Soil Survey Manual, 1951, Pp. 139-40.

[2] Determined using 1:2 soil:water paste.