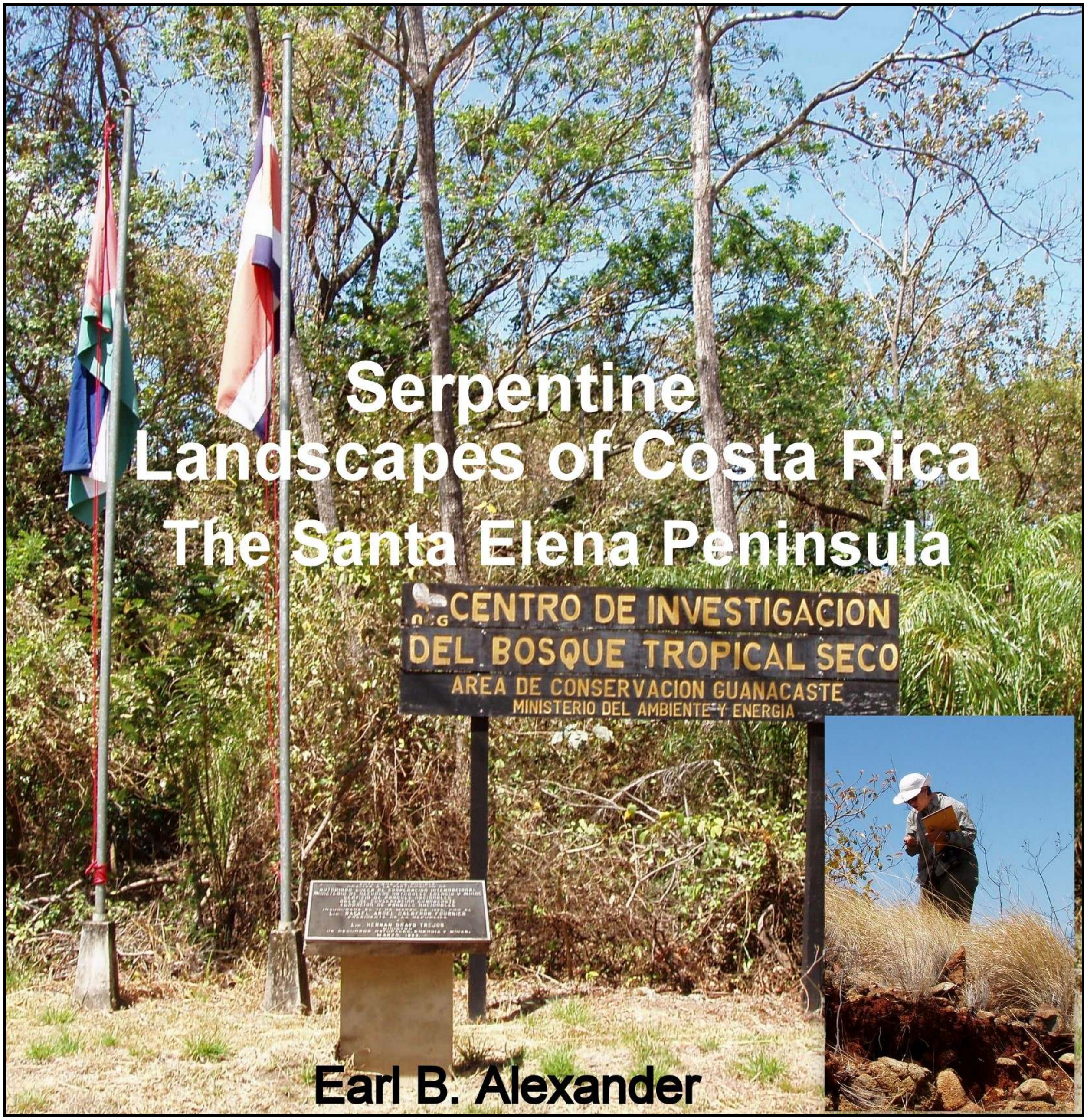
Serpentine Landscapes of Costa Rica

The Santa Elena Peninsula



Earl B. Alexander

Serpentine Landscapes of Costa Rica
The Santa Elena Peninsula

Earl B. Alexander
Soils and Geoecology

2008, revised 2018
2018 draft

Contents

September 2018

Preface

Serpentine landscapes of the Santa Elena Peninsula are in the Area de Conservación Guanacaste. I was fortunate to be able to accompany Maria Marta Chavarria Diaz as she drove along the roads of the Santa Elena Peninsula. She is a very competent ecologist and was a very pleasant companion for the two weeks that we spent investigating the landscapes of the Santa Elena Peninsula. I am grateful that her supervisors allowed her to spend the two weeks with me.

Cultural aspects of the Santa Elena landscapes were not considered in the currant report. The management and ecological history of the Area de Conservación Guanacaste were expounded in an article of Janzen and Hallwachs (2006).

Introduction

Costa Rica is on the trailing edge of the Carribean Plate, a plate that was initially produced over a hot spot, or mantle plume, in the Pacific Ocean during the Jurassic period (Mann 2007). The Carribean plate drifted through a gap that developed between Laurasia and Gondwana and it now rests between the North and South American continents. During the Cenozoic era, subduction of the Cocos plate has raised the western margin of the Caribbean plate, forming a volcanic arc from Panama and Costa Rica to Guatemala. The raised margin of the Carribean plate has formed a bridge connecting the North and South America. Oceanic terranes of the Santa Elena Peninsula and the Nicoya complex are exposed south of volcanoes in Nicaragua and west of volcanoes in Costa Rica (Fig. 1). The serpentine (ultramafic) terrain is on the Santa Elena Peninsula.

Figure 1. A view eastward from the Cerros Santa Elena to volcanic terrain of the Cordillera Guanacaste.

Most of the soils on the Santa Elena Peninsula are derived from weathered serpentinized peridotite, or serpentinite. The exposure of ultramafic rocks on the Peninsula is the only large one with ultramafic rocks along the Pacific margin of the Carribean plate, between Guatemala and Colombia (Lewis et al. 2006). As such, it represents a unique geoecological environment.

Savana perpetuated by frequent burning (Jiménez 2016) is the dominant cover on serpentine soils of the eastern two-thirds of the Santa Elena Peninsula, with dense forest on nonserpentine soils along the Rio Potrero Grande (Fig. 1), and nonultramafic soils along the northern margin of the Peninsula. Also, forest prevails on N-facing slopes on the western one-third of the Peninsula (Fig. 2). A landscape map was made of the serpentine area and Maria Marta Chavarria Diaz of the Area de Conservacíon Guanacaste and I characterized the soils and plant communities in the various landscapes. Maria Marta knew the plants very well and we were able to relate the distributions of the plant communities and soils to the different kinds of landscapes. There are no roads on the western one-third of the Santa Elena Peninsula, where the slopes are very steep, and access is difficult. With considerable oceanic influence and greater relief, up to 700 m, the vegetation differs substantially from that on the eastern two-thirds of the Peninsula, which lacks appreciable oceanic influence and the higher elevations are no more than about 300 m on the south to 500 m on the north. Dauphine and Grayum (2005) have a fascinating account of the vegetation and other biota on the western part of the Santa Elena Peninsula.

Geology

The ultramafic body on the Peninsula is dominated by spinel harzburgite. It is representative of only slightly fractionated mantle that has been largely serpentinized in an oceanic environment. Minimal fractionation in the mantle to produce the harzburgite is indicated by relatively high Al in the orthopyroxene and high Al, Na, and Ti in the clinopyroxene of the peridotite (Tournon 1994). The serpentinized peridotite has been laced with numerous dolorite (diabase) dikes and thrust over a Jurassic-Cretaceous basement of basalt and sea-floor sedimentary deposits. This basement is exposed along the Rio Potrero Grande, which has cut through the ultramafic body, and along the southern coast of the Peninsula. The basement and the recent fluvial deposits on it were not characterized in the serpentine landscape investigation.

Figure 2. Santa Elena Peninsula, and its location in Costa Rica.

Remnants of an old erosion surface are evident across the eastern part of the Santa Elena ultramafic body, and some ignimbrite (a pyroclastic, or volcanoclastic, deposit) has been deposited on it. The pyroclastic deposits have been assigned to the Bagaces formation (Guillot et al. 1994). They are a composite of Neogene to Quaternary deposits that have been dated from about 8 Ma to 0.65 Ma (Vogel et al. 2004). Assuming that the base level of the old erosion surface was the ocean, it has been lifted about 350 meters and deeply dissected within the last 0.65 Ma. Uplift of the western part of the Santa Elena ultramafic body, where elevations are up to about 700 m asl, has been greater. No old erosion surface is evident there, and any pyroclastic deposits that might have been present have been removed by erosion.

Climate and Vegetative Cover

The Santa Elena Peninsula is at a subtropical latitude on the western side of the Isthmus of Panama. It is very warm. Because the prevailing winds are from the east, or northeast, the Peninsula is on the drier side of the Isthmus. There is a wet season when the sun passes northward in the spring and another, wetter season when the sun returns southward in the autumn (Figure 3). There is very little rain from January until April.

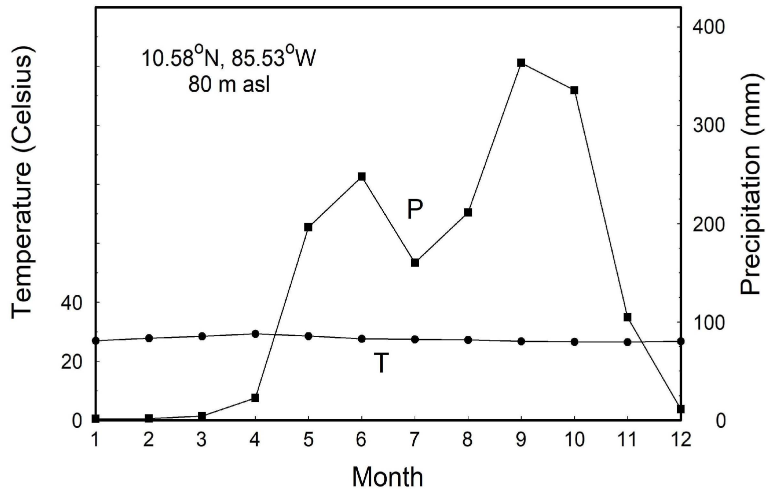


Figure 3. Climate at Liberia, about 45 km southeast of the Santa Elena Peninsula.

The annual precipitation is about 1500 mm and savana is the dominant vegetation cover across most of the Cerros Santa Elena, with semi-deciduous forest along the Rio Potrero Grande and on the lower reaches of north-facing slopes in ravines (Fig. 1). A cloud drenched forest with abundant epiphytes is present above about 500 m on the western part of the Santa Elena Peninsula (Dauphine et al., 2005), and quite disimilar from anything on the eastern part of the Peninsula. The areas of denser forest and scrub are evident from the greener colors in Figure 2.

Methods for the Landscape Investigation

Serpentine and ignimbrite landscape map units were delineated on stereographic pairs of 1:40,000 color photographs of the Santa Elena Peninsula. These delineations were based on landscape dissection and dominant slope gradients. Soil landscape patterns were observed along roads in the more accessible eastern part of the Peninsula. Soils perceived to be representative of the landscapes were described and sampled in fresh road-cuts and in hand-dug pits. The plant species at each soil and landscape characterization site were identified by Maria Marta Chavarria Diaz and areas covered by each of the main species on the sites were estimated visually.

Landscapes on the western two-thirds of the Santa Elena Peninsula were observed on Google Earth with satellite images from October 2010 and January 2014.

The Landscape Units and Classes

The different kinds of soils and vegetation distributions are closely related to the soil parent materials, landforms, and slope gradients. Six general landscape map units were delineated with these features in mind – four with serpentinized peridotite (or serpentinite), one with ignimbrite, and one lowland landscape unit for recent fluvial and coastal deposits (Fig. 4). Besides slope gradient, azimuth, slope configuration (convex or concave), and the position on slopes (summit to footslope) are very important for soil development and plant habitat. Considering these additional features, the landscape map units with serpentinite and ignimbrite, can be grouped into six landscape classes (Table 1). Four of the landscape classes have soils with serpentinite parent materials: (Cs) on convex upper slopes and steep sideslopes, (Ds) on very steep mountain sideslopes with colluvial footslopes, (Bs) on gentle planar to convex slopes on plateaus, and (Ds) on very gentle planar and concave plateau slopes. Two of the landscape classes have soils on pyroclastic deposits: (Ct) on gentle planar to convex plateau slopes and (Dt) on gentle planar and concave plateau slopes. No specific landscape classes were identified in the S4* map unit.

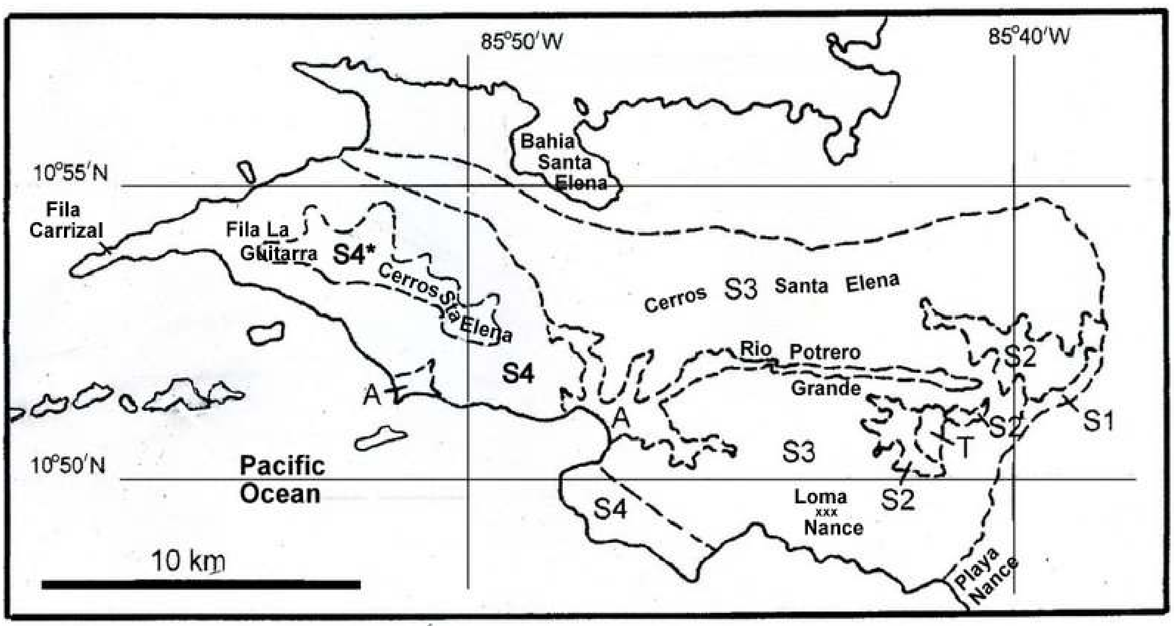


Figure 4. Landscape map units of the serpentine area on the Santa Elena Peninsula.

A	recent alluvium and coastal sediments	15 km^2
S1	undulating plateau, serpentine, 1-15% slopes	3 km^2
S2	dissected plateau, serpentine, 10-40% slopes	21 km^2
S3	steep mountains, serpentine, 30-60% slopes	190 km^2
S4	very steep mountains, serpentine, 40-80% slopes	102 km^2
S4*	very steep mountains, serpentine, high elevations	8 km^2
T	undulating plateau, pyroclastic deposits, 1-15% slopes	1 km^2

The relative areas of the six landscape classes in the upland landscape map units are indicated in Table 1. The lowland landscape map unit (unit A), which consists of the floodplain along the Rio Potrero Grande, alluvial fans, deltaic features, and sand bars, was not characterized other than at two sites in mangroves at the mouth of the Rio Potrero Grande.

Table 1. Presence of landscape classes in the landscape map units.

Land-scape Map Unit	Landscape Class					
	Ds	Cs	Bs	Bt	As	At
	very steep mountain and colluv. slopes	convex to steep mountain slopes	gentle serpentin. plateau slopes	gentle ignimbrite plateau slopes	very gentle serpentin. plateaus	very gentle ignimbrite plateaus
S1	–	–	++	–	++	–
S2	–	++	++	–	–	–
S3	+	+++	–	–	–	–
S4	++	++	–	–	–	–
T	–	–	–	++	–	++

Relative areas within each map unit: +++ dominant; ++ common; + sparse, – none or trace.
Note that landscape class Cs has a larger proportion of Alfisols in map unit S2 than in unit S3.

Soil distributions in the landscape map units are indicated in Table 2. Soils were described in detail and the vegetative species were recorded at ten sites that are representative of the soils and plants in the upland landscape map units and landscape classes. Soils were described in Rhizophora and in Pelliciera mangrove, also. The soil-landscape site descriptions follow the landscape class descriptions.

West of the Rio Potrero Grande the S4 map unit is practically inaccessible and was not visited in the serpentine landscapes investigation. Initially it was assumed to be similar to that part of unit S4 that is south of the Rio Potrero Grande with landscapes similar to those on nearby Loma Nance. They not entirely similar, however, because of oceanic influences on the western one-third on the Santa Elena peninsula. Oceanic influences are particularly notable in landscape map unit S4*, above 500 m, as described by Dauphine and Grayum (2005). Map unit S4* is described following the landscape class descriptions.

Catherine Hulshof has visited the area from the the southern coast of the Santa Elena Peninsula up into unit S4* and noted that “almost complete plant species turnover for woody species occurs at about 450 m in elevation, whereas for herbaceous species near complete turnover of species occurs at 550m in elevation. That is, there are distinctly different plant communities above and below these elevations” (Hulshof, personal communication, 2018).

Table 2. Soils in the landscape map units.

A	recent alluvium and coastal sediments	
	including small areas of Mesozoic basement in the valley of the Rio Potrero Grande	
S1	Undulating plateau, serpentinite, 1-15% slopes	
	+++	moderately deep Alfisols, bedrock weathered soft, 3-15% slopes
	++	deep old Alfisols on flats and concave slopes, 1-6% slopes
	+	inclusions of rock outcrop, very shallow Entisols, shallow Inceptisols, and shallow Alfisols on very stony hillocks and ridges
S2	Dissected plateau, serpentinite, 10-40% slopes	
	++	very shallow Entisols, 10-40% slopes
	++	shallow Inceptisols, 10-40% slopes
	++	moderately deep Alfisols, soft bedrock, on sideslopes < 15% and concave slopes
	+	inclusions of rock outcrop on summits and ridges, shallow Alfisols on summits and moderately steep sideslopes, and deep old Alfisols on concave slopes < 12%
S3	Steep mountains, serpentinite, 30-60% slopes	
	++	very shallow Entisols on summits and sideslopes
	++	shallow Inceptisols on summits and sideslopes
	+	moderatley deep Alfisols, hard bedrock, on concave slopes
	+	inclusions of rock outcrop on summits and ridges, and shallow Alfisols
S4	Very steep mountains, serpentinite, 50-80% slopes	
	+	very shallow Entisols on summits and sideslopes
	+	shallow Inceptisols on summits and sideslopes
	+	deep Inceptisols on very steep sideslopes and on colluvial footslopes
	+	deep Alfisols on very steep sideslopes and on colluvial footslopes
	+	inclusions of rock outcrop on summits and on irregular (not smooth) sideslpes
T	Undulating plateau, ignimbrite, 1-15% slopes	
	+++	shallow Alfisols on gentle planar and convex slopes
	++	deep Mollisols on concave slopes and very gentle planar slopes
	+	inclusions of rock outcrop and Inceptisols on ridges elevated above the plateau

Areal extent of components within map units

+++ 50-90% of area

++ 25-50% of area

\+ 10-25% of area

Map unit slope designations are for charactereristic slopes, not absolute ranges

Map units S3 and S4 are not separated with much detail

map unit S3 indicates delineations (polygons) with more landscape S3 than S4

map unit S4 indicates delineations (polygons) with more landscape S4 than S3

Landscape Class Descriptions

Landscape class Ds, serpentinite. Very steep mountain sideslopes and colluvial footslopes. *Soil-landscape site descriptions SE03 and SE04, Inceptisols and deep Alfisols.*

Figure 5. Soil-landscape site SE03.

Figure 6. Soil-landscape site SE04.

We described Ds and Cs class landscapes only on the eastern part of the Santa Elena Peninsula. Very steep slopes and colluvial footslopes are dominant in soil-landscape map unit S4 and common in S3. There are shallow to deep soils on the very steep slopes and very deep soils on the colluvial footslopes below them. Both Inceptisols (Typic Haplustepts) with cambic Bw horizons and Alfisols (Typic Rhodoxeralfs) with argillic Bt horizons were described on the very steep slopes, but our investigations were insufficiently complete to decide whether shallow, moderately deep, or deep soils were predominant on the steep slopes. The predominance of Inceptisols and Alfisols indicates that most of the slopes have been reasonably stable for thousands of years under natural conditions. Few recent landslides were observed on the very steep slopes.

Currently soil landscapes in class Ds have *Byrsonima crassifolia–Roupala montana/Turnera pusilla/Trachypogon plumosus* savanna plant communities. The rapid runoff of water and low exchangeable Ca/Mg ratios of the soils, or high Ni concentrations, that might retard the conversion of savanna to forest also prevent the invasion of jaragua. Dense forest cover is becoming established on some north-facing slopes.

Landscape class Cs, serpentinite. Convex upper slopes and steep sideslopes.
Soil-landscape site descriptions SE01, SE06, and SE07, very shallow Entisols shallow Inceptisols, and moderately deep Alfisols .

Convex upper slopes and steep sideslopes are predominant in map units S2 and S3 and common in S4. Natural fluvial erosion on these slopes removes soil at rates comparable to rates of soil development. Because weathering rates of the serpentinized peridotite are quite variable within distances of a few meters, or less, a complex pattern of very shallow Entisols (Lithic Ustorthents) and shallow (25-50 cm deep) Inceptisols (Lithic Haplustepts) is cmmon. Most of the soils in this complex pattern have Bw subsoil horizons that are indicative of weathering and soil development. These Bw horizons are considered to be cambic horizons (Soil Survey Staff 1999) in the shallow soils, but not in the very shallow soils. The very shallow and shallow soils might be classified separately as Entisols, lacking cambic horizons, and Inceptisols with cambic horizons. Instead both were considered to be different aspects of the same soil, the classification being Lithic Ruptic-Entic Haplustepts; that is, seasonally dry Inceptisols with cambic horizons that are interrupted within short distances by hard bedrock. They are in loamy-skeletal, magnesic, isohyperthermic families, which means they have loamy textures with coarse fragments (2-250 mm) > 35% by volume, have serpentine mineralogy, and are very warm throughout the year.

Figure 7. Soil-landscape site SE01.

Enough clay has accumulated in some of the soils for them to have argillic horizons, changing the classification to Rhodustalfs, both shallow (SE05) and moderatley deep (SE07) Rhodoxeralfs..

Currently soil landscapes in class Cs have *Byrsonima crassifolia–Roupala montana/Turnera pusilla/Trachypogon plumosus* savanna plant communities. The severely limiting plant available water storage capacities (AWC) of most of the soils, and low exchangeable Ca/Mg ratios, or high Ni concentrations, that might retard the conversion of savanna to forest, also prevent the invasion of jaragua.

Landscape class Bs, serpentinite. Gentle planar to convex serpentinite slopes on plateaus. *Soil-landscape site description SE02, moderately deep Alfisols with soft bedrock contacts.* Gentle planar to convex slopes are common on the plateaus of map units S1 and S2. The dominant soils on these slopes are strongly weathered red Alfisols (Rhodustalfs). Erosion has been sufficient to maintain depths < 100 cm, which is less depth than might be expected of soils in which the bedrock is weathered soft to depths > 100 cm. Nearly 5% Fe in serpentinized peridotite (harzburgite, Desmet 1985) of the parent material has probably been concentrated two or three fold and oxidized to yield on the order of 20% Fe-oxides in the soils. The red colors are due to hematite (Fe_2O_3), although there is likely more goethite (FeOOH) than hematite in the subsoils. Weathering and leaching have removed much of the silicon and magnesium, but magnesium is still the dominant exchangeable cation in both surface and subsoils (Table 5).

Currently soil landscapes in class Bs have *Byrsonima crassifolia–Roupala montana/Turnera pusilla/Trachypogon plumosus* savanna plant communities. The low exchangeable Ca/Mg ratios in the soils, and possibly high nickel concentrations, that might retard the conversion of savanna to forest, also prevents the invasion of jaragua.

Figure 8. Soil-landscape site SE02.

Landscape class Bt, ignimbrite. Gentle planar to convex ignimbrite slopes on plateaus. *Soil-landscape site description SE09, shallow Alfisols with moderately hard bedrock contacts.* Gentle planar to convex slopes are common on the plateau of soil-landscape map unit T.

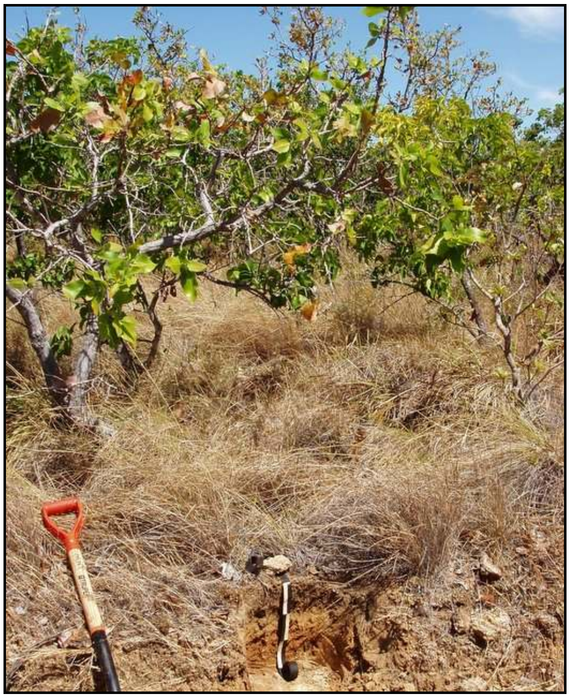


Figure 9. Soil-landscape site SE09.

The dominant soils on these slopes are shallow Alfisols (Lithic Haplustalfs). Basic cations (Na, K, Mg, and Ca) are much more thoroughly leached from these soils than from the soils with serpentinite parent materials, and the base saturation of the cation-exchange complex is much lower (Table 5). Exchangeable Ca is only slightly higher than Mg in the surface A horizon, for some unknown reason, but Ca is much higher in the subsoil Bt horizon. Although it must have taken many thousands of years for the development of clayey argillic horizons in these soils, they are still shallow while soils on comparable landscape positions on serpentinite plateaus (landscape class Cs) are moderately deep. Greater erodibility of these soils and slower weathering of ignimbrite are presumed to be reasons that they are more shallow than soils on similar serpentinite plateau slopes.

Currently the soil landscapes in class Bt have *Curatella americana–Roupala montana/ Trachypogon plumosus* savanna plant communities, with some jaragua. The soils are presumed to be relatively infertile and the plentiful raspaguacal (*Curatella americana*) and predominance of *Trachypogon plumosus* over jaragua support this presumption.

Figure 10. Soil-landscape site SE08

Landscape class As, serpentinite. Very gentle planar and gentle convave serpentinite slopes on plateaus. *Soil-landscape site description SE08, deep old Alfisols.*

Very gentle planar to convex slopes are common on the plateau of map unit S1. The dominant soils on these slopes are deep old Alfisols (Oxyaquic Vertic Paleustalfs). They have been strongly weathered and much of the magnesium has leached from the surface soils. Although exchangeable Ca/Mg ratios are > 1 in the surface soils, the ratios are much < 1 in subsoils (Table 5), which are argillic horizons with enough expandible clay to produce slickensides. These subsoils are only very slowly permeable, which slows the leaching of basic cations and maintains highly saturated cation-exchange complexes in subsoils. They have gray matrix colors and are mottled at depths > 70 cm, indicating somewhat poor drainage.

Currently the soils in landscape class As have *Byrsonima crassifolia–Rehdera trinervis–Roupala montana/Hyparrhenia rufus* savanna plant communities. Because of intensive weathering and leaching for hundreds of thousands of years has reduced the dominance of magnesium in the surface soils, these soils are relatively fertile, compared to the other serpentinite soils.

Landscape class At, ignimbrite. Very gentle planar to convave ignimbrite slopes on plateaus. *Soil-landscape description SE10, deep old Mollisols.*

Very gentle planar to convex-concave slopes are common on the plateau of map unit T. The dominant soils on these slopes are deep old Mollisols (Vertic Paleustolls). They have been strongly weathered and basic cations have leached from the surface soils to leave the cation-exchange complexes only moderately saturated with basic cations, but with sufficient base saturation (BS > 50%) for mollic epipedons (Soil Survey Staff 1999). Exchangeable Ca is much greater than exchangeable Mg in all horizons of the soil (Table 5). The argillic Bt horizon has enough expandible clay to produce slickensides. These subsoils are very slowly permeable, which slows the leaching of basic cations and maintains highly saturated cation-exchange complexes. They have gray matrix colors and are mottled at depths > 70 cm, indicating somewhat poor drainage.

Figure 11. Soil-landscape site SE10.

Currently the soil landscapes in class At have mixed angiosperm savanna plant communities, with only traces of jaragua. Although these soils are only moderately fertile, they may be more productive (greater NPP) than any of the serpentinized peridotite soils.

Landscapes in landscape map unit S4*

The S4* map unit is distinguished from the S4 map unit in being at higher elevations and having relatively common cloud cover. It is at about 400 to 600 m asl along the Fila La Guitarra and about 500 to 700 m asl along the backbone of the Cerros Santa Elena on the western part of the Santa Elena Peninsula (Fig. 4). It is distinguished by extremely steep (80-100%, ~ 40 to 45º), sparsely vegetated slopes down to about 400 or 500 m on the south and some high narrow ridges extending northward, with very steep slopes downward from the ridges.

It is only about a kilometer down from below the extremely steep slopes along the south side of the Fila La Guitarra to the coastline. The upper half is very steep with predominantly savanna and the lower half is moderately steep to more gentle colluvial slopes with dense forest.

The extremely steep slopes southward down from the Fila La Guitarra and the Cerros Santa Elena are unique features of the S4 map unit and would warrant the addition of a separate map unit on a serpentine landscape inventory of more detail. Landslides down the extremely steep slopes are visible on the satellite photos of Google Earth.

It is two or more kilometers down from below the extremely steep slopes along the south side of the Cerros Santa Elena to the coastline. The landscape is highly dissected and the slopes are very steep. The physiographic nature of the vegetation is similar to that in landscape map unit S4 on the eastern part of the Santa Elena Peninsula, with shrubby forest on N-facing slopes and savanna on S-facing slopes, but the plant species may be very different.

Northward from the east-west crest, there are dense forests on N-facing slopes and in deep ravines. On S-facing slopes there are fewer trees, and shrubs are common. A similar vegetation pattern persists in the S4 unit north of the S4* unit, and it differs from the vegetation pattern in the S4 unit in the eastern two-thirds of the Santa Elena Peninsula.

Dauphine and Grayum (2006) have named some of the common trees, shrubs, and vines in map unit S4* (Table 3). There observed many epiphytes and they named a few ferns, bromeliads, and orchids. They found that corticolous bryophytes were dominant, whereas they were scarce in the lower, drier areas of the Santa Elena Peninsula.

CM Hulshof (internet communnication) noted that *Hematoxylon brasileto* was common in low elevation forests south of the Fila La Guitarra, whereas *Lonchocarpus phlebophyllus* was found at all elevations up to summit forests.

Table 3. Some of the common trees, shrubs, and vines in landscape map unit S4* (Dauphine ad Grayum, 2006).

Family	Species
Bignoniaceae	*Arrabidaea costericensis*
Burceraceae	*Bursera permollis*
Fabaceae	*Callandra tergemina*, *Coursetia elliptica*, *Diphysa humilis*, *Lonchocarpus phlebophyllus*
Euphoriaceae	*Croton niveus*, *C. Yucatanensis*, *Euphorbia schlechtendalii*, *Pedilanthus nodiflorus*
Ebenaceae	*Diospyros salicifolia*
Erythroxylaceae	*Erythroxylum rotundifolium*
Rubiaceaae	*Guettarda macrosperma*
Protaceae	*Roupala montana*

Soil-Landscape Site Descriptions

Soils were described in detail and the vegetation was recorded at ten sites that are representative of the landscape classes and at two sites in mangrove landscapes (Table 3). Complete descriptions of the soils at these sites follow.

Table 4. A list of sites where soils and plant communities were described in serpentinite and ignimbrite landscapes.

Site	Landscape Class	Soil	Plant Community (trees/shrubs/grasses)
SE01	Cs	shallow Inceptisol	BYCR–ROMO/TUPU/TRPL savana
SE02	Bs	moderately deep Alfisol/ Cr	BYCR–ROMO/TUPU/TRPL savana
SE03	Ds	(deep) Inceptisol, colluvium	BYCR–ROMO/TUPU/TRPL savana
SE04	Ds	deep Alfisol, colluvium	ROMO–BYCR/TUPU/TRPL savana
SE05	Cs	shallow Alfisol/bedrock (R)	BYCR/TRPL savana
SE06	Cs	shallow Inceptisol	BYCR–ROMO/TUPU/TRPL savana
SE07	Cs	moderately deep Alfisol/ R	BYCR/TUPU/TRPL savana
SE08	As	deep old Alfisol	BYCR–ROMO-RETR/HYRU savana
SE09	Bt	shallow Mollisol, ignimbrite	CUAM–ROMO/TRPL savana
SE10	At	deep Alfisol, ignimbrite	mixed angiosperm forest
SE11	—	Halic Haplosaprist	*Rhizophora* mangrove
SE12	—	Fluvaquent or Hydraquent	*Pellicociera* mangrove

Soil parent material of SE01 through SE08 is serpentinized peridotite
Plant species codes: BYCR, *Byrsonima crassifolia*, nancite; CUAM, *Curatella americana*, raspaguacal: HYRU, *Hyparrhenia rufa*, jaragua; mixed angiosperm forest - *Rehdera trinervis*; *Luehea seemanii*, and many other species; RETR, *Rehdera trinervi*s; ROMO, *Roupala montana;* TRPL, Trachypogon plumosus; TUPU, *Turnera pusilla*.

Soils were described utilizing terminology found in the *Soil Survey Manual* (Soil Survey Staff 1993) and classified by *Soil Taxonomy* of the USDA (Soil Survey Staff 1999, 2014). Two soils were described in mangrove plant communities of landscape map unit A: an organic soil (Histosol) in a *Rhizophora* sp. plant community and a wet Entisol in fluvial sediments with a *Pelliciera rhizophorae* plant community.

Maria Marta Chavarria Diaz identified the plants at each site and Earl Alexander assigned them to abundance classes. Plant cover abundance classes in the soil-landscape site descriptions are as follows: dominant, canopy area > 60%; abundant, 30-60% (or 30-90% for understory plants); plentiful, 12-30%, common, 3-12%; sparse, 1-3%; and trace, cover < 1%.

Site SE01

Earl Alexander – December 23, 2006

Location: Lambert coordinates 354.673 E, 317.066 N; 10.873ºN latitude, 85.662ºW longitude, Murciélago 1:50,000 quadrangle, 350 m altitude

0.3 km SW of intersection (cruce) to Cerro Calera (east) and Cerro El Inglés (north)

Landform: hillside, convex-convex slope 28% southwest

Parent material: serpentinized peridotite

Precipitation, drainage: 150 cm/year, excessively well drained soil

Plant community: BYCR–ROMO/TUPU/TRPL savanna

Surface rock and stoniness: 5% rock outcrop; 5% “stones”, 16% cobbles

Oi		scattered (discontinuous) dicot leaf and grass detritus
A	0-6 cm	dark reddish brown (5YR 3/4, 4/4 dry) very cobbly loam: moderate, fine, subangular blocky; slightly hard, friable, and slightly sticky and slightly plastic; 5% “stones”, 16% cobbles, 30% gravel; common very fine and fine, and very few medium roots; neutral (pH 6.8); clear, wavy boundary
Bw	6-21	brown (7YR 4/4, 5/6 dry) very cobbly clay loam: moderate, fine, subangular blocky; slightly hard, friable, and sticky and plastic; 6% “stones”, 20% cobbles, 35% gravel; common fine and medium roots; neutral (pH 7.0); gradual, discontinuous boundary
C	21-38	dark yellowish brown (10YR 4/4, 6/4 dry) extremely cobbly clay loam, black where roots descend along some fractures into bedrock; weak, fine, subangular blocky; slightly hard, friable, and sticky and plastic; 8% “stones”, 22% cobbles, 40% gravel; few fine and medium roots; neutral (pH 7.0); abrupt, irregular boundary
R	38-100+	highly fractured, hard bedrock, weathered soft in places

Notes: pH by bromthymol blue indicator; Bw horizon < 15 cm thick in about 20 to 40% of pedon

Soil class: loamy-skeletal, magnesic, isohyperthermic Lithic Ruptic-Entic Haplustept

World Reference Base (WRB) classification: Leptic Cambisol

Vegetative cover: SE01

15% trees - common *Byrsonima crassifolia* and *Roupala montana*, sparse *Simarouba glauca*, and trace of *Mabea occidentalis*;

10% shrubs - common *Turnera pusilla*, sparse *Simsia santarosensis* and *Calliandra tegermina*; and traces of *Jaquinea nervosis, Widelia fruticosa*, *Buchnera pusilla*, and *Croton* sp.;

vine - sparse *Marsdenia trinvirgulata*;;

forbs - traces of a Convolvulaceae;

60% grass - abundant *Trachypogon plumosus* and traces of *Schizachyrium malocostachyon*

Site SE02

Earl Alexander – February 19, 2008

Location: Lambert coordinates 354.491 E, 316.155 N; 10.864ºN latitude, 85.663ºW longitude, Murciélago 1:50,000 quadrangle, 300 m altitude

0.5 km west of intersection to Cerro El Inglés (north) and to Loma Nance (west)

Landform: undulating plateau, linear-concave slope 11% west (255º azimuth)

Parent material: serpentinized peridotite

Precipitation, drainage: 150 cm/year, well drained soil

Plant community: BYCR–ROMO/TUPU/TRPL savanna

Surface rock and stoniness: no rock outcrop; 2% "stones", 12% cobbles

Oi	1-0 cm	loose grass leaves
A	0-3 cm	dark reddish brown (5YR 3/4, 3/4 dry) gravelly loam, 7.5YR 3/3 on ped faces; moderate, very fine, granular structure; friable and sticky and slightly plastic; 1% "stones", 3% cobbles, 15% gravel; few very fine and fine roots; neutral (pH 6.7); clear, smooth boundary
Bt1	3-16	dark reddish brown (2.5YR 3/4, 5YR 3/4 dry) very gravelly clay loam, with distinct 5-2.5YR 3/3 coatings on ped faces; moderate, coarse, subangular blocky; very hard and very sticky and plastic; "stones" < 1%, 18% cobbles, 20% gravel; common very fine and fine, and few medium roots; common fine and few medium tubular pores; neutral (pH 6.7); clear, smooth boundary
Bt2	16-45	dark red (10R 3/4, 2.5YR 3/4 dry) clay, with prominent 2.5YR 3/3 coatings on ped faces; moderate, medium, subangular blocky; very hard and very sticky and very plastic; "stones" < 1%, 1% cobbles, 5% gravel; few fine, common medium, and few coarse roots; neutral (pH 6.7); gradual, smooth boundary
C	45-62	dark reddish brown (5YR 3/4, 3/4 dry) clay loam; moderate, fine, subangular blocky; firm and sticky and plastic; no "stones", cobbles < 1%, 1% gravel; many cobbles weathered soft; few fine roots; neutral (pH 6.8); clear, wavy boundary
Cr	62-90+	moderately fractured bedrock weathered soft, few relatively hard parts

Notes: pH by bromthymol blue indicator; top of Bt1 horizon may have been a former erosion surface

Soil class: fine, magnesic, isohyperthermic Typic Rhodustalf

World Reference Base (WRB) classification: Rhodic Luvisol

Vegetative cover: SE02

10% trees - common *Byrsonima crassifolia* and *Roupala montana*;

10% shrubs - common *Turnera pusilla* and traces of *Porophyllum punctatum*, *Buchnera pusilla*, *Russelia sarmentosa*, and *Calliandra* sp.;

vine - sparse *Marsdenia trinvirgulata*;

60% grass - abundant *Trachypogon plumosus*

Site SE03

Earl Alexander and Maria Marta Chavarria Diaz – February 20, 2008

Location: Lambert coordinates 349.433 E, 312.368 N; 10.833ºN latitude, 85.710ºW longitude,
Ahogados 1:50,000 quadrangle, 240 m altitude
2 km northeast of Loma Nance

Landform: very steep mountains, linear-linear "back" slope 75% south (185º azimuth)

Parent material: serpentinized peridotite coluvium

Precipitation, drainage: 150 cm/year, excessively well drained soil

Plant community: BYCR–ROMO/TUPU/TRPL savanna

Surface rock and stoniness: rock outcrop < 1%; boulders < 1%, 5% "stones", 15% cobbles

Oi	1-0 cm	loose grass leaves
A	0-5 cm	dark reddish brown (5YR 3/3, 4/4 dry) cobbly loam: moderate, fine, granular structure; hard and slightly sticky and slightly plastic; 5% "stones", 10% cobbles, 5% gravel; few very fine, and very few fine roots; slightly acid (pH 6.6); clear, smooth boundary
Bw	5-32	dark reddish brown (2.5YR 3/4, 4/4 dry) very stony clay loam, with faint 5YR 3/3 coatings on ped faces: moderate, fine and medium, subangular blocky; very hard and sticky and plastic; 20% "stones", 20% cobbles, 10% gravel; few very fine, fine, and medium and very few coarse roots; neutral (pH 6.8); clear, irregular boundary
C	32-68	reddish brown (5YR 4/4, 4/6 dry) extremely stony loam; weak, medium, subangular blocky; hard and sticky and slightly plastic; 30% "stones", 25% cobbles, 20% gravel; very few fine, medium, and coarse roots; neutral (pH 7.0); abrupt, irregular boundary
R	68-100+	hard, moderalely fractured bedrock

Notes: pH by bromthymol blue indicator; pedon represents moderately deep to very deep soils

Soil class: loamy-skeletal, magnesic, isohyperthermic Typic Haplustept

World Reference Base (WRB) classification: Skeletic Cambisol

Vegetative cover: SE03

15% trees - common *Byrsonima crassifolia* and *Roupala montana* and sparse *Simarouba glauca*;

10% shrubs - common *Turnera pusilla*, sparse *Simsia santarosensis*, and traces of *Porophyllum punctata*, *Hemiangium* sp., *Lysiloma* sp., *Mimosa* sp., and *Xylosma* sp.;

vine - sparse *Convolvulus nodiflorus*;

forbs - sparse *Oxalis* sp. and *Convolvulus* sp.;

70% grass - abundant *Trachypogon plumosus*;

mistletoe - *Phorodendron* sp. on *B. crassifolia* and *Mimosa* sp.

Site SE04

Earl Alexander and Maria Marta Chavarria Diaz – February 20, 2008

Location: Lambert coordinates 347.418 E, 311.617N; 10.822^{o}N latitude, 85.727^{o}W longitude, Ahogados 1:50,000 quadrangle, 250 m altitude
1 km west of Loma Nance

Landform: very steep mountains, linear-linear "back" slope 72% north (325^{o} azimuth)

Parent material: serpentinized peridotite colluvium

Precipitation, drainage: 150 cm/year, excessively well drained soil

Plant community: ROMO–BYCR/TUPU/TRPL savanna

Surface rock and stoniness: rock outcrop < 1%; 5% boulders, 15% "stones", 20% cobbles

Oi	1-0 cm	loose grass leaves
A	0-5 cm	dark reddish brown (2.5YR 3/4, 3/4 dry) very stony loam: moderate, very fine, granular structure; soft and slightly sticky and slightly plastic; 15% "stones", 20% cobbles, 10% gravel; common very fine and fine roots; neutral (pH 6.8); clear, wavy boundary
Bt	5-58	dark reddish brown (10R 3/4, 3/4 dry) very stony clay loam, with distinct 2.5YR 3/4 coatings on ped faces: moderate, medium, subangular blocky; friable and sticky and plastic; 20% "stones", 30% cobbles, 10% gravel; common fine, medium, and coarse roots; neutral (pH 7.0); diffuse boundary
C	58-125+	reddish brown (2.5YR 4/4, 4/6 dry) extremely stony loam, with faint 2.5YR 3/4 coatings on ped faces:; moderate, fine, subangular blocky; friable and sticky and slightly plastic; 30% "stones", 30% cobbles, 20% gravel; few fine and medium and very few coarse roots; neutral (pH 7.2)

Notes: pH by bromthymol blue indicator; pedon represents moderately deep to very deep soils

Soil class: loamy-skeletal, magnesic, isohyperthermic Typic Rhodustalf

World Reference Base (WRB) classification: Skeleti-Rhodic Luvisol

Vegetative cover: SE04

60% trees - plentiful *Roupala montana* and common *Byrsonima crassifolia*:

7% shrubs - common *Turnera pusilla*, sparse *Convolvulus* sp. and *Porophyllum punctata*, and traces of *Simsia santarosensis*, *Ruselia sarmentosa*, and *Hyptis suaveolens*;

vine - sparse *Marsdenia trivirgulata*;

forbs - sparse *Oxalis* sp.

succulent - sparse *Agave* sp.;

30% grass - plentiful *Trachypogon plumosus*

orchid - trace, Orchidaceae

Site SE05

Earl Alexander and Maria Marta Chavarria Diaz – February 21, 2008

Location: Lambert coordinates 341.850 E, 320.215 N; 10.899ºN latitude, 85.777ºW longitude, Santa Elena 1:50,000 quadrangle, 110 m altitude along road to Cerros Santa Elena, 0.9 km south of road from Murciégalo

Landform: steep mountains, convex-linear slope 32% north-northeast (40º azimuth)

Parent material: serpentinized peridotite

Precipitation, drainage: 150 cm/year, well drained soil

Plant community: BYCR/TRPL savanna

Surface rock and stoniness: 5% rock outcrop, boulders < 1%; 12% "stones", 25% cobbles

Oi	1-0 cm	loose grass leaves
A	0-3 cm	dark reddish brown (5YR 3/3, very 3/4 dry) very cobbly loam: moderate, fine, granular structure; slightly hard and slightly sticky and slightly plastic; 12% "stones", 25% cobbles, 12% gravel; common very fine and fine roots; neutral; clear, wavy boundary
Bt	3-24	dark reddish brown (2.5YR 3/4, 3/4 dry) very cobbly clay loam, with distinct 2.5YR 3/3 coatings on ped faces; moderate, coarse, subangular blocky; very hard and sticky and plastic; 6% "stones", 20% cobbles, 10% gravel; few very fine, fine, and medium, and very few coarse roots; neutral; gradual, discontinuous boundary
C	24-48	reddish brown (5YR 4/4, 4/6 dry) extremely cobbly clay loam; weak, medium, subangular blocky; slightly hard and sticky and plastic; 12% "stones", 40% cobbles, 20% gravel; very few fine and medium roots; neutral; abrupt, irregular boundary
R	48-50+	hard bedrock with a thick, soft weathering rim

Notes: pH by bromthymol blue indicator; sparse dolorite (diabase) rock fragments

Soil class: loamy-skeletal, magnesic, isohyperthermic Lithic Rhodustalf

World Reference Base (WRB) classification: Lepti-Rhodic Luvisol

Vegetative cover: SE05

6% trees - common *Byrsonima crassifolia*, sparse *Curatella americana*, and trace of *Roupala montana*;

2% shrubs - sparse *Porophyllum punctata*, *Russelia sarmentosa*, and *Hyptis suaveolens*;

vine - sparse *Marsdenia trivirgulata*;

forbs - sparse *Oxalis* sp.

60% grass - abundant *Trachypogon plumosus* and trace of *Schizachyrium malacostachyum*

Site SE06

Earl Alexander and Maria Marta Chavarria Diaz – February 23, 2008

Location: Lambert coordinates 355.075 E, 318.287 N; 10.882ºN latitude, 85.658ºW longitude,
Murciélago 1:50,000 quadrangle, 380 m altitude
Cerro Calera, north side

Landform: hillside, inflection point of a short convex-conave slope 52% north (30º azimuth)

Parent material: serpentinized peridotite

Precipitation, drainage: 150 cm/year, excessively well drained soil

Plant community: BYCR–ROMO/TUPU/TRPL savanna

Surface rock and stoniness: rock outcrop < 1%; boulders < 1%, 2% “stones”, 20% cobbles

Oi	1-0 cm	loose grass leaves
A	0-5 cm	dark reddish brown (5YR 3/4, 4/6 dry) very cobbly loam: weak, very fine, subangular blocky; slightly hard, very friable, and slightly sticky and slightly plastic; 2% “stones”, 20% cobbles, 40% gravel; slightly acid (pH 6.6); clear, wavy boundary
Bw	5-21	red (2.5YR 4/6, 4/6 dry) very cobbly loam: moderate, fine, subangular blocky; hard, friable, and sticky and slightly plastic; 1% “stones”,15% cobbles, 30% gravel; neutral (pH 6.8); clear, discontinuous boundary
C	21-42	reddish brown (5YR 4/6, 7.5YR 4/6 dry) extremely cobbly loam; weak, medium, subangular blocky; slightly hard, friable, and slightly sticky and slightly plastic; 5% “stones”, 30% cobbles, 30% gravel; neutral (pH 7.0); abrupt, irregular boundary
R	42-50+	moderately fractured, hard bedrock, weathered soft in places

Notes: pH by bromthymol blue indicator; Bw horizon < 15 cm thick in about 20 to 40% of pedon

Soil class: loamy-skeletal, magnesic, isohyperthermic Lithic Ruptic-Entic Haplustept

World Reference Base (WRB) classification: Leptic Cambisol

Vegetative cover: SE06

6% trees - common *Byrsonima crassifolia* and *Roupala montana*;

10% shrubs - common *Turnera pusilla*, sparse *Simsia santarosensis*, and traces of *Turnera ulmifolia*, *Porophyllum punctatum*, and *Evolvulus alsinoides*;

vine - sparse *Marsdenia trinvirgulata*;

forbs - *Oxalis* sp. and *Russelia sarmentosa*;

60% grass - abundant *Trachypogon plumosus* and traces of *Schizachyrium malocostachyon*

sedge - traces of *Carex* sp.

Site SE07

Earl Alexander and Maria Marta Chavarria Diaz – February 23, 2008

Location: Lambert coordinates 351.274 E, 318.679 N; 10.887ºN latitude, 85.693ºW longitude, Murciélago 1:50,000 quadrangle, 490 m altitude

Cerro El Inglés, southwest side

Landform: steep mountains, inflection point on short mountain side-slope 54% southwest (210º)

Parent material: serpentinized peridotite

Precipitation, drainage: 150 cm/year, well drained soil

Plant community: BYCR/TUPU/TRPL savanna

Surface rock and stoniness: no rock outcrop; boulders < 1%, 8% "stones", 35% cobbles

Oi	1-0 cm	loose grass leaves
A	0-5 cm	dark reddish brown (5YR 3/3, 4/4 dry) very cobbly loam, weak, very fine, subangular blocky; hard and slightly sticky and slightly plastic; 5% "stones", 30% cobbles, 20% gravel; very few very fine roots, common under clumps of bunch grass; neutral (pH 6.7); clear, smooth boundary
Bt1	5-22	dark reddish brown (5YR 3/4, 4/4 dry) very cobbly clay loam: discontinuous, faint coatings on ped faces; strong, fine, subangular blocky; very hard and sticky and plastic; 5% "stones", 30% cobbles, 20% gravel; few very fine and fine roots; neutral (pH 6.8); diffuse boundary
Bt2	22-46	reddish brown (5YR 4/5, 4/5 dry) very cobbly clay loam, continuous, faint 5YR 3/4 coatings on ped faces; moderate, fine, subangular blocky; very hard and very sticky and plastic; 10% "stones", 30% cobbles, 20% gravel; few fine and very few medium roots; neutral (pH 6.9); gradual, wavy boundary
Bt3	46-62	strong brown (7.5YR 4/6 moist) extremely cobbly clay loam, common, faint reddish brown coatings on ped faces; weak, fine, subangular blocky; firm and very sticky and plastic; 15% "stones", 40% cobbles, 15% gravel; very few fine and medium roots; neutral (pH 7.0); abrupt, irregular boundary
R	62+	moderately hard bedrock, increased hardness with depth

Notes: pH by bromthymol blue indicator; many rock fragments weathered soft in Bt3 horizon

Soil class: fine, magnesic, isohyperthermic Typic Haplustalf

World Reference Base (WRB) classification: Endolepti-Chromic Luvisol

Vegetative cover: SE07

6% trees - common *Byrsonima crassifolia* and sparse *Roupala montana*;

4% shrubs - common *Turnera pusilla*, sparse *Simsia santarosensis*, and traces of *Hyptis suaveolens* and *Isocarpa oppositifolia*;

forbs - sparse *Oxalis* sp.

60% grass - abundant *Trachypogon plumosus* and sparse *Schizachyrum malacostachyrum*

sedge- sparse *Bulbostylis paradoxa*

Site SE08

Earl Alexander and Maria Marta Chavarria Diaz – February 24, 2008

Location: Lambert coordinates 354.366 E, 317.283 N; 10.875ºN latitude, 85.658ºW longitude, Murciélago 1:50,000 quadrangle, 490 m altitude at intersection (cruce) to Cerro Calera (east) and Cerro El Inglés (north)

Landform: dissected plateau, flat linear-linear 6% slope northwest (50º)

Parent material: serpentinized peridotite

Precipitation, drainage: 150 cm/year, moderately well drained soil

Plant community: BYCR–RETR–ROMO/HYRU savanna

Surface rock and stoniness: no rock outcrop; cobbles < 1 %

Oi	1-0 cm	loose grass leaves
A1	0-5 cm	very dark brown (10YR 2/2, 3/3 dry) loam; moderate, very fine, subangular blocky; slightly hard, friable, and slightly sticky and slightly plastic; cobbles < 1%, 1% gravel; many very fine and common fine roots; slightly acid (pH 6.4); clear, wavy boundary
A2	5-21	dark brown (7.5YR 3/2, 4/3 dry) loam; weak, coarse, subangular blocky; friable, and slightly sticky and slightly plastic; cobbles < 1%, 1% gravel; common very fine and fine, and few medium and coarse roots; moderately acid (pH 6.0); gradual, smooth boundary
A3	21-36	dark brown (7.5YR 3/4, 4/6 dry) loam; massive, structureless; friable, and slightly sticky and slightly plastic; cobbles < 1%, 1% gravel; few very fine, fine, medium, and coarse roots; common fine and few medium and coarse tubular pores; slightly acid (pH 6.2); abrupt, wavy boundary
Btss	36-70	dark brown (7.5YR 3/4, 3/4 dry) clay; continuous faint coatings on ped faces that lack slikensides, 7.5YR 3/2 in upper part and 10YR 3/2 in lower part of horizon; moderate, coarse, prismatic structure; extremely firm and very sticky and very plastic; 1% cobbles, 2% gravel; few fine, medium, and coarse roots; few fine, medium, and coarse tubular pores; neutral (pH 6.8); gradual, smooth boundary
C	70-105+	olive gray (2.5Y 4/2 moist) very gravelly clay, with common, fine 7.5YR 5/6 mottles; massive, structureless; firm and very sticky and very plastic; 2% “stones”, 10% cobbles, 30% gravel; sparse roots; neutral (pH 7.2)

Notes: serpentinized peridotite rock fragments with thick (several mm) diffuse weathered rims grading inward to less weathered cobble centers; relatively few dolerite rock fragments, with thin (1-2 mm) weathered rims to rock that is fresh except for kaolinization of feldspars.

Soil class: fine, magnesic, isohyperthermic Oxyaquic Vertic Paleustalf.

World Reference Base (WRB) classifation: Verti-endogleyic Luvisol

Vegetative cover: SE08

15% trees - common *Byrsonima crassifolia*, *Rehdera trinervis*, and *Roupala montana*, sparse *Curatella americana*, and *trace of Gliricidia sepium*;

5% shrubs - sparse *Senna pallida* and *Psidium guineense*, and traces of *Croton morifolius*, *Semialarium mexicanum*, *Calliandra tergemina*, *Aliberta edulis*, and *Xylosma* sp.;
vine - sparse *Convolvulus nodifolius*;
1% forbs - traces of *Evolvulus alsinoides*, *Russelia sarmentosa*, and *Waltheria indica*; and
90% grass - abundant *Hyparrhenia rufa*; traces of *Trachypogon plumosus*

Site SE09

Earl Alexander and Maria Marta Chavarria Diaz – February 26, 2008
Location: Lambert coordinates 351.781 E, 314.821 N; 10.852ºN latitude, 85.688ºW longitude, Murciélago 1:50,000 quadrangle, 360 m altitude
Santa Elena tuff plateau (plano de toba)
Landform: undulating plateau, flat linear-linear 5% slope southeast (110º azimuth)
Parent material: ignimbrite, Bagaces formation
Precipitation, drainage: 150 cm/year, well drained soil
Plant community: CUAM-ROMO/TRPL savanna
Surface rock and stoniness: no rock outcrop; stones and cobbles < 1 % each

Oi	1-0 cm	loose grass leaves
A	0-8 cm	very dark grayish brown (10YR 3/2, 6/3 dry) loam; weak, fine, subangular blocky; soft and slightly sticky and nonplastic; pebbles < 1%; common very fine and fine roots; moderately acid (pH 6.0); clear, smooth boundary
E	8-17	dark brown (7.5YR 3/4, 6/6 dry) loam; weak, coarse, subangular blocky; soft, friable, and slightly sticky and nonplastic; pebbles < 1%; few very fine, fine, and medium roots; slightly acid (pH 6.2); abrupt, wavy boundary
Bt	17-30	strong brown (7.5YR 4/5, 6/6 dry) clay loam, 10YR 3/3 continuous, distinct coatings on ped faces; weak, very coarse, subangular blocky; very hard, very firm, and sticky and plastic; 1% pebbles; few fine and medium roots; slightly acid (pH 6.4); abrupt, wavy boundary
R	30-50+	massive bedrock, moderately hard

Notes: pH by bromthymol blue indicator
Soil class: fine-loamy, mixed, superactive, isohyperthermic Lithic Haplustalf
World Reference Base (WRB) classification: Lepti-Chromic Luvisol

Vegetative cover: SE09
40% trees - plentiful *Curatella americana* and *Roupala montana*, sparse *Byrsonima crassifolia*;
2% shrubs - sparse *Porophyllum punctatum* and *Stachytarpheta* sp. and trace of *Krameria ixine*;
1% forbs - traces of *Waltheria indica*; *Oxalis* sp. and *Polygala* sp.; and
70% grass - abundant *Trachypogon plumosus* and common *Hyparrhenia rufa*

Site SE10

Earl Alexander and Maria Marta Chavarria Diaz – February 26, 2008

Location: Lambert coordinates 352.482 E, 314.613 N; 10.851ºN latitude, 85.682ºW longitude, Murciélago 1:50,000 quadrangle, 360 m altitude, Santa Elena tuff plateau (plano de toba)

Landform: undulating plateau, nearly flat concave-linear 8% slope south (190º azimuth)

Parent material: ignimbrite, Bagaces formation

Precipitation, drainage: 150 cm/year, moderately well drained soil

Plant community: mixed angiosperm forest

Surface rock and stoniness: no rock outcrop; cobbles < 1 %

Oi	4-0 cm	loose dicot and grass leaves
Ap1	0-4 cm	very dark grayish brown (10YR 3/2, 4/3 dry) clay loam; moderate, medium granular structure; hard and very sticky and plastic; 2% pebbles; common very fine and fine roots; slightly acid (pH 6.6); abrupt, smooth boundary
Ap2	4-15	very dark grayish brown (10YR 3/2, 4/3 dry) clay loam; weak, coarse, subangular blocky; very hard and very sticky and plastic; 2% pebbles; few very fine, fine, and medium roots; neutral (pH 6.8); clear, wavy boundary
A	15-48	very dark brown (10YR 2/2, 3/3 dry) clay loam; weak, medium, subangular blocky; hard and sticky and plastic; 1% pebbles; few fine, medium, and coarse roots; slightly acid (pH 6.2); gradual, smoth boundary
E	48-70	dark brown (7.5YR 3/4, 5/4 dry) clay loam; massive, structureless; soft, friable, and sticky and plastic; 1% pebbles; very few fine and medium roots; very few fine and medium pores; slightly acid (pH 6.2); clear, wavy boundary
Btss	70-100+	dark gray (2.5Y 4/1, 5Y 5/1 dry) clay, with common, medium 10YR 4/3 mottles in upper part and few, fine 7.5YR 4/6 mottles in lower part; prominent slickensides; extremely hard, very firm, and very sticky and very plastic; 1% pebbles; negligible roots; slightly acid (pH 6.6)

Notes: the upper 15 cm is overburden (Ap), presumably displaced during road construction

Soil class: fine, smectitic, isohyperthermic Vertic Paleustoll

World Reference Base (WRB) classification: Verti-endogleyic Phaeozem

Vegetative cover: SE10

70% trees - plentiful *Rehdera trinervis* and *Luehea altrnifolia*; common *Curatella americana*; sparse *Cochlospermum vitifolium;* and traces of *Byrsonima crassifolia, Simarouba glauca, Aliberta edulis*, *Bauhinia ungulata, Diphysia humilis, Roupala momtana,* and *Swietenia* sp.;

20% shrubs - sparse (or common to trace) *Acacia* sp., *Bonellia nervosa*, Croton morifolius, *Helicteres guazumifolia*, *Mimosa tricephata*, *Porophyllum punctatum, Pidium guineense, Senna pallida*, *Stachytarpheta* sp., *Waltheria glomerata,* and *Ximenia americana*;

vines - M. trivirgulata, *Cynanchum schleschtendalii, Halpighia glabra*, *Securidaca diversifolia*

forbs - traces, *Banisteriopsis* sp., *Polygala* sp., *Ruellia* sp., *Russelia sarmentosa,* and *Smilax* sp.

10% graminoids - *Guadua paniculata* (bamboo); and traces of *Hyparrhenia rufa* and *Carex* sp.

Site SE11

Earl B. Alexander and Maria Marta Chavarria Diaz – February 22, 2008
Location: mangrove at mouth of Rio Potrero Grande
Landform: tidal wetland
Parent material: organic detritus and minor silt and clay
Precipitation, drainage: 150 cm/year, tidal flooding
Plant community: mangrove (*Rhizophora racemosa* and/or *R. mangle*), no understory
Surface rock and stoniness: none

Oa1 0-7 cm black (10YR 2/1) loamy muck, with common medium, distinct, brown (7,5YR 4/4) mottles; massive, structureless; slightly sticky and slightly plastic; common very fine roots; strongly saline; neutral (pH 6.6); clear, smooth boundary

Oa2 7-50+ black (10YR 1/1) fine peat: massive, structureless; very few very fine, fine, medium, and coarse roots; strongly saline; neutral (pH 7.2)

Notes: pH by bromthymol blue indicator
brown loam had washed about 15 m into the mangrove at site SE11
Soil class: Halic Haplosaprist

Site SE12

Earl B. Alexander and Maria Marta Chavarria Diaz– February 22, 2008
Location: mangrove near mouth of Rio Potrero Grande
Landform: alluvial plain adjacent to Rio Potrero Grande, 2% slope toward the river.
Parent material: alluvium from mixed sources, including serpentine
Precipitation, drainage: 150 cm/year, seasonal stream flooding and bidaily tidal flooding
Plant community: mangrove (*Pelliciera rhizophorae*), no understory
Surface rock and stoniness: none

A 0-14 cm very dark grayish brown (2.5Y 2/1) sandy loam, with many coarse, faint, dark brown (10YR 3/3) mottles; :massive, structureless; slightly sticky and nonplastic; pebbles 2% by volume; few very fine, fine, medium, and coarse roots; strongly saline; neutral (pH 6.8)

AC 14-28 black (2.5Y 2/2) loam, with few medium, faint, dark brown (10YR 3/3) mottles: massive, structureless; slightly sticky and slightly plastic; pebbles 1% by volume; common very fine, fine, medium, and coarse roots; strongly saline; neutral (pH 6.9)

Cg 28-100+ very dark gray (2.5Y 3/1) loam, with few medium, faint 5Y 3/1 mottles that are not evident when the soil is dried in the ambient atmosphere; massive, structureless; slightly sticky and slightly plastic; common very fine, fine, medium, and coarse roots; strongly saline; neutral (pH 7.0)

Notes: pH by bromthymol blue indicator, few crab holes
Soil class: Fluvaquent or Hydraquent

Soil Characteristics

The ultramafic rocks from which the serpentine soils of the Santa Elena Peninsula developed have higher concentrations of most first transition chemical elements (at least atomic numbers 23 or 24 to 28) and magnesium than nonultramafic rocks. Reeves et al. (2007) sampled six serpentine surface soils on the eastern part of the Santa Elena Peninsula and subjected them to aggressive digestion (Table 4). Weathering and leaching have reduced the amounts of calcium (Ca) and magnesium (Mg) in the serpentine soils, but the serpentine soils still have much more Mg than the average for soils (soils of USA, Table 4). The concentrations of elements 24 through 28 (chromium, manganese, iron,, cobalt, and nickel) are all high. Nickel (Ni) is especially high, even for ultramafic soils, and its toxicity may be limiting the distributions and growth of plants on the serpentine soils. The well drained serpentine soils that are common on the Santa Elena Peninsula have high Fe concentration, with Fe released from the rocks by weathering being bound in oxides that resist leaching.

Table 5. Mean elemental composition of Santa Elena serpentine soils compared to other parts of Earth.

Atomic number	12	13	20	24	25	26	27	28	29
Element	Mg	Al	Ca	Cr	Mn	Fe	Co	Ni	Cu
	---------- g/kg (parts/thousand) --------------						mg/kg (parts/million)		
[a]Santa Elena serpentine soils									
mean (n=6)	38	18	5	1.40	1.45	102	152	3610	48
maximum	156	36	14	3.64	2.60	160	325	7220	72
[b]UM rocks	204	20	25	1.6	1.62	94	150	2000	10
[c]Upper Crust	16	78	32	0.07	0.77	42	17	55	39
[d]Soils of USA	9	72	24	0.05	0.55	26	9	19	25

[a] Reeves et al. (2007), [b] Turekian and Wedepohl (1961), [c] Li, 2000, [d]Shacklette and Boerngen (1984).

Both the serpentine soils and those in the pyroclastic deposits have broad ranges of depth and textural differentiation.. The serpentine soils are distinguished by reddish colors (Soil-Landscape Site Descriptions, pages 12-23) and low Ca/Mg ratios, Table 5).The proportions of basic cations on the exchange complexes (base saturation) are high in all of the serpentine soils, but lower in the ignimbrite soil that is well drained (Table 5). The Ca/Mg ratios are all less than 0.3 in the serpentine soils, except in the surface horizon of the somewhat poorly drained soil (site SE08). Plant growth limitations on the serpentine soils are assumed to be caused by the low Ca/Mg ratios and possibly high Ni concentrations.

Table 6. Soil chemical analyses, including estimation of organic matter by weight loss at 360°C.

Pedon sample	Horizon sym.	Horizon depth	LOI [a] 360°C	Exchange. Ca	Exchange. Mg	Acidity [b] pH 7	Acidity [b] pH 8	Sum cat.[c]	Base Satn.[d]	Ca/Mg ratio [e]	Soil React.
		cm	g/kg	mmol+/kg					%	molar	pH[f]
S01-1	A	0-6	56	21	173	–	71	265	73	0.12	6.8
S01-2	Bw	6-21	–	15	348	–	72	435	83	0.04	7.0
S01-3	C	21-38	–	14	395	–	58	467	88	0.04	7.0
S02-1	A	0-3	72	54	521	43	97	673	86	0.10	6.7
S02-2	Bt1	3-16	–	49	579	–	110	737	85	0.08	6.7
S02-3	Bt2	16-45	–	51	372	–	117	540	78	0.14	6.7
S02-4	C	45-62	–	49	488	–	–	–	–	0.10	6.8
S06-1	A	0-5	93	27	145	41	96	268	64	0.19	6.6
S06-2	Bw	5-21	–	24	222	–	93	339	73	0.11	6.8
S06-3	C	21-42	–	12	291	–	–	–	–	0.04	7.0
S08-1	A1	0-5	200	253	100	112	214	568	63	2.5	6.4
S08-2	A2	5-21	122	117	104	93	197	417	53	1.12	6.0
S08-3	A3	21-36	58	63	98	52	107	269	60	0.64	6.2
S08-4	Btss	36-70	–	136	485	–	91	712	87	0.28	6.8
S08-5	C	70-105	–	87	383	–	50	519	90	0.23	7.2
S09-1	A	0-8	71	19	13	68	125	158	21	1.5	6.0
S09-2	E	8-17	60	26	7	54	111	144	23	3.7	6.2
S09-3	Bt	17-30	–	86	23	–	86	195	56	3.7	6.4
S10-2	Ab	15-48	61	144	40	59	120	304	61	3.6	6.2
S10-3	E	48-70	30	80	24	33	69	173	60	3.3	6.2
S10-4	Btss	70-100	–	283	130	–	82	496	83	2.2	6.6

[a] Loss on ignition at 360°C
[b] Exchangeable acidity at pH 7.0 and at pH 8.2
[c] Sum of basic cations and exchangeable acidity at pH 8.2
[d] Base saturation, pH 8.2
[e] Ratio of exchangeable calcium and magnesium (mol/mol)
[f] pH by bromophenol blue indicator color on a LaMotte chart

Vegetation, Plants in the Serpentine Landscapes

The domiant plant cover on serpentine soils of the eastern two-thirds of the Santa Elena Peninsula is savana, with nancite (*Byrsonima crassifolia*) and danto (*Roupala montana*) trees, turnera (*Turnera pussila*) bushes, and crinkle-awn (*Trachypogon plumosus*) grass. The savana is perpetuated by frequent buning. Dominance of crinkle-awn grass is the most distinctive feature that is unique on serpentine soils.. Jaragua (*Hypharrenia rufus*) is the main grass on the tephra soils (landscape classes Ct and Dt), but on serpentine soils, jaragua is the dominant grass only on a soil in the Ds landscape class (site SE09) with Mg leached from the surface soil (Table 5).

Table 7. Plant species found at the soil-landscape description sites, and some foliar analyses data from Reese et al. (2007). They found no Ni-hyperaccumulators

Family Species	Life Form	Soil-landscape Sites where Present	Cr	Co	Ni	Cu
			— mg/kg —			
Acanthaceae						
Ruellia sp.	forb	10				
Apocynaceae (Asclepiadoideae)						
Cynanchum schlectendalii	vine	10	2	tr	235	8
Marsdenia trivirgulata	vine	1, 2, 4, 5, 6, 10				
Asparagaceae						
Agave sp.	succulent	4				
Asteraceae						
Isocarpa oppositifolia	shrub	9				
Porophyllum punctatum	shrub	2, 3, 4, 5, 6, 9, 10				
Simsia santarosensis	shrub	1, 3, 4, 6, 7	8	7	16	7
Widelia fruticosa	shrub	1				
Bixaceae						
Cochlospermum vitifolium	tree	10				
Celastraceae						
Hemiangium sp.	vine	3				
Semialarium mexicanum	shrub	8				
Convolvulaceae						
Convolvulus nodifolious	vine	3, 8				
Convolvulus sp.	forb or shrub	3. 4				
Evolvulus alsinoides	forb	6, 8	6	1	52	1
Cyperaceae						
Bulbostylis paradoxa	graminoid	7	3	1	24	4
Dilleniaceae						
Curatella americana	tree	5, 8, 9, 10				
Euphorbiaceae						
Croton morifolius	shrub	8, 10				

Croton sp.	shrub	1				
Mabea occidentalis	shrub	1				
Fabaceae						
Caesalpiniodeae						
Bauhinia ungulata	shrub	10				
Lysiloma sp.	tree	3				
Senna pallida	shrub	8. 10	3	1	13	4
Faboideae (or Papilionoideae)						
Acacia sp.	shrub	10				
Diphysa humilis	tree	10	1	1	5	20
Gliricidia sepium	tree	8				
Macroptilium gracile			16	6	114	10
Mimosoideae						
Calliandra tergemina	shrub	1, 2, 8	4	2	12	8
Mimosa sp.	shrub	3				
Mimosa tricephala	shrub	10	3	tr	17	2
Krameriaceae						
Krameria ixine	shrub	9	4	3	42	8
Lamiaceae						
Hyptis suaveolens	shrub	4, 5, 7	27	4	175	13
Malvaceae						
Helicteres guazumifolia	shrub	10				
Luehea alternifolia	tree	10				
Malpighiaceae						
Banisteriopsis sp.	vine	10				
Byrsonima crassifolia	tree	1, 2, 3, 4, 5, 6, 7, 8, 9, 10				
Meliaceae						
Swietenia sp.	tree	10				
Myrtaceae						
Psidium gueense	tree	8				
Olacaceae						
Ximenia americana	shrub	10				
Orchidaceae	orchid	4				
Oxalidaceae						
Oxalis frutescens			16	5	106	10
Oxalis sp.	forb	3, 4, 5, 6, 7, 9				
Poaceae						
Guadua paniculatum						
Bambusoideae	bamboo	10				
Hyparrhenia rufa	grass	9, 10				
Paspalum pectinatum			25	4	170	4
Schizachyrium malacostachyum	grass	1, 5, 6, 7				
Trachypogon plumosus	grass	1, 2, 3, 4, 5, 6, 7, 9				
Polygalaceae						
Polygala sp.	forb	9, 10				

Securidaca diversiloba	vine	10				
Primulaceae						
Bonellia nervosa	shrub	10				
Proteaceae						
Roupala montana	tree	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	6	tr	19	3
Rubiaceae						
Aliberta edulis	tree	8, 10				
Diodia teres			39	3	246	4
Salicaceae						
Xylosma sp.	shrub	3, 8				
Scrophulariaceae (or Pantaginacae)						
Buchnera pusilla	shrub	1, 2	8	2	185	14
Russelia sarmentosa	shrub	2, 4, 5	7	1	130	15
Simaroubaceae						
Simarouba glauca	tree	1, 3, 10				
Stachytarpheta sp.	shrub	9, 10				
Smilacaceae						
Smilax sp.	forb	10				
Sterculiaceae						
Waltheria indica	forb	8, 9	6`	6	57	8
Waltheria glomerata	shrub	10				
Theophrastaceae						
Jaquinea nervosa	shrub	1	2	tr	19	3
Turneriaceae						
Turnera pusilla	shrub	1, 2, 3, 4, 6, 7				
Turnera ulmifolia	shrub	6	22	3	86	6
Verbenaceae						
Rehdera trinervis	tree	8, 10				
Viscacaceae						
Phorodendron sp,	mistletoe	3				

Several plants have been found in Costa Rica only in serpentine (or ultramafic) landscapes: *Agave seemanniana* (Agavaceae), *Simsia santarosensis* (Asteraceae), *Bursera schlechtendalii* (Burseraceae), *Melocactus ruestii* (Cactaceae), and *Schizachyrium malacostachyum* (Poaceae). Only one of them, *Simsia santarosensis* (Fig. 12), is a serpentine endemic plant.

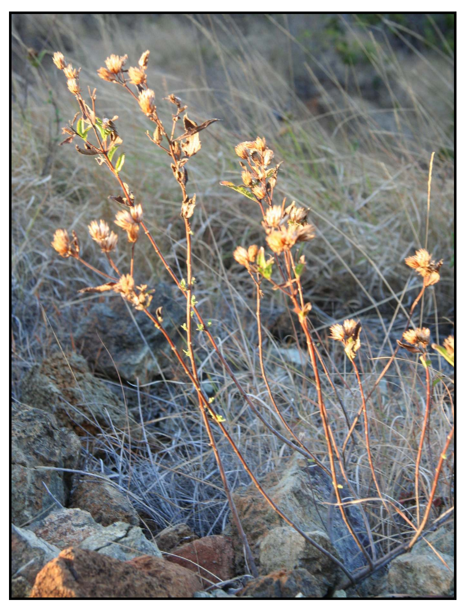


Figure 12. *Simsia santarosensis.*

Soil Sampling and Laboratory Analyses

Soil reaction (pH) was assessed in the field with bromthymol blue indicator and a LaMotte color chart. All serpentine soils, and those sampled on ignimbrite, were within the pH 6.0 to 7.2 range of the indicator.

Soils were sampled at each soil-landscape description site. Soil samples were air dried and passed through a 2 mm sieve, and the fine earth (particles < 2 mm) was retained for laboratory analyses. The methods of soil sampling and laboratory analysis follow the Landscape Class Descriptions. The primary concerns were the ratios of exchangeable Ca and Mg and the proportions basic ions on the exchange complexes. Because the amounts of Na and K are always very low in serpentine soils, the amounts of exchange cations are practically equal to the sums of Ca + Mg that are exchangeable. The cation exchange capacity is assesed by the amounts of acid ions, mostly H^+ in serpentine soils, that are held on the soils. This capacity to hold acidic ions is greater in more basic soils in which smaller proportions of the acidic ions are dissociated. The base saturation is the sum of the basis catons (Ca+Mg here) divided by the sum of all exchangeable cations as measured here by exchange acidity.

Pedon sampling, sample preparation, and estimation of coarse fragment volume
Volumes of stones (cobbles and coarse gravel, 30-600 mm fraction) were estimated visually in soils when they were sampled (Vs). Samples of soil < 30 mm were air-dried and sieved to obtain fine-earth (particles < 2 mm) for laboratory analyses. The volume of 2-30 mm gravel retained on the sieve was estimated visually, or weighed and converted to volume (Vg) by assuming that the density of the gravel was twice that of the bulk density of the soil. The field, or total, volume of “coarse fragments” (Vf) was computed by the field estimate of stones plus the lab estimate of 2-30 mm gravel times 100 minus the field estimate of stones: $Vf = Vs + Vg(100-Vs)$.

Laboratory Methods

Hygroscopic water
Air-dry soils were dried in a micowave oven to determine ratios of air-dry:oven-dry weights for converting laboratory measurements to oven-dry bases.

Exchangeable cations
Cations were extracted be leaching with KCl or NH_4Cl. Alkaline earth elements Ca and Mg were titrated with EDTA (Heald 1965).

Extractable acidity, pH 8.2
Soils were leached with pH 8.2 BaCl-triethanolamine solution and the leachate was titrated with HCl to a pink end point (pH 5.1) of a mixed bromocresol green and methyl-red indicator (Peech 1965). The extractable acidity is the difference between the amount of acid used to titrate the leaching solution and the amount of acid used to titrate the leachate.

Extractable acidity, pH 7.0, acid soils
The method is practically the same as the pH 8.2 extractable acidity method, except that the buffer solution is para-nitrophenol, rather than triethanolamine. Soils were leached with pH 7.0 KCl-PNP (*p*-nitrophenol) solution and back titrated with HCl (Alexander 2010).

References

Dauphin, G., and M.H. Grayum. 2005. Bryophytes of the Santa Elena Peninsula and Islas Murciélago, Guanacaste, Costa Rica, with special attention to neotropical dry forest habitats. Lankesteriana 5(1): 53-61.

Desmet, A. 1985. Les ultramafites de Santa Elena (Costa Rica): Harzburgites residuelles ou cumulats serpentinises? Ofioliti 10:225-254.

Grayum, M. 2004. Botanical exploration of the Peninsula de Santa Elena, Costa Rica. Final Report. Missouri Botanical Garden, St. Louis.

Guillot, P-V., S. Chiesa, and G.E. Alvarado. 1994. Chronostratigraphy of upper Miocene-Quaternary volcanism in northern Costa Rica. Revista Geológica de América Central 17: 45-53.

Heald, WR. 1965. Calcium and magnesium. Pages 999-1010 *in* C.A. Black (editor), Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties. American Society of Agronomy, Madison WI.

IUSS Working Group WRB. 2015. World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Food and Agriculture Organization of the United Nations, Rome, Italy.

Janzen, DH, and W Hallwachs.. 2016. Biodiversity history and future in Costa Rica: The case of Area de Consevación Guanacaste (ACG). Pages 290-341 *in* M. Kappelle (editor), Costa Rican Ecosystems. The University of Chicago Press, IL.

Jiménez M, Q, E Carrillo J, and M Kappelle. 2016. The northern Pacific lowlands, seasonal dry forests of Guanacaste and the Nicya Peninsula. Pages 247-289 *in* M Kappelle (editor), Costa Rican Ecosystems. The University of Chicago Press, IL.

Lewis, J.F., G Draper, J.A. Proenza, J. Espaillat, and J. Jiménez. 2006. Ophiolite-related related ultramafic rocks (serpentinites) in the Caribbean region: A review of their occurrence, composition, origin, emplacement, and Ni-laterite formation. Geologica Acta 4: 237-264.

Li, Yuan-Hui. 2000. A Compendium of Geochemistry. Princeton University Press. Princeton NJ.

Loria-Naranjo, M, J Samper-Villarreal, and J Cortéz. 2014. Potrero Grande and Santa Elena mangrove forest structure, Santa Rosa National Park, North Pacific, Costa Rica. Revista de Biologia Tropical 62 (Suppl. 4): 33-41.

Mann, P. 2007. Overview of the tectonic history of northern Central America. Pages 1-19 *in* Geological and Tectonic Development of the Carribean Plate Boundary in Northern Central America. Geological Society of America, Special Paper 428.

Peech, M. 1965. Exchange acidity. Pages 905-913 *in* C.A. Black (Edtor), Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties. American Society of Agronomy, Madison, WI

Reeves, R.D., A.J.M. Baker, and R. Romero. 2007. The ultramafic flora of the Santa Elena peninsula, Costa Rica: A biogeochemical reconnaissance. Journal of Geochemical Exploration 193(3): 153-159.

Shacklette, HT, and JG Boerngen. 1984. Element concentrations in soils and other surficial materials of the conterminous United States. US Geological Survey, Professional Paper1270.

Soil Survey Staff. 1993. Soil Survey Manual. USDA Handbook 18.

Soil Survey Staff. 1999. Soil Taxonomy (A Basic System of Soil Classification for Making and Interpreting Soil Surveys). USDA, Agriculture Handbook 436.

Soil Survey Staff. 2014. Keys to Soil Taxonomy. US Department of Agriculture.

Tournon, J. 1994. The Santa Elena Peninsula: an ophiolitic nappe and a sedimentary volcanic relative autochthonous. Profil 7: 87-96.

Turekian, KK, and KH Wedepohl. 1961. Distribution of the elements in some major units of the earth's crust. Geological Society of America, Bulletin 72:175-192.

Vogel, T.A., L.C. Patino, G.E. Alvarado, and P.B. Gans. 2004. Silicic ignimbtites within the Costa Rican volcanic front: evidence for the formation of continental crust. Earth and Planetary Science Letters 226: 149-159.

WRB. 2015. World Reference Base for Soil Resources, International soil classification system for naming soils and creating legends for soil maps. Food and Agriculture Organization of the United Nations, Rome, Italy.

Note on degrees latitude and longitude; converting degrees to minutes and seconds.

For example; 10.686 degrees,

multiply the decimal fraction by 60, 60 x 0.686 = 41.16 minutes

multiply the decimal fraction of minutes by 60, 60 x 0.16 = 9.6 seconds

thus $10.686^{o} = 10^{o}\,41'\,9.6''$