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CORPS OF ENGINEERS, U.S. ARMY
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PREFACE

This report was prepared by Capt. Timothy Simpson and Dr. Paul Murrmann of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. It is published under DA Task 1J662708A46206, *Tunnel Detection Research.*

DESCRIPTION OF SOILS AT MINE-TUNNEL DETECTION RESEARCH SITES, PUERTO RICO

by

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The necessity to consider the influence of environmental parameters on the response of the various types of detection devices to objects of military significance has become generally accepted. In meeting this requirement, Puerto Rico was selected as an area where, due to a wide variety in environmental conditions, a facility would be developed for use in mine-tunnel detection work with special emphasis on subtropical and tropical conditions. Waterways Experiment Station, which maintains an environmental study group in Puerto Rico, has made a selection of about twenty sites for future development. In this site selection, the requirements associated with both long-term environmental research programs and performance appraisal of current and future generations of detection devices were considered.

In developing a research or evaluation program which utilizes these sites or samples collected at a site, one is immediately faced with the problem of selecting a minimum number of sites which will be most useful in achieving the desired objective. Thus, the sites selected from those available may vary from one investigation to another. To make this choice, the investigator must develop a set of criteria for site selection and have access to knowledge of the environmental characteristics of each site. In the process of developing our research programs, we have made a description of the soil, and photographed the general area in the vicinity of each site. Needless to say, this type of effort is time consuming even to those of us familiar with soil science.

This report has several objectives. First, we wish to point out that we have made an independent evaluation of the sites selected by WES. We feel that the sites selected do represent most of the major categories of soils, landforms, climatic and vegetative conditions available in Puerto Rico which are of importance in this program. Nevertheless, as in any research program, it will be necessary to sample or utilize areas which were not required initially. Second, we wish to make our description of the sites available as background information for other investigators to use in site selection. Third, we have indicated the priority which we place on development of each of the mine sites. We feel that this development sequence should be of general use in mine detection research. Fourth, we have delineated what we feel are the more important subsoil layers found in tropical and sub-tropical climates. Finally, we wish to express our desire to interact, along with WES personnel, with other investigators in selecting sites with soil properties most suitable for meeting the criteria of their research objectives. We recommend that upon final acceptance of a site in Puerto Rico a qualified soil survey expert who is familiar with the soils of Puerto Rico be retained to prepare a detailed description of the soil properties at each site.

Soils of Puerto Rico

In order to have a reference point for description and characterization of the soil at the mine-tunnel sites, a summary of the types of soils in Puerto Rico was made. This information was extracted from the soil survey report of Puerto Rico.* The classification system used is the old USDA system which categorizes soils according to:

I. Order (zonal, azonal, intrazonal)
  A. Great soil group (i.e. laterite etc.)
    1. Soil series (nipe series)
      1a. Soil type (nipe clay)

The most important great soil groups typical of subtropical and tropical environments which are found in Puerto Rico are listed in Appendix B. Appendix A is a glossary which indicates common terminology used in the description of soils. Included in Appendix B are the environmental and diagnostic features of each soil group. There is at least one site representative of every major soil group except gray-brown podzolic soils. However, although this is an important soil group, this omission is not serious because of the close similarity of this group to red and yellow podzolic soils. It is worth pointing out that more than 80 percent of the land area in Vietnam is represented by soils at the mine-tunnel detection sites.†

Description of Sites for Mine Detection Research

A brief description of the soil at each site is given in Appendix C. Much of the information given in this section is summarized in Table I in which we have also indicated our choice of priority for site development. The priority was placed in the following manner. Our requirements are that sites be available which represent major environmental areas. The number of sites required to achieve this objective is so great that duplication of common parameters must be minimized. Much of our research in mine and tunnel detection is concerned with the identification of trace gases characteristic of an environmental area and, for mine detection, diffusion of trace gases in earth materials. The diffusivity of trace gases through soil depends on 1) soil porosity (texture), 2) interaction of chemicals with soil water and minerals (texture and parent material), and 3) micro-climatic conditions near the soil surface (vegetation, physiographic location). The presence of natural trace gases in the atmosphere at each site is expected to depend upon many of these same factors. Thus, we require a wide diversity in each of these experimental parameters. Assuming that the only sites available at this time are those originally selected by WES, we first selected those sites which constituted a single representative of a physiographic location. Next, we selected sites to obtain a range in surface horizon textures while at the same time seeking an overall diversity in parent material and vegetation. The result is the selection of eleven primary sites which represent the widest possible range in all the above parameters. The remaining sites were classified as secondary sites to be used as substitutes or as required for other experimental objectives. The primary sites were then ranked in order of development priority. Laguna Joyuda was given a high priority for use in mine detection because it has already been selected as a permanent tunnel facility. The next three sites, all given priority 1 ratings, were selected to represent extremes in conditions, particularly texture. We feel that at least these four sites must be used for any meaningful progress to be made. The next three sites were assigned a priority 2 rating because of properties intermediate to the priority 1 sites. The priority 3 sites were selected

* Roberts, R.C. (1942) Soil survey of Puerto Rico. United States Department of Agriculture.

† Moormann, F.R. (1961) The soils of the Republic of VietNam. National Geographic Service of VietNam, Da Lat.

Table I. Description of mine detection research sites.

Devel. priority	Site name	Group classification	Physiographic classification	Surface texture	Parent material	Vegetation
			Primary Sites (USA CRREL Research)			
1a	Laguna Joyuda	Laterite	Upland, deep	Clay loam	Serpentine rock	Sugar cane
1b	Lajas	Alluvial	River floodplain, poorly drained	Clay	Alluvium	Grass
1c	Isabela	Sand	Coastal lowlands, well drained	Sand	Coral, shells	Grass, palm
1d	El Yunque	Yellow podzol	Upland, medium deep	Silt loam	Cretaceous, tuff-aceous sediments	Tropical forest
2a	Florida	Yellow-brown laterite	Coastal plain, compact	Sandy clay	Limestone	Grass
2b	Salinas	Red prairie	Terrace and alluvial fans, compact	Clay loam	Cretaceous, tuff-aceous sediments	Sugar cane
2c	Manati	Alluvial	River floodplain, well drained	Silt loam	Alluvium	Sugar cane
3a	Sierra Bermeja	Rendzina	Upland, shallow	Clay loam	Limestone	Grass, shrub, cactus
3b	Parguera	Half-bog	Coastal lowland, poorly drained	Loam	Coral, shells	Mangrove
4	Yauco	Chernozem	Terrace and alluvial fans, medium friable	Clay	Limestone	Sugar cane
5	Laguna Tortuguero	Yellow-brown laterite	Coastal plain, very friable	Sandy loam	?	Grass, palm
			Secondary Sites (USA CRREL Research)			
6	Rio Guayanes	Red prairie	River flood plain, well drained	Sandy loam	Granodiorite and quartz diorite	Grass
7	Rio Abajo	Lithosol	Upland, medium deep	Clay	Cretaceous, tuff-aceous sediments	Forest
8	Yaubauco	Wiesenboden	River floodplain, poorly drained	Sandy loam	Alluvium	Sugar cane
9	Sabana Hoyos	Brown laterite	Coastal plains, compact	Sandy clay	Alluvium	Sugar cane
10	Toro Negro	Red-brown laterite	Upland, deep	Clay loam	Cretaceous, tuff-aceous sediments	Forest
11	Llanos	Planosol	Coastal plain, compact	Loam	Cretaceous, tuff-aceous sediments	Grass, palm
12	Moca	Alluvial	River floodplain, poorly drained	Clay	Alluvium	Sugar cane
–	Rio San Patricio	Red-brown laterite	Upland, deep	Clay loam	Cretaceous, tuff-aceous sediments	Forest
–	Dorado	Alluvial	River floodplain, well drained	Silt loam	Alluvium	Sugar cane
–	Loiza	Alluvial	River floodplain, well drained	Silt loam	Alluvium	Sugar cane

because of unusual extreme environmental conditions. Finally, the last two sites were given a priority of 4 and 5 because they differ mainly only in physiographic location. An attempt was also made to assign priority ratings to the group of secondary sites. However, we felt that these sites will be most useful to us as substitutes or, in certain cases, where an unusual soil property is desirable such as a very high water table (Moca site) or a clay hard pan (Llanos site). Also, it should be pointed out that many of the secondary sites represent typical soils in soil groups not included among our selection of primary sites.

Description of Sites for Tunnel Detection Research

In selecting sites for mine detection, only the surface soil properties were compared. For use in tunnel detection, the soil properties of each site with depth must be considered. Moreover, since the final choice of a site depends on soil engineering characteristics, selection of a site for tunnel construction is difficult and requires on-site investigation. For this reason, we have not attempted to recommend sites for tunnel construction. However, we do feel that when tunnel sites are selected, each site should be characteristic of a broad environmental condition, including soil properties. Although the sites finally selected for tunnel construction may not be among those already suggested, the sites available will probably be useful for trace gas detection research as well as for research on other detection methods. This is because it should be possible to learn of the effects of a surface environment without the presence of a tunnel. Also, response of detection devices to natural subsurface discontinuities can be tested at many of the sites. Although use of a specific site will depend on the specific objective at hand, we can illustrate how the subsurface properties at some of the sites may be important.

The type of soil exhibited at the El-Yunque site is a representative of the yellow-podzolic soil group which has properties commonly found in Vietnam soils. Soils of this group usually have a well defined clay enriched subsoil layer. The effect of such layers on tunnel detection devices is not well known. Also common to this soil group is an iron rich layer, the position of which is dependent upon the soil moisture properties, the height of the water table in particular. These layers range from thin to very thick and occur at a depth of from one to five meters. Gray and red podzolic soils also exhibit these properties.

The soils at the Laguna Joyuda and Toro Negro sites are representatives of the laterite and reddish-brown laterite soil groups, respectively. We feel that these groups are important for two reasons. First, they are very common in all tropical and subtropical climates. Second, both have a near absence of weatherable mineral matter which greatly diminishes the number of soil variables.

Laterites, and to a lesser degree reddish-brown laterites, can exhibit a wide range of environmental conditions due to the fact that once they are cleared, regrowth is extremely slow due to the lack of primary minerals which supply plant nutrients. The result of this is that tree size and density are not primarily dependent upon rainfall pattern, but rather on land use practices. Since it is more realistic for tunnels to be located in forested soil than in cleared land, we can see the value in developing a test site in a forested area in addition to the site at Laguna Joyuda.

The soil at Yauco exhibits subsurface properties that we consider to be important in tunnel detection research. Most important is the fact that the predominant clay mineral in the soil has chemical and physical properties much different from those exhibited by the clay minerals at the sites mentioned above. Of secondary importance is the occurrence of a subsoil layer that is very high in calcium and magnesium carbonates that accumulated during many years of weathering. Since this type of layer is common in soils developed from limestone, a common parent material, it is of more than passing interest.

There are other types of subsurface features which are represented by other sites; however, we feel that they are of only secondary importance.

APPENDIX A: GLOSSARY OF TERMS

Diagnostic surface horizons

Mollic epipedon is a thick dark surface layer dominantly saturated with bivalent cations, with narrow carbon-nitrogen ratios and with moderate to strong structure.

Umbic epipedon is a surface horizon that resembles the mollic epipedon but differs in that the dominant exchangeable cation is hydrogen or that the carbon-nitrogen ratio is high or both.

Ochric epipedon is a surface horizon that is light in color, lower in organic carbon or in some cases thinner than a mollic epipedon.

Histic epipedon is a surface or near surface horizon that is characterized by a very high amount of organic matter. It is saturated with water at least one season of the year.

Diagnostic subsurface horizons

Albic horizon is a horizon from which clay and free iron oxides have been removed, or in which the oxides have been segregated, to the extent that the color of the horizon is determined primarily by the color of the primary sand and silt particles rather than by coatings on these particles. It usually lies just below surface horizon.

Argillic horizon is a horizon in which silicate clays have accumulated to a significant extent. It is formed below the surface and is usually overlain by an albic horizon.

Oxic horizon is a horizon in which weathering has removed or altered a large part of the silica that is combined with iron and aluminum, but not necessarily the quartz of 1:1 lattice clays. The result is a concentration of clay-size minerals consisting of sesquioxides mixed with varying amounts of silicate clays having a 1:1 lattice. It occurs below the surface horizon and may extend to great depth.

Plinthite horizon is a sesquioxide rich, humus poor, highly weathered mixture of clay with quartz and other weather resistant minerals. It may occur in a soft or hard form. These layers commonly occur from one to five meters deep and range from thin to very thick.

Natric horizon is a special kind of argillic horizon. It has in addition to the properties of an argillic horizon 1) columnar structure, and 2) more than 15 percent saturation with exchangeable sodium.

Master horizons and layers

A1 – Mineral horizons, formed or forming at or adjacent to the surface, in which the feature emphasized is an accumulation of humified organic matter intimately associated with the mineral fraction.

A2 – Mineral horizons in which the feature emphasized is loss of clay, iron, or aluminum, with resultant concentration of quartz or other resistant minerals in sand and silt sizes.

A3 – A transitional horizon between A and B, and dominated by properties characteristic of an overlying A1 or A2 but having some subordinate properties of an underlying B.

B1 – A transitional horizon between B and A1 or between B and A2 in which the horizon is dominated by properties of an underlying B2 but has some subordinate properties of an overlying A1 or A2.

B2 – A horizon in which the dominant feature or features is one or more of the following: 1) an alluvial concentration of silicate clay, iron, aluminum or humus, alone or in combination, and 2) a residual concentration of sesquioxides or silicate clays, alone or mixed.

B3 – A transitional horizon between B and C.

C – A mineral horizon that has been relatively unaffected by pedogenic processes, and lacking properties diagnostic of A or B.

Ca – An accumulation of carbonates of alkaline earth, commonly of calcium.

p – Plowing or other disturbance.

t – An accumulation of translocated silicate clay is indicated by the suffix t.

APPENDIX B: DESCRIPTION OF MAJOR SOILS OF PUERTO RICO

Soils of Puerto Rico

I. *Zonal:* Soils having well-developed soil characteristics that reflect the influence of the active factors of soil genesis-climate and vegetation.

A. Gray-brown podzolic

Environment: Humid forest

Diagnostic features: A mineral soil that has an argillic horizon and an absence of oxic or natric horizons. The argillic horizon, unlike that in U.S. gray-brown podzolic soils, is acidic and contains less than 35 percent base saturation. An albic horizon is present immediately above the argillic horizon.

Tunnel and mine sites: None

B. Red and yellow podzolic

Environment: Thick stands of forest vegetation in humid or subhumid warm climate.

Diagnostic features: A mineral soil that has both an albic and an argillic horizon. The argillic horizon is massive, acid and red (red podzolic) or yellow (yellow podzolic). Plinthite is often present.

Tunnel and mine sites: El Yunque

C. Reddish-brown lateritic

Environment: Humid tropical

Diagnostic features: A mineral soil that has both an albic and an argillic horizon. The free iron content ranges from 12 to more than 30 percent of the clay fraction. Very little weatherable material left. Very permeable to water due to abundance of well structured kaolinitic material.

Tunnel and mine sites: Toro Negro, Sabana Hoyos, Rio San Patricio

D. Yellowish-brown lateritic

Environment: Same as IC

Diagnostic features: Same as IC except argillic horizon is yellowish-brown and has a very high percentage of colloidal iron and aluminum oxides in clay fraction.

Tunnel and mine sites: Florida, Laguna Tortuguero

E. Reddish prairie

Environment: Grassy open forest in a subhumid climate

Diagnostic features: A mineral soil that has a mollic epipedon with a brown or reddish brown subsoil which grades to a lighter colored parent material.

Tunnel and mine sites: Rio Guayanes, Salinas

F. Laterite

Environment: Tropical forest in a hot moist climate

Diagnostic features: These soils occupy old land surfaces. All soils that have oxic horizons are included in this group. Plinithite, either hard or soft, is common. There is an absence or near absence of weatherable minerals.

Tunnel and mine sites: Laguna Joyuda

G. Chernozem

Environment: Thick stands of grasses and scattered trees in a warm subhumid climate.

Diagnostic features: A mineral soil with mollic epipedon overlying a yellow brown subsoil which rests on a layer of lime accumulation.

Tunnel and mine sites: Yauco

II. *Intrazonal:* Soils with well-developed soil characteristics that reflect the dominating influence of some local factor of relief or parent material.

A. Rendzina

Environment: Grasses or mixed grasses and forest semiarid subhumid climate.

Diagnostic features: Soils with a granular neutral or calcareous surface soil ranging from brown to black in color and a thin yellowish brown calcareous layer that grades into white calcareous parent material.

Tunnel and mine sites: Sierra Bermeja

B. Planosol

Environment: Grass or forest vegetation in a humid, subhumid or semiarid climate.

Diagnostic features: These soils are characterized by an alluviated surface horizon overlying an alluviated horizon that is strongly cemented or compacted.

Tunnel and mine sites: Llanos

C. Wiesenboden

Environment: Grasses, sedges, or open swamp forest

Diagnostic features: Soils with a mollic and histic epipedon. Sodium saturation of more than 15 percent in the upper part of the mollic epipedon and decreasing with depth.

Tunnel and mine sites: Yaubauco

D. Half bog

Environment: Mangrove swamps

Diagnostic features: A thick organo-mineral surface layer (30% organic, 70% mineral) overlying a peaty subsoil.

Tunnel and mine sites: Parguera

III. *Azonal:* These are relatively young soils, formed on recent alluvial deposits and occuring in all climatic zones. They show little profile development, mostly limited to only the formation of a humiferous surface horizon.

A. Alluvial

Environment: Variable

Diagnostic features: Little profile development; silt content is high in comparison to older soils of Puerto Rico.

Tunnel and mine sites: Lajas, Moca, Manati, Dorado, Loiza

B. Sand

Environment: Variable

Diagnostic features: None

Tunnel and mine sites: Isabela

C. Lithosol

Environment: Variable

Diagnostic features: Absence of clearly expressed soil morphology and consisting of freshly and slightly weathered moss and rock fragments. Largely confined to steeply sloping land.

Tunnel and mine sites: Rio Abajo

APPENDIX C: DESCRIPTION OF SOILS

Laguna Joyuda

Soil Category:	Upland, deep
Soil Group:	Zonal, laterite
Soil Type:	Nipe clay
Parent Material:	Serpentine rock
Vegetation:	Sugar cane
Soil Profile:	

Ap	0-12"	Dark reddish-brown (2.5 YR 2/4) clay loam, slightly sticky and plastic wet; soft dry with a strong crumb structure; very friable; pH = 5.0.
A_3	12-20"	Dark reddish-brown (2.5 YR 3/4) clay; weak fine blocky structure; very friable; non sticky and non plastic wet; pH = 4.7.
B_2	20-65"+	Dark red (10YR 3/6) to red (10YR 4/6) clay; massive and firm; non sticky and non plastic wet; pH = 5.2.

Lajas

Soil Category:	River floodplain, poorly drained
Soil Group:	Azonal, alluvial
Soil Type:	Aguirre clay
Parent Material:	Alluvium
Vegetation:	Grasses
Soil Profile:	

A	0-12"	Very dark brown (10YR 3/6) clay; few distinct dark red (2.5YR 3/6) mottles; very sticky and very plastic wet; pH = 6.3.
B_{11}	12-36"	Dark gray (10YR 4/1) clay; common coarse, prominent red (2.5YR 5/6) mottles; very sticky and very plastic wet; pH = 6.7.
B_{12}	36-69"	Grades from dark gray to yellowish.brown (10YR 5/6) clay; very sticky and very plastic wet; gypsum crystal and iron concretions are common below the 48" level; pH = 7.2.

Isabela

Soil Category: Coastal lowland, well drained
Soil Group: Azonal, sand
Soil Type: Aguadilla sand
Parent Material: Beach sand
Vegetation: Sparse grass and palm trees
Soil Profile:

A 0-7" Brown sand; loose; pH = 8.8.

C 7" Light brown to gray brown sand loose; pH = 8.8.

El Yunque

Soil Category: Upland, medium deep
Soil Group: Zonal, yellow podzol
Soil Type: Los Guineos clay, smooth phase
Parent Material: Cretaceous, tuffaceous sediments
Vegetation: Forest
Soil Profile:

A 0-8" Dark brown (7.5YR 4/4) silt loam; friable moist, sticky and plastic wet; porous; roots common; pH = 4.8.

A_2 8-16" Brown (10YR 5/3) silt loam; friable moist, sticky and plastic wet, porous, roots common, pH = 4.8.

B_2 16-30" Matrix of light brown (10YR 5/2) and strong brown (7.5YR 5/8) with many dark grayish brown (10YR 3/2) root casts; silty clay loam; pH = 4.6.

C 30"+ Olive brown (2.5Y 4/4) silt loam with prominent, medium yellowish red (5YR 4/6) mottles; pH = 4.6.

Florida

Soil Category: Coastal plain, compact
Soil Group: Zonal, yellowish-brown laterite
Soil Type: Almirante sandy clay
Parent Material: Limestone
Vegetation: Grasses
Soil Profile:

A 0-10" Dark brown (7.5YR 3/2) sandy clay; granular; pH = 4.4.

A_2 10-16" Strong brown (7.5YR 5/6) sandy clay; slightly sticky and slightly plastic wet; compact; pH = 4.5.

B_2 16-24" Strong brown (7.5YR 5/6) clay; few distinct red (2.5YR 4/6) mottles; compact; pH = 4.5.

C 24" + Yellowish-brown (10YR 5/6) clay; many distinct red (2.5YR 5/6) mottles; compact; pH = 4.8.

Salinas

Soil Category:		Terraces and alluvial fans, compact
Soil Group:		Zonal, reddish prairie
Soil Type:		Paso Seco clay loam
Parent Material:		Cretaceous, tuffaceous material
Vegetation:		Sugar,cane
Soil Profile:		
A_p	0-12"	Dark brown (10YR 3/2) clay loam; sticky and plastic wet; firm dry; pH = 7.8.
B_1	12-22"	Dark yellowish brown (10YR 3/4) clay loam; firm dry; pH = 7.7.
C	36-60"	Grayish brown (10YR 5/2) sandy loam; slightly hard dry; pH = 7.7.

Manati

Soil Category:		River floodplain, well drained
Soil Group:		Azonal, alluvial
Soil Type:		Toa silt loam
Parent Material:		Alluvium
Vegetation:		Sugar cane
Soil Profile:		
A_p	0-14"	Dark yellowish brown (10YR 3/4) very friable; pH = 5.8.
B	14-21"	Dark yellowish brown (10YR 4/4) loam; friable; pH = 6.8.
C	24-36"	Dark brown (7.5YR 4/4) loam; friable; pH = 7.2.

Sierra Bermeja

Soil Category:		Upland, shallow
Soil Group:		Intrazonal, rendzina
Soil Type:		Aguilita stony clay
Parent Material:		Limestone
Vegetation:		Grasses, shrubs and cactus
Soil Profile:		
A	0-10"	Dark brown (10YR 3/3) clay loam with some stones; sticky and plastic wet; medium friable dry; pH = 7.7.
B	10-20"	Dark brown (10YR 3/3) sandy clay loam with stories; sticky and plastic wet; massive; pH = 7.7.
Cca	20-30"	Dark brown (10YR 3/3) sandy clay loam with stories; sticky and plastic wet; massive; pH = 8.2.
C	30" +	Grayish silty clay with soft limestone rocks.

Parguera

Soil Category:	Coastal lowland, poorly drained organic soils
Soil Group:	Intrazonal, half bog
Soil Type:	Reparada clay
Parent Material:	Coral, shells
Vegetation:	Mangrove
Soil Profile:	

A	0-18"	Dark-gray loam, plastic; pH = 7.0.
B,C	18" +	Dark gray peaty loam; pH = 8.2.

Yauco

Soil Category:	Terraces and alluvial fans, medium friable
Soil Group:	Zonal, chernozem
Soil Type:	Coamo clay
Parent Material:	Alluvium derived from limestone material
Vegetation:	Sugar cane
Soil Profile:	

A_p	0-12"	Dark reddish brown (5YR 3/2) clay; medium friable; stocky and plastic wet; pH = 7.3.
B	12-22"	Yellowish brown (10YR 5/4) silty clay loam; few, medium, faint yellowish red (5YR 6/6) mottles; medium friable; sticky and plastic wet; pH = 7.8.
C	22-50"	Light yellowish brown (2.5YR 6/4) silt loam; moderately friable dry; sticky and slightly plastic wet; pH = 8.1; calcareous concretions below 36" level.

Laguna Tortuguero

Soil Category:	Coastal plain, very friable
Soil Group:	Yellowish-brown laterite
Soil Type:	Espinosa sandy loam
Parent Material:	Limestone
Vegetation:	Palm trees and grasses
Soil Profile:	

A_p	0-10"	Light brown (10YR 5/4) sandy loam; very friable; pH = 5.9.
B	10-30"	Light reddish brown (7.5YR 4/4) sandy loam; very friable; pH = 5.7.
C	30" +	Yellowish red (5YR 4/6) sandy clay loam; friable; pH = 6.0.

Rio Guayanes

Soil Category:	River floodplain, well drained
Soil Group:	Zonal, reddish prairie
Soil Type:	Yivi sandy loam
Parent Material:	Tertiary-Cretaceous granodiorite and quartz diorite
Vegetation:	Grasses
Soil Profile:	

A	0-7"	Brown sandy loam; loose; pH = 5.0.
B	7-24"	Red sandy loam; loose; pH = 5.1.
C	24" +	Grayish brown sand; loose; pH = 5.5.

Rio Abajo*

Soil Category:	Upland, medium deep
Soil Group:	Azonal, lithosol
Soil Type:	Tanama stony clay, colluvial phase
Parent Material:	Cretaceous tuffaceous sediments
Vegetation:	Forest
Soil Profile:	

A_1	0-4"	Dark yellowish brown (10YR 4/4) stony clay; sub angular blocky structure; very sticky and very plastic wet; pH = 5.5.
A_3	4-12"	Dark brown (7.5YR 4/4) stony clay; few, fine, distinct yellowish red (5YR 5/6) mottles; very sticky and very plastic wet; sub angular blocky structure; pH 5.5.
B	12-24"	Color grades from dark brown (7.5YR 4/4) to reddish brown (5YR 4/4) clay; more massive than above but still sub angular blocky; very sticky and plastic wet; pH = 5.1.
C	24-36"+	Yellowish red (5YR 4/6) with a few thin layers of brown (10YR 5/4) clay; platy structure, plastic and sticky wet; pH = 5.1.

* This soil is nearly impervious to water due to high clay content and platy structure. The position of this soil on the hill side aids surface runoff causing this soil to be only imperfectly drained. Down slope on more level ground, a very poorly drained soil was observed.

Yaubauco

Soil Category:	River floodplain, poorly drained
Soil Group:	Intrazonal, wiesenboden
Soil Type:	Maunabo loam
Parent Material:	Alluvium
Vegetation:	Sugar cane

Yaubauco (Cont'd)

Soil Profile:

A_p	0-10"	Dark brown (10YR 3/3) sandy loam; very friable; pH = 6.1.
B	10-24"	Dark brown (1-YR4/3) sandy loam, very friable; pH = 5.8.
C	24-48"+	Yellowish brown (10YR 5/4) sand; common, faint mottles (5YR 5/6); pH = 5.9.

Sabana Hoyos

Soil Category: Coastal plain, compact
Soil Group: Zonal, brown laterite
Soil Type: Bayamon sandy clay
Parent Material: Alluvium
Vegetation: Pineapple
Soil Profile:

A_p	0-10"	Reddish-brown sandy clay loam; friable; sticky and plastic wet, porous; pH = 4.2.
A_2	10-16"	Yellowish-red sandy clay; friable; sticky and plastic wet, porous-pH = 4.3.
B_2	16" +	Red sandy clay; pH = 4.8.

Toro Negro

Soil Category: Upland, deep
Soil Group: Zonal, reddish brown laterite
Soil Type: Cialitos clay, eroded phase
Parent Material: Cretaceous, tuffaceous sediments
Vegetation: Forest
Soil Profile:

A, B, C	0-5'	Mixture of yellowish red (5YR 5/6) and brownish yellow (10YR 6/6) in the form of coarse prominent mottles; clay loam; blocky structure; slighty sticky and plastic wet; medium friable dry; pH = 4.8.

Llanos

Soil Category: Coastal plain, compact
Soil Group: Intrazonal, planosol
Soil Type: Sabana Seca sandy clay loam
Parent Material: Cretaceous tuffaceous sediments
Vegetation: Grasses and palm trees

Llanos (Cont'd)

Soil Profile:

A	0-12"	Dark reddish-brown (5YR 3/3) loam; very friable, non sticky and non plastic wet; pH = 5.9.
A_2	12-20"	Dark reddish-brown (5YR 3/4) sandy loam; very friable; non sticky and non plastic wet; pH = 6.0.
B_{21}	20-36"	Dark red (10YR 3/6) sandy loam, common coarse distinct yellowish brown (10YR 5/8) mottles; compact; pH = 5.8.
B_{22}	36-48"	Red (10R 4/6) and yellowish-brown (10YR 5/6) with a few pockets of white (5Y 8/2) kaolinite; sandy loam, extremely firm.
C	48" +	Grades from 50% red, 20% yellowish brown, 30% white to 70% white and 30% red; clay; extremely firm; pH = 4.8.

Moca

Soil Category: River floodplain, poorly drained
Soil Group: Azonal, Alluvial
Soil Type: Coloso clay, poorly drained phase
Parent Material: Alluvium
Vegetation: Sugar cane
Soil Profile:

A	0-12"	Dark grayish brown (10YR 4/2) clay; few, fine, distinct reddish-brown (5YR 5/4) mottles; very sticky and plastic wet; pH = 6.0.
B	12-24"	50% yellowish red (5YR 4/6) and 50% light brown gray (2.5Y 5/2) clay; very sticky and plastic wet; pH = 6.3.
C	24-96"	Grades from 60% blueish gray (5B 6/1) and 40% yellowish brown (10YR 5/8) to 100% blueish gray; clay; very sticky and plastic wet; pH = 6.5.

Rio San Patricio

Soil Category: Upland, deep
Soil Group: Zonal, reddish brown laterite
Soil Type: Cialitos clay
Parent Material: Tuffaceous sediments (stream deposited)
Vegetation: Forest
Soil Profile:

A, B, C	0-4"	Dark red, brown and yellow silt loam in surface. Grading to brown and gray brown sandy loam subsoil layers.

Dorado

Soil Category:	River floodplain, well drained
Soil Group:	Azonal, alluvial
Soil Type:	Toa silt loam
Parent Material:	Alluvium
Vegetation:	Sugar cane
Soil Profile:	

A_p	0-14"	Dark yellowish brown (10YR 3/4) clay loam;very friable; pH = 5.0.
B	14-21"	Dark yellowish brown (10YR 4/4) clay loam;friable; pH = 6.1.
C	24-36"	Dark brown (7.5YR 4/4) clay loam; friable;pH = 6.7.

Loiza

Soil Category:	River floodplain, well drained
Soil Group:	Azonal, alluvial
Soil Type:	Toa silt loam
Parent Material:	Alluvium
Vegetation:	Sugar cane
Soil Profile:	

A_p	9-14"	Dark yellowish brown (10YR 3/4) silt loam; very friable; pH = 4.4.
B	14-21"	Dark yellowish brown (10YR 4/4) silt loam; friable; pH = 5.7.
C	24-36"	Dark brown (7.5YR 4/4) silt loam; friable; pH = 6.3.

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13. ABSTRACT

Soils at mine-tunnel detection research sites, Puerto Rico, were described and classified. A priority for development of the sites for USA CRREL needs was arrived at using both this information and that on landform, climate and vegetation. The suitability of the various great soil groups for both mine and tunnel detection was discussed.

14. Key Words:

Mine detection
Site surveys
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