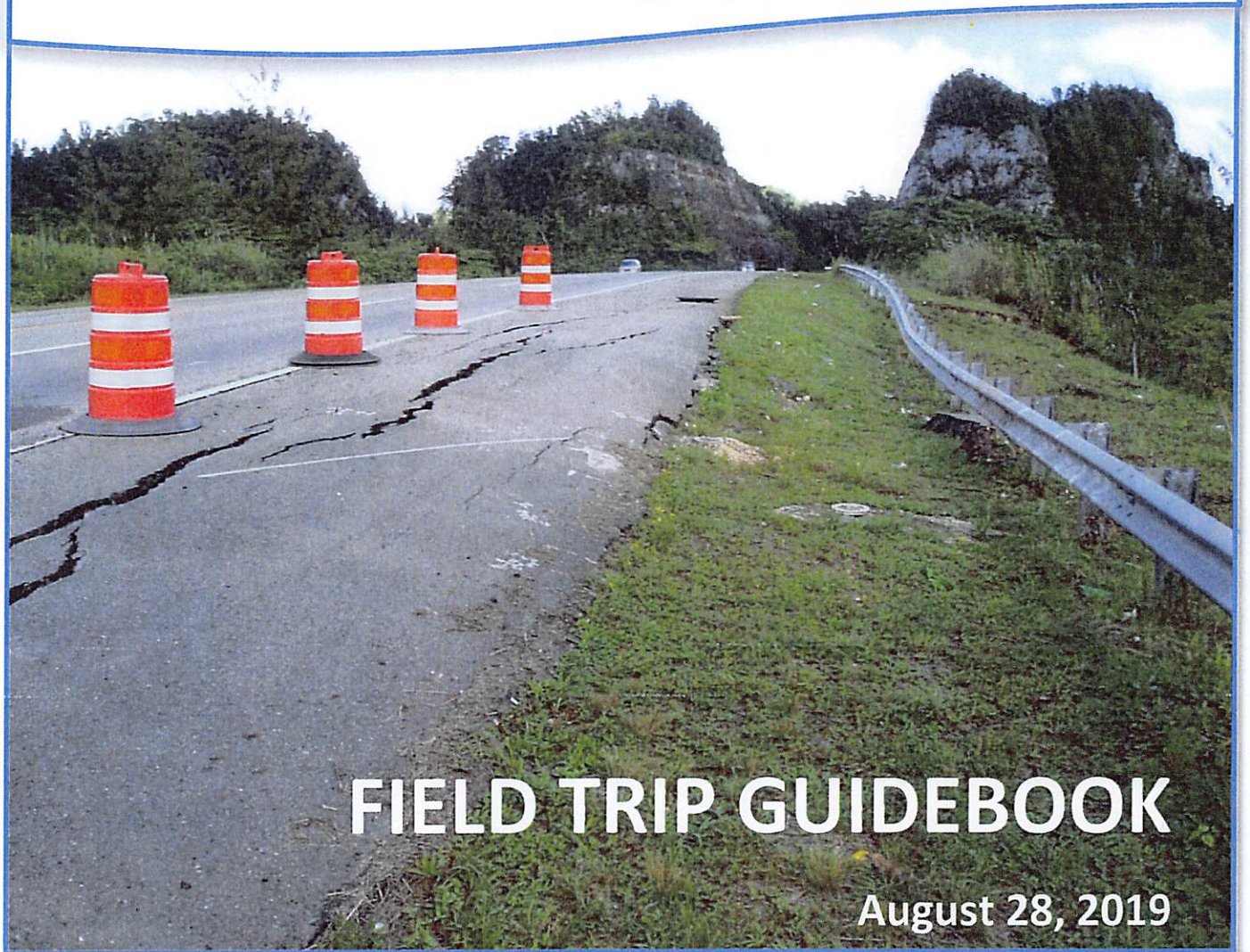
APPENDIX C: GAMPE FIELD TRIP GUIDE

Geotechnical Asset Management
Peer Exchange (GAMPE)



FIELD TRIP GUIDEBOOK

August 28, 2019

HIGHWAY AND TRANSPORTATION AUTHORITY

Oficina de Ingeniería de Suelos

CDOT

New Hampshire DOT
Department of Transportation

WSDOT

U.S. Department of Transportation
Federal Highway Administration

TABLE OF CONTENTS

Wednesday, August 28, 2019 - Day 2
Geotechnical Asset Management Peer Exchange

FIELD TRIP ITINERARY

7:15 – 7:30 AM	Departure:	Soils Engineering Office – PRHTA, Bayamón (https://goo.gl/maps/XYUafWfko2ADjVXq6) (Lat: 18.416449° Long: -66.146357°)
9:00 – 9:30 AM	Stop #1:	PR-10 Km 57.2, Arecibo (https://goo.gl/maps/hsHuKkuhRqQJ2Liy5) (Lat: 18.362978° Long: -66.692865°)
9:45 - 10:15 AM	Break:	PR-10 Km 44.3 La Placita del Viví, Utuado (https://goo.gl/maps/Fupn5hMxPnuJgVFMA) (Lat: 18.282650° Long: -66.708574°)
10:30 – 11:00 AM	Stop #2:	PR-10 Km 52.8, Arecibo (https://goo.gl/maps/gJSeRX7MNqxDGynK7) (Lat: 18.328821° Long: -66.679387°)
11:45 - 1:00 PM	Lunch:	Restaurant Las Garzas, Adjuntas (https://goo.gl/maps/qxTxRsoySgQkSmmY8) (Lat: 18.172464° Long: -66.738047°)
1:30 - 2:00 PM	Stop #3:	PR-9, Ponce (https://goo.gl/maps/oZhJRKtPwBhGTfcZ8) (Lat: 18.033108° Long: -66.636308°)
2:30 - 3:00 PM	Stop #4:	PR-52 Km 68.3, Salinas (https://goo.gl/maps/kmjMR1yuxgdsTSHv9) (Lat: 17.995341° Long: -66.305431°)
3:30 - 4:00 PM	Stop #5:	PR-52 Km 52.3, Salinas (https://goo.gl/maps/tbJjK7K8nt9smno2A) (Lat: 18.046572° Long: -66.211484°)
4:00 - 5:00 PM	Return:	Soils Engineering Office - PRHTA, Bayamón (https://goo.gl/maps/XYUafWfko2ADjVXq6) (Lat: 18.416449° Long: -66.146357°)

Note: This schedule may vary depending on events or circumstances outside the organizer's control.

INTRODUCTION

This field trip is part of the activities related to a State Planning and Research (SPR) peer exchange hosted by the Soils Engineering Office (SEO) of the Puerto Rico Highway and Transportation Administration (PRHTA). The main subject of the peer exchange is the development of an unstable slope management program as part of a geotechnical assets management program (GAMP).

The field trip was designed to demonstrate the slope collection procedure currently being used by the SEO to populate the inventories, and as many different challenges and conditions commonly encountered during slope asset collection in PR as possible in the limited amount of time available. The location of each stop was selected based on the ease of access of the slope and safety of the participants in addition to the characteristics of each slope.

The trip will start and end at the SEO's Office in Bayamón (PR-5). See figure 1. The vehicles will head west along toll highway PR-22 until we reach PR-10 in Arecibo. Highway PR-10 and road PR-123 will take us due south, across the mountainous center of the island, from Arecibo to Ponce. **Stops # 1** and **#2** will take place in the Arecibo segment of highway PR-10. After a lunch break in Adjuntas we will continue south, towards **stop #3** in highway PR-9, Ponce. **Stops #4** and **#5** will take place in toll highway PR-52, Salinas. Highways PR-52 and PR-18 will take us back to highway PR-22 and to the **SOE**.

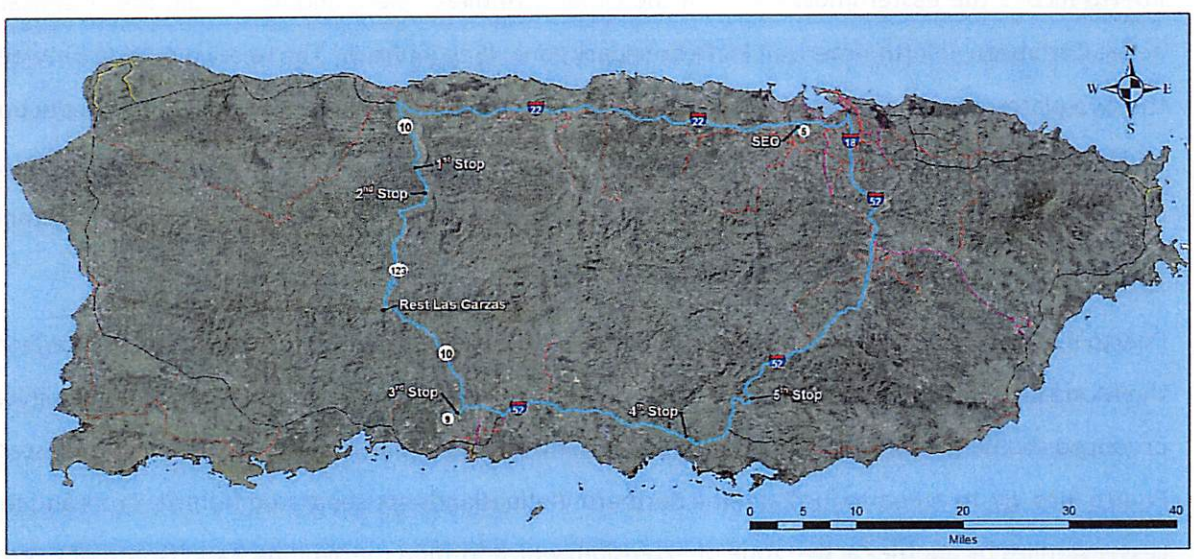


Figure 1. Field trip route and stops.

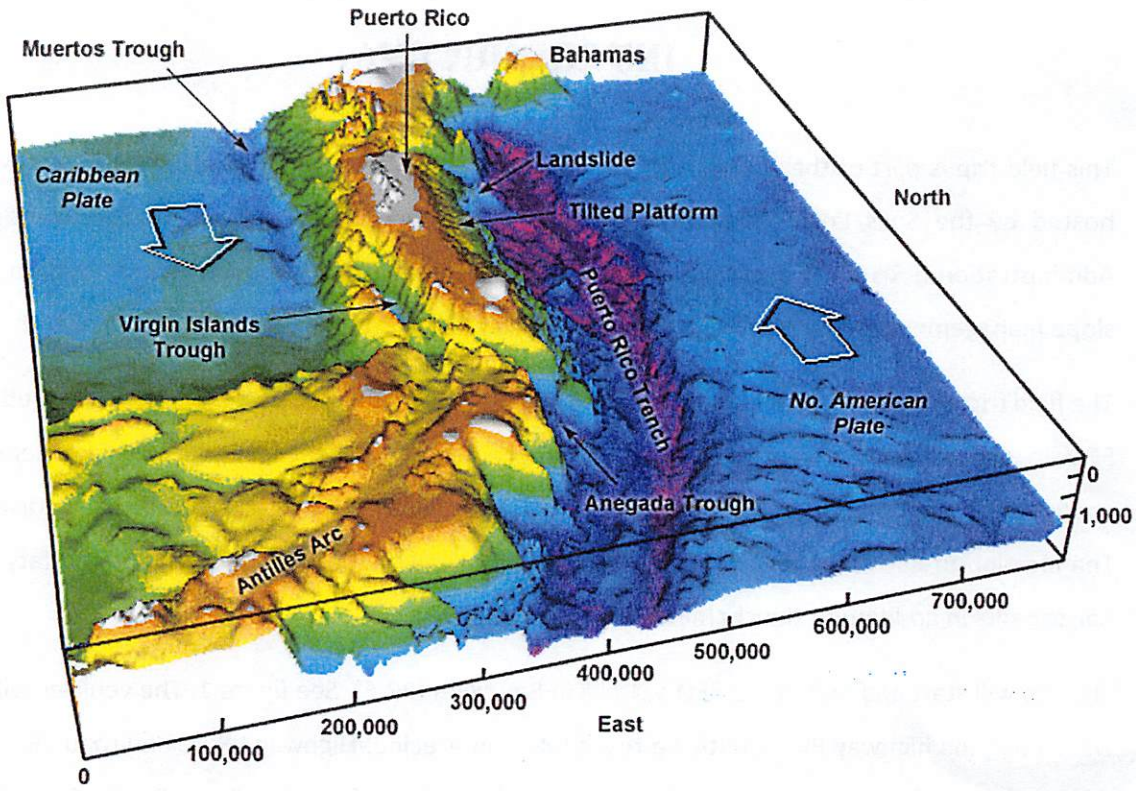


Figure 2. 3D view of the contact between the Caribbean and North American tectonic plates. (USGS)

Physical Characteristics of Puerto Rico

Puerto Rico is the easternmost island of the Greater Antilles. The island lies within the seismically active Caribbean - North American Plate boundary zone. (See figure 2.) The relative motion between the two plates is on the order of 2 cm per year and is taken up mainly by strong oblique subduction and left-lateral faulting in the Puerto Rico trench. Some plate motion and subduction also occur south of Puerto Rico in the Muertos Trough. Puerto Rico and the Virgin Islands are in a separate tectonic block or micro-plate, within the plate boundary zone.

Puerto Rico is separated from Hispaniola on the west by a zone of active extension, which runs from the Mona Canyon through the southwestern quarter of the island. On-land extensional faulting has produced the distinctive ridge and valley topography and generally low elevations of southwestern Puerto Rico. Eastern Puerto Rico and the northern Virgin Islands are separated from St. Croix and the Lesser Antilles by another active zone of extension, which formed the Whiting Basin (south of Puerto Rico), the Virgin Islands Basin, and the Anegada Passage.

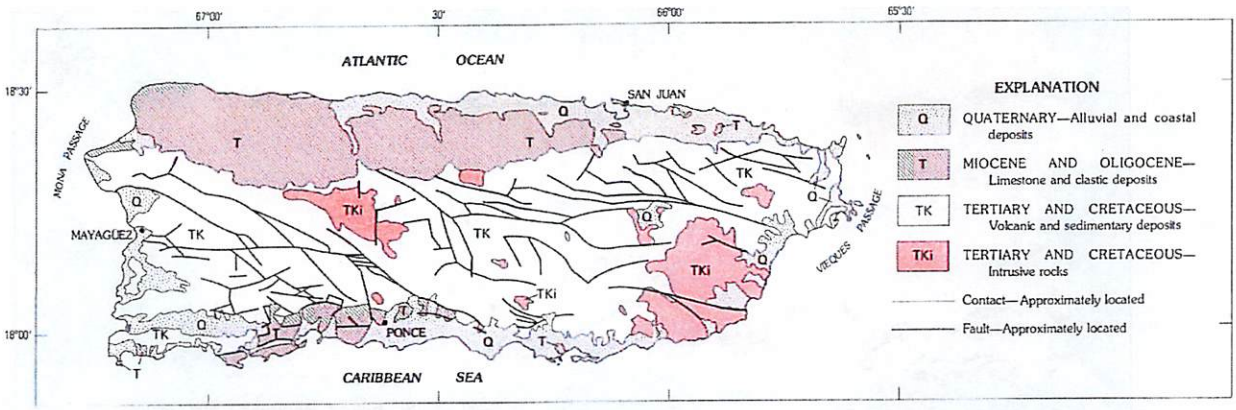


Figure 3. Generalized geology of Puerto Rico.

Puerto Rico is an island-arc terrane with a geologic record of approximately 160 million years. It consists of volcanic, volcaniclastic, and sedimentary rocks of Late Jurassic to Early Tertiary age, which were intruded by felsic plutonic rocks during the Late Cretaceous and Early Tertiary and are overlain by slightly tilted Oligocene and younger sedimentary rocks and sediments. (See figure 3.) The main island is divided into three igneous provinces, the southwestern, central, and northeastern igneous provinces, based on differences in stratigraphy, lithology, petrology and geochemistry. (See figure 4.) The oldest rocks (Late Jurassic) are found in a small outcrop in Sierra Bermeja at the southwestern corner of Puerto Rico. The Oligocene and younger sedimentary rocks consist mostly of carbonate rocks which form a continuous belt of well-developed karstic topography along the north coast of Puerto Rico, known as the "Northern Puerto Rico Karst Zone". (See figure 5.) Along the south coast and center of the main island carbonate rocks form a discontinuous band, some of which has developed pockets of tower karst, sometimes surrounded by dry shrubland.

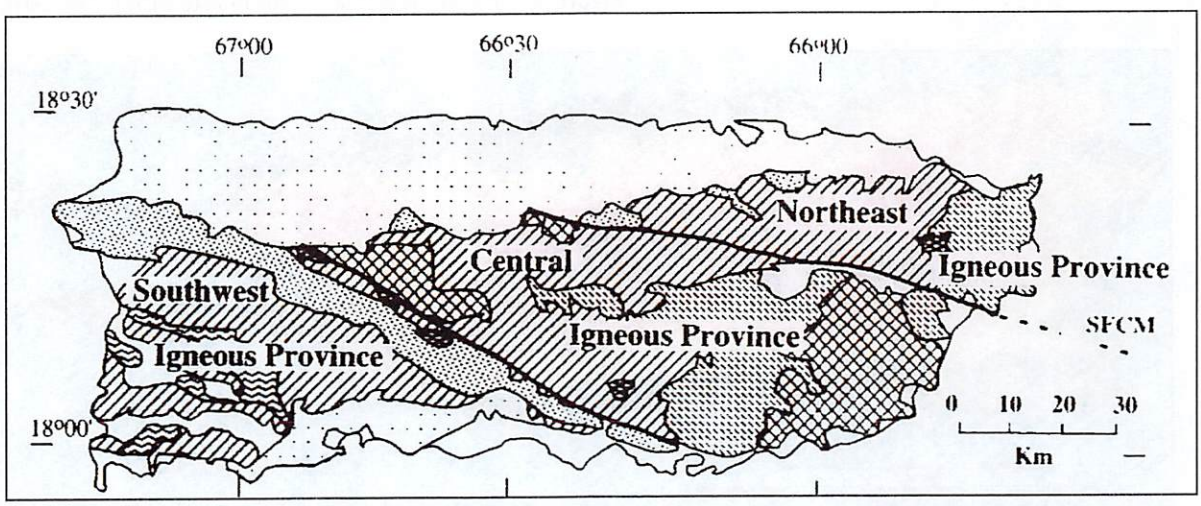


Figure 4. The three igneous provinces of Puerto Rico.

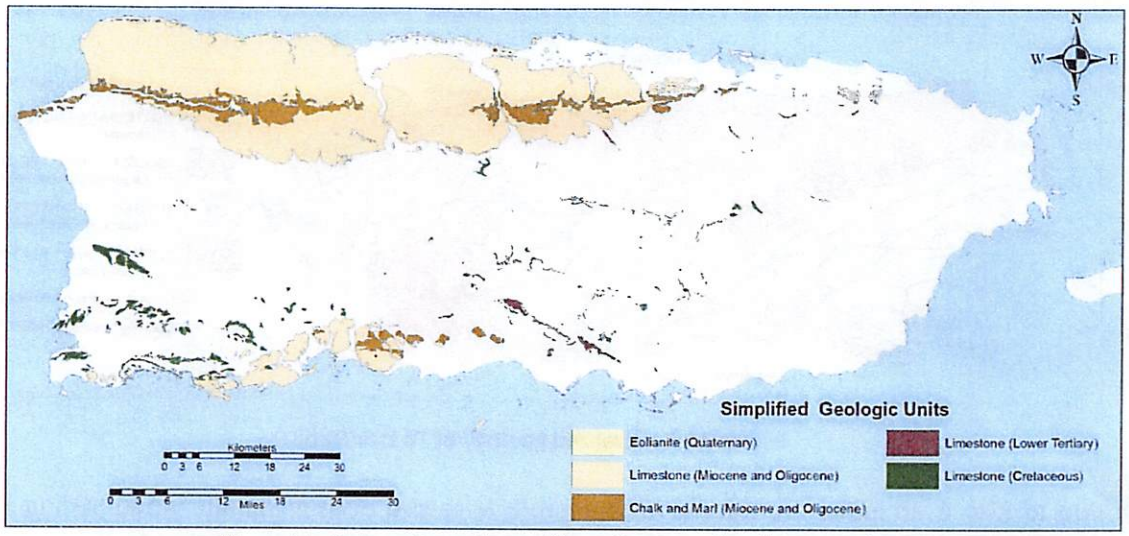


Figure 5. Carbonate rocks and Karst Topography of Puerto Rico.

The mean annual rainfall (Fig. 6) for all of Puerto Rico is about 70 inches, but it varies greatly due to the trade winds and regional geographic differences. The topography of Puerto Rico (Fig. 7) consists of 40% mountainous terrain, 35% hilly terrain, and 25% coastal and alluvial plains. The highest point in Puerto Rico is Cerro Punta (1,338 m) located between the municipalities of Ponce and Jayuya.

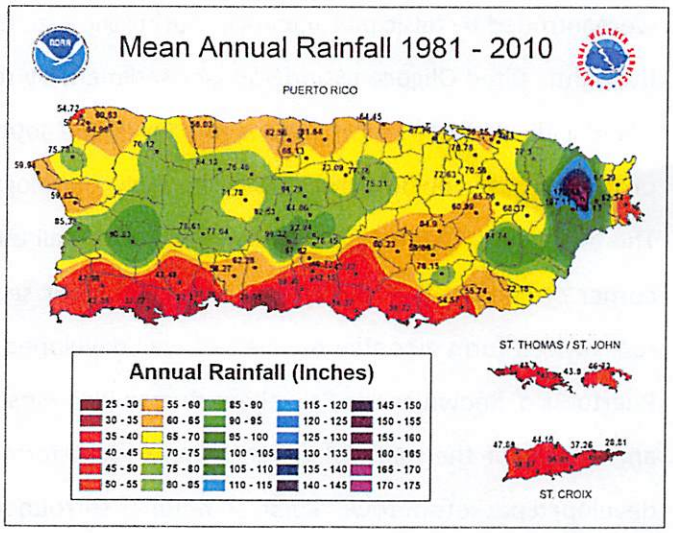


Figure 6. Mean Annual Rainfall for Puerto Rico (1981-2010)

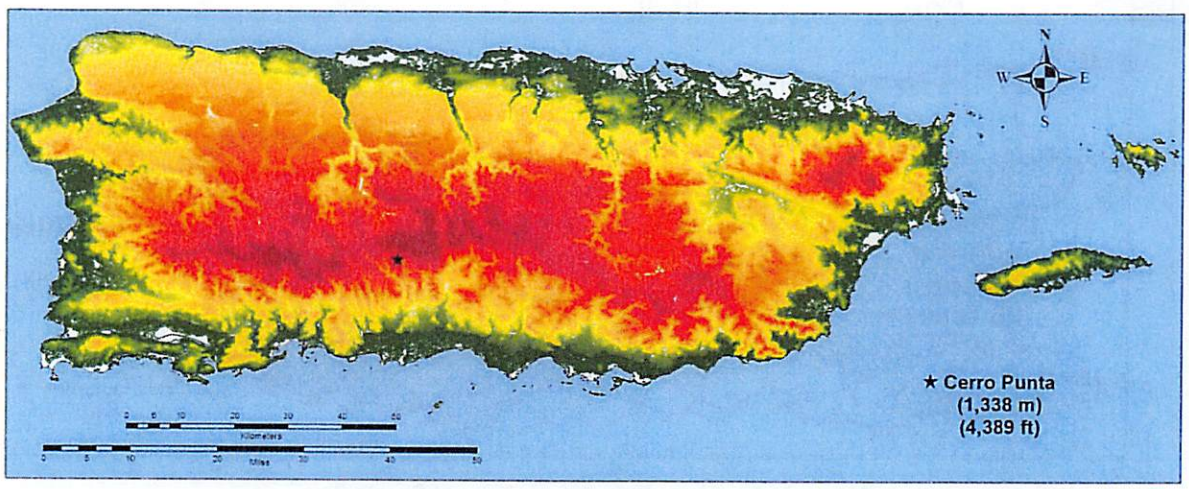


Figure 7. Topography of Puerto Rico.

FIELD TRIP

The field trip will depart from the SEO's building in Bayamón, heading west through highway PR-22 parallel to the Atlantic coast of norther Puerto Rico. Once in the municipality of Arecibo we will turn south through Highway PR-10, where we will make two stops for site description and discussion. We will cross the "*Cordillera Central*" towards the municipality of Ponce, reaching the south coast of Puerto Rico. To complete the field trip, we will take highway PR-52 heading east and driving parallel to the Caribbean Sea, where we will make stops #4 and #5 in the municipality of Salinas.

Toll Highway PR-22 Bayamón - Arecibo

Highway PR-22, also known as "*Expreso José de Diego*", is a toll road that runs parallel to the north coast of Puerto Rico and to highway PR-2. Its length is about 52 miles (84 kilometers) and it connects San Juan (PR-26) to Hatillo (PR-2). It is currently managed by Puerto Rico Metropolitan Highways, a private consortium. Construction of its first segment started in 1969, and the most recent segment was opened in 1997. Most of the population and economic growth that Puerto Rico experienced during the 1990's occurred along its northern coast, hence the construction of highway PR-22 was essential to reduce heavy traffic along highway PR-2. Highway PR-22 offers a relatively good view of how the karstic terrain of northern Puerto Rico developed closer to the coast and coastal valleys. (See figure #8.) It also crosses the alluvial valleys of several of the biggest rivers of Puerto Rico which flow from the central mountains to the Atlantic Ocean, cutting deep narrow valleys further south and relatively wide flood plains closer to the north coast. Highway PR-22 is part of Interstate PRI-2.

Figure 8. Geology of PR-22, from PR-5 (Bayamón) to PR-10 (Arecibo).

Highway PR-10 Arecibo - Ponce

PR-10 is a highway that runs perpendicular to the north and south coast of Puerto Rico, and mostly parallel to the "old PR-10", today road PR-123. Although some segments around urban Arecibo were built as early as the 1970's most of its current extension was built between the late 1980's and the mid 1990's. Its construction has faced many challenges, including karst terrain (caves and sinkholes are protected under PR environmental laws), crossing land protected as a nature reserve managed by the Puerto Rico Department of Natural and Environmental Resources (Río Abajo Forest, DNER), crossing the landscape with the highest susceptibility to landslides in all of Puerto Rico, etc. (See figures 9-13.) A section of about 10 miles (16 kilometers) between the towns of Utuado and Adjuntas remains to be built, but it's currently bridged by road PR-123.

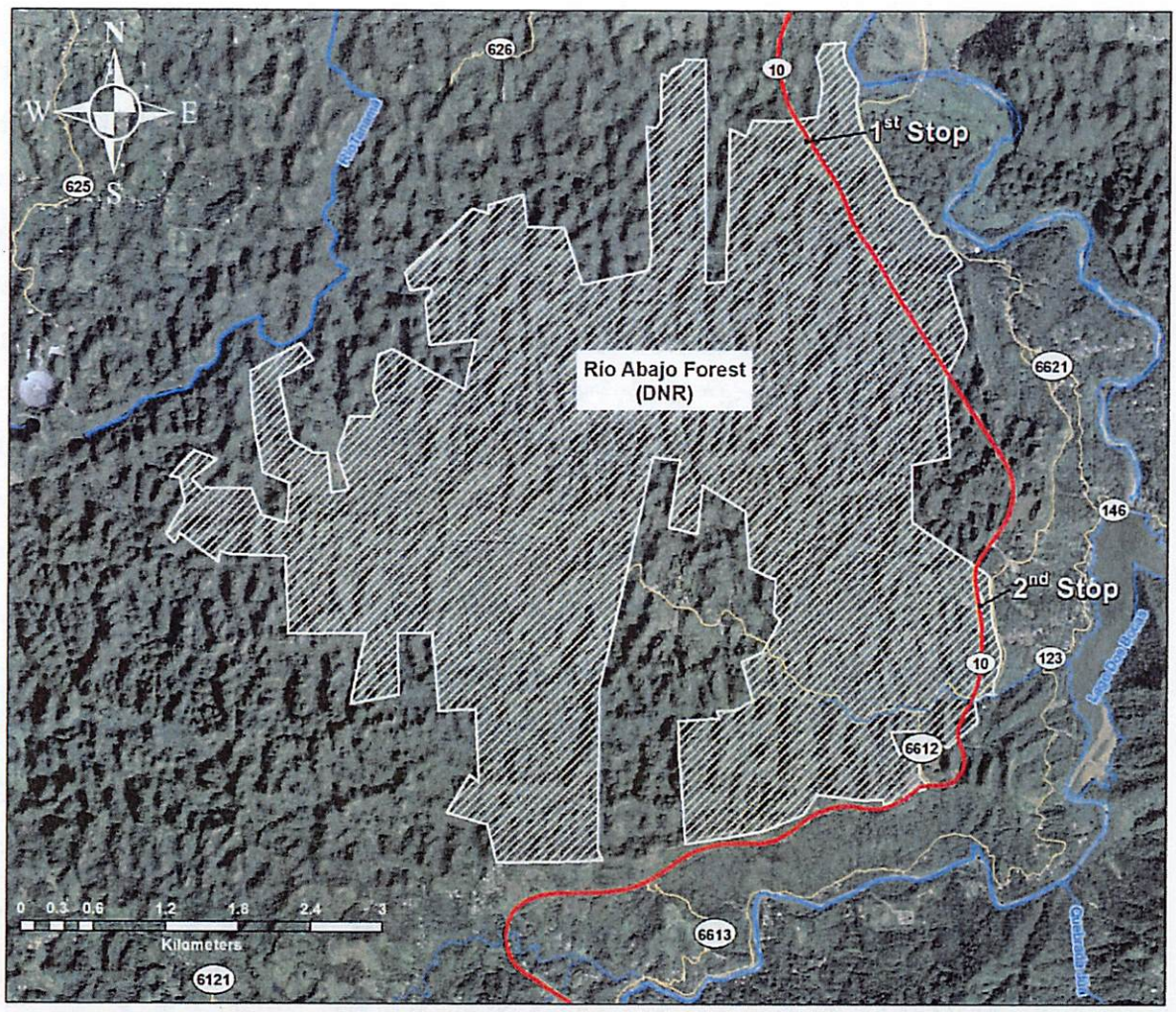


Figure 9. Land area of the Río Abajo Forest, PR-10 Arecibo.

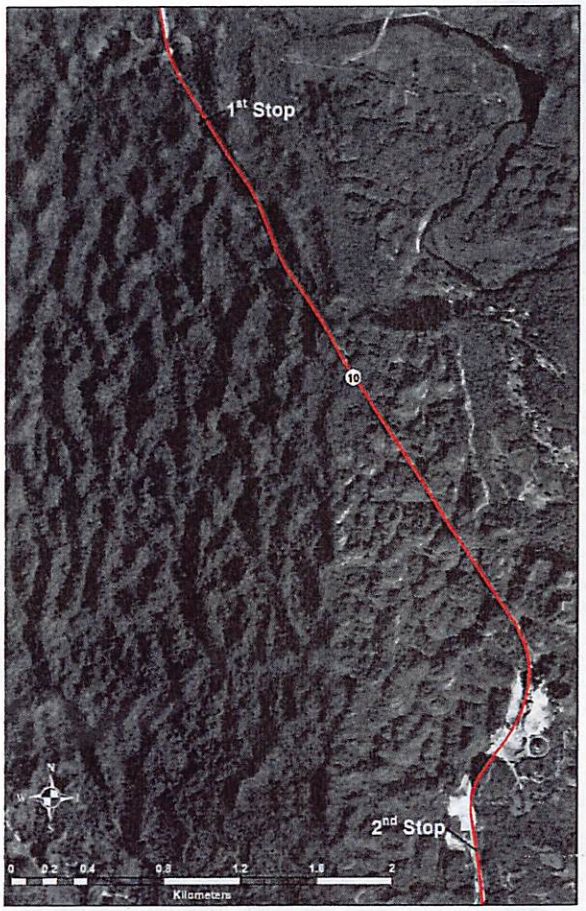


Figure 10. Aerial photograph, PR-10 Arecibo (1993).

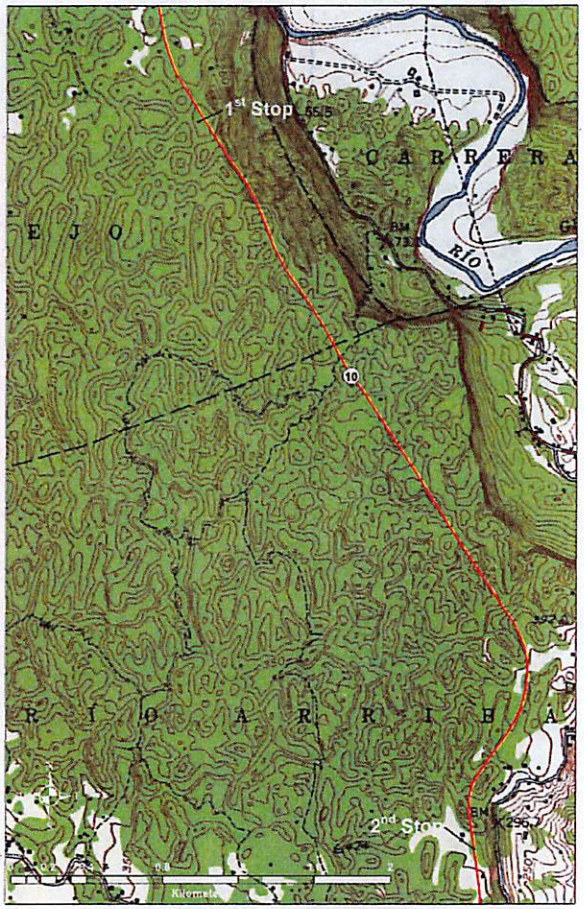


Figure 11. Topographic map, PR-10 Arecibo (USGS).

Once completed highway PR-10 will be one of only two major roadways that cross the center of the island from north to south, reducing distance and travel time between Arecibo and Ponce in half, compared to the distance and time it takes to drive around towards the west (PR-2) or towards the east (PR-52). Highway PR-10 is also important to the economy and quality life of the population of the center of the Island, reducing the cost of transporting goods and produce to and from the area and providing easier and safer access to hospitals and other services provided in Ponce or Arecibo.

The section of road PR-123 ("old PR-10") that currently connects the Utuado segment of highway PR-10 to the Adjuntas segment, will provide an example of the how precarious the Arecibo - Utuado and Ponce - Adjuntas trips used to be, and why the construction of PR-10 was so necessary.

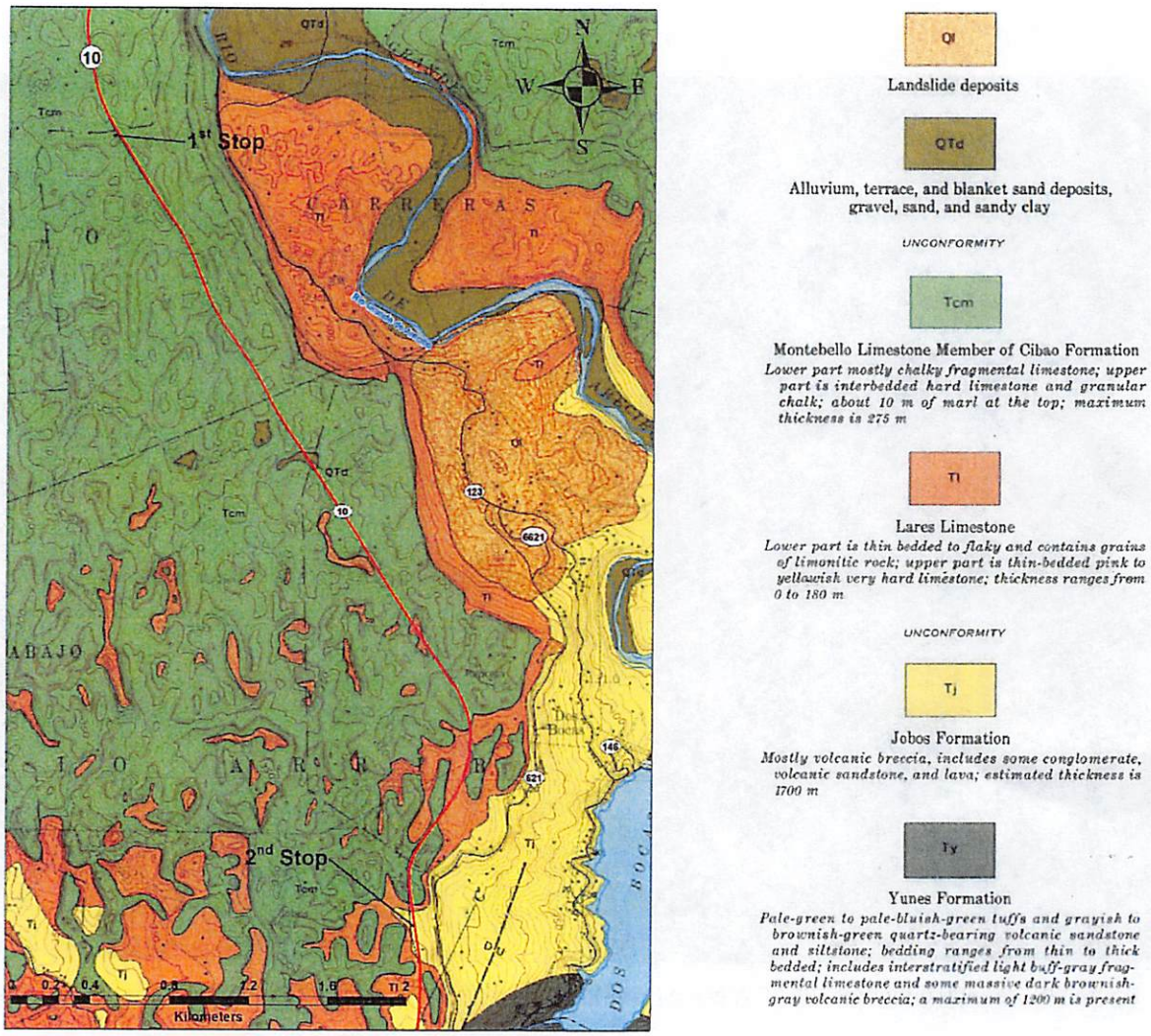


Figure 12. Geologic map of PR-10, Arecibo (stops #1 and #2).

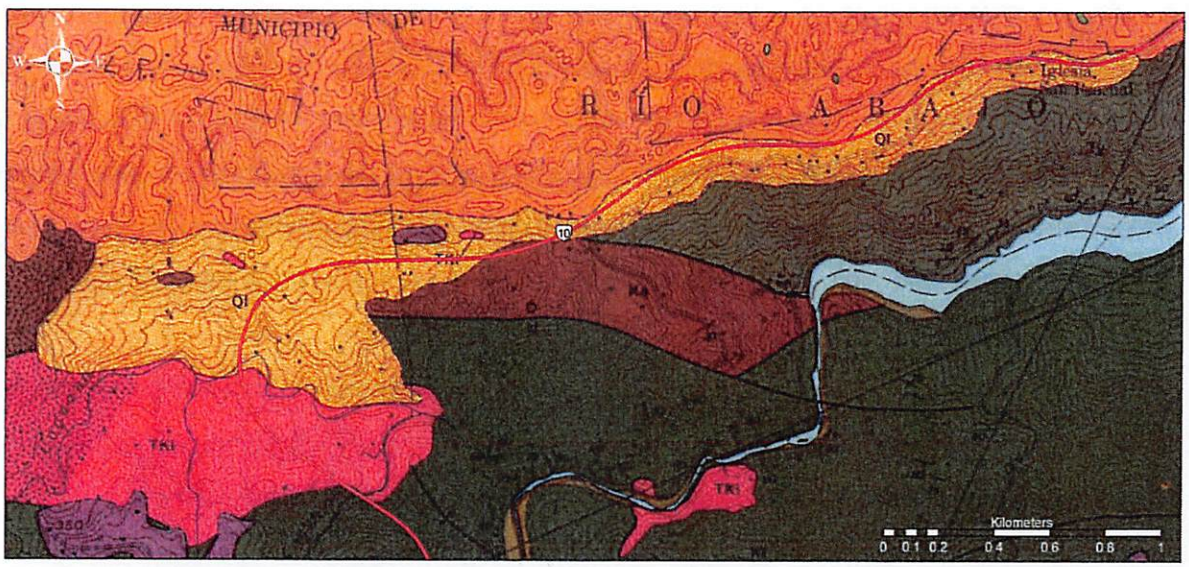


Figure 13. Extensive landslide deposits (Ql) along the Lares Scarp, PR-10 Arecibo.

Stop #1 – PR-10 Km 57.2 Arecibo

This rock slope represents the section highway PR-10 that crosses the Río Abajo Forest. The nearly vertical rock cuts and small rockfall catchment areas between the roadway and the base of the slope resulted in part from the agreements established between DNER and PRHTA. To reduce impacts to the forest, the total width of this section of PR-10 had to be kept as small as possible.

The resulting rock cuts have not produced any significant rockfalls since their construction about 25 years ago. However, the rock of these "mogotes" (Montebello Limestone member of the Cibao Formation, Tcm) is not homogeneous, and the effects of differential erosion and raveling are starting to become an obvious problem. (See figure 12.)

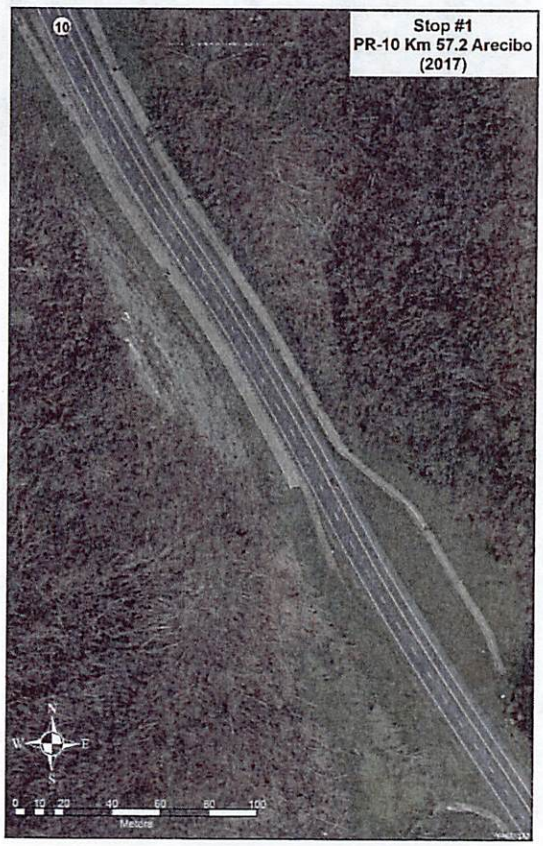
Photograph **A** shows the view of the slope towards the south and photograph **B** towards the north. During our stop the vehicles will park on the relatively wide unpaved and grassy shoulder seen on photograph B. This wide area is a sinkhole that was "*filled*" during construction. (See 1987 and 1998 aerial images.)

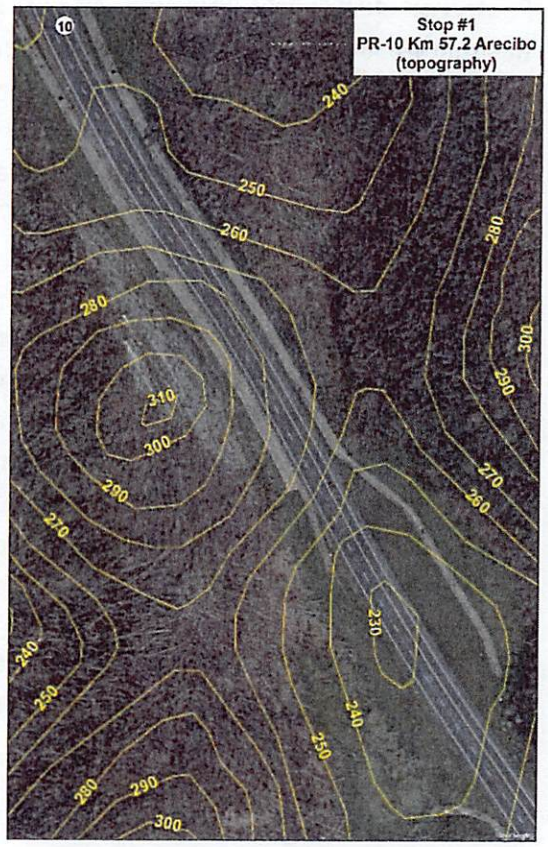
In order to comply with Puerto Rico's environmental laws and regulations, the process used to *"fill"* this and all other sinkholes along this section of highway PR-10 had to preserve their pre-construction ability to collect runoff from the surrounding areas and infiltrate it underground. Dye tracing methods and other studies were used to characterize the hydrology and hydrogeology of the sinkholes. The method used to "*fill*" the sinkholes involved complete clearing and grubbing of the sinkholes, lining them with permeable geotextiles, layering coarse aggregates with geotextile at a fixed thickness, vertical drains, etc. The result was basically designed to be a filter that 1s able to support a highway.

The sinkholes of highway PR-10 are so important to its performance that it made us realize sinkholes are also a type of geotechnical asset that should also be inventoried and monitored by PRHTA.


10
Stop #1
PR-10 Km 57.2 Arecibo
(1987)
N
W
E
S
0 20 40 80 120 160 200
Meters


10
Stop #1
PR-10 Km 57.2 Arecibo
(1998)
N
W
E
S


10
Stop #1
PR-10 Km 57.2 Arecibo
(2017)
N
W
E
S
0 10 20 40 60 80 100
Meters


10
Stop #1
PR-10 Km 57.2 Arecibo
(topography)
240
250
260
280
310
300
280
220
240
250
280
290
300
280
300
290
270
260
230
240
250

Stop #2 – PR-10 Km 52.8 Arecibo

This slope represents a fill or embankment section built over the contact between the Lares Limestone (Tl) and an underlying volcaniclastic sequence (Tj).

Figures 10 and 14 show that the fill started failing only a few years after construction ended. The conditions found during the landslide investigations determined that the best option available was to move this segment towards the west. Photograph A and B are from 2005 and 2008, respectively.

Figure 15 shows that by 2017 there was very little visual indication of the history of the site, and that inventorying, and description of site like this one can be improved by using aerial or satellite images.

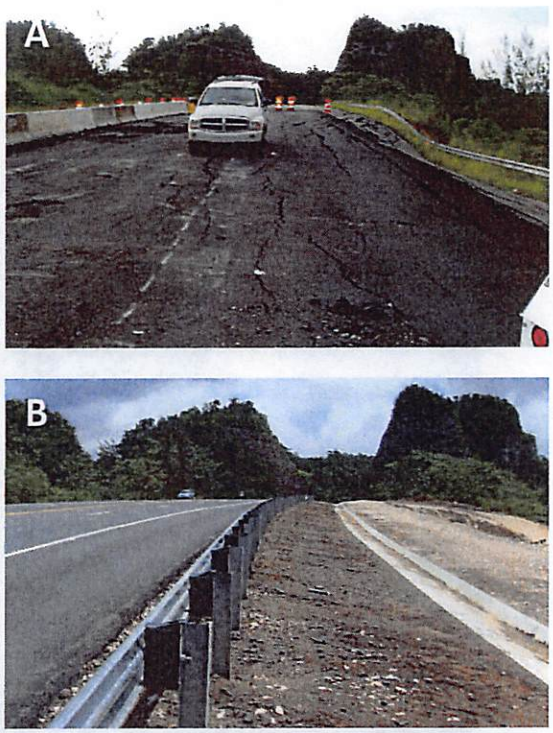


Figure 14. Condition of highway segment in 1998 and 2006, PR-10 Arecibo. (Stop #2)

Figure 15. Condition of highway segment in 2010 and 2017, PR-10 Arecibo. (Stop #2)

Highway PR-9, Ponce

Highway PR-9 is a ring road located entirely within the municipality of Ponce. Once completed it will connect PR-10 to PR-52 but even though it was 90% completed by 2017, it has not been possible to open the last section, due to several slope failures. From year 2005 to 20017 several attempts were made to control the landslides, along with additional borings up to 68' deep, inclinometers and observations wells.

Stop#3 – PR-9 Ponce

This section of highway PR-9 involved the construction of two kilometers of new roadway and three bridges. Several slope failures have delayed its completion.

Photographs A and B are from 2016 and 2017 respectively. Figures 16-18 show an aerial view, the geologic map and a topographic map of the landslide, respectively.

The geology of this landslide consists of Juana Díaz Formation Chalk Member and underlying Mudstone Member. The Mudstone member contains highly plastic and expansive clays (montmorillonite).

Geotechnical recommendations include flattening the slope to 6H:1V and adding a drainage key.

Figure 16. Slope failure PR-9 Ponce. (Stop #3)

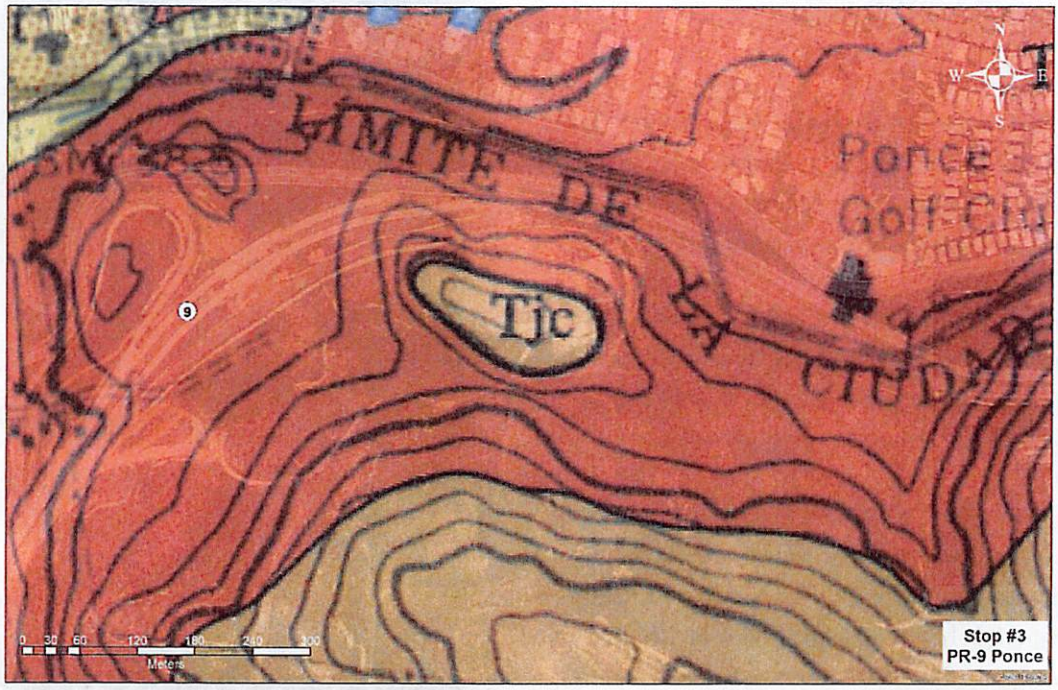


Figure 17. Geologic map of the Ponce Quadrangle, PR-9 Ponce. (Stop #3)

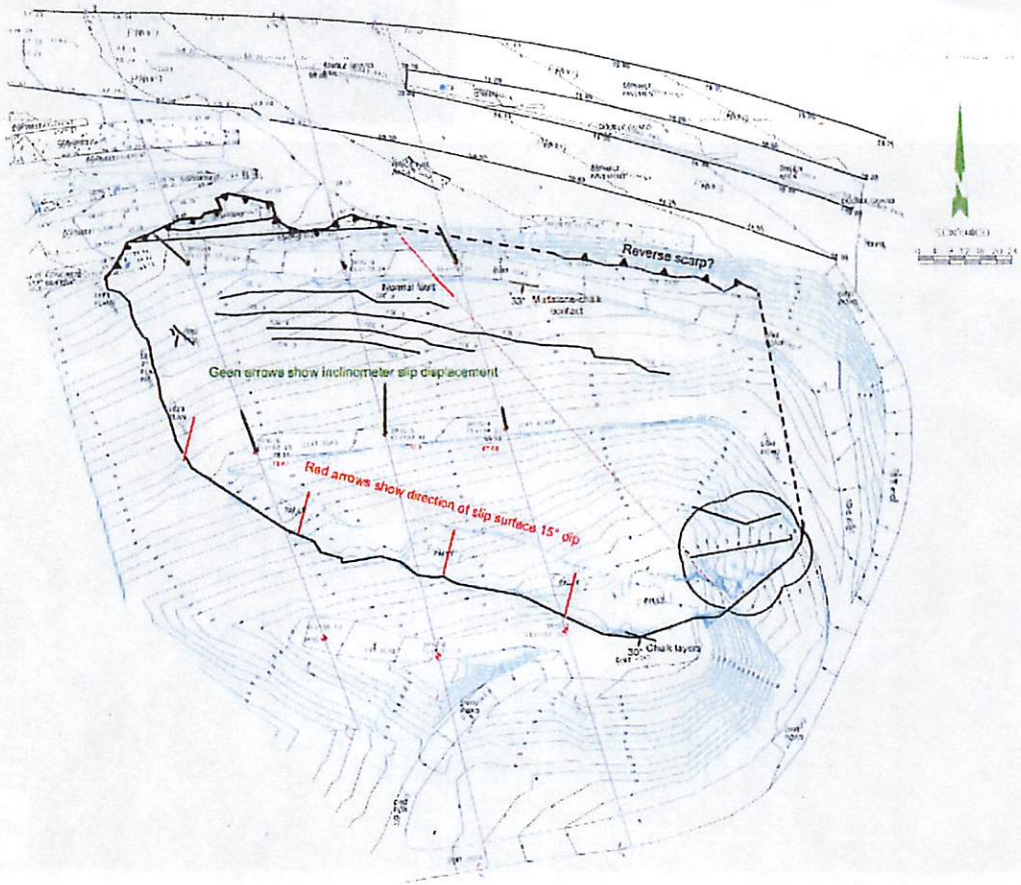


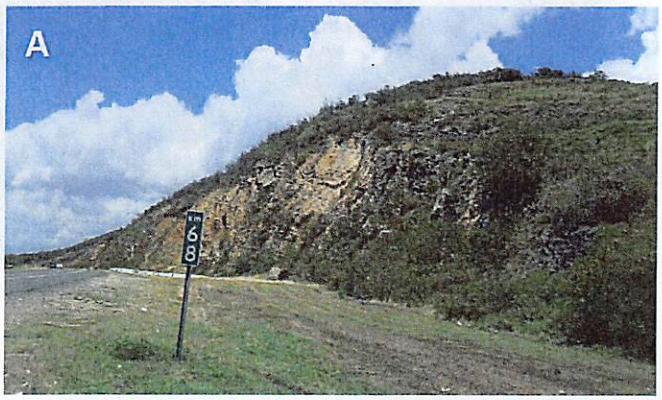
Figure 18. Map of landslide at PR-9 Ponce. (Stop #3)

Toll Highway PR-52 Ponce – San Juan

Highway PR-52, also known as "*Autopista Luis A. Ferré*" is a major toll road that connects highway PR-1 in San Juan to highway PR-2 in Ponce. Its total length is 108 kilometers (67 miles). It was build between 1968 and 1975. Highway PR-52 is part of Interstate PRI-1.

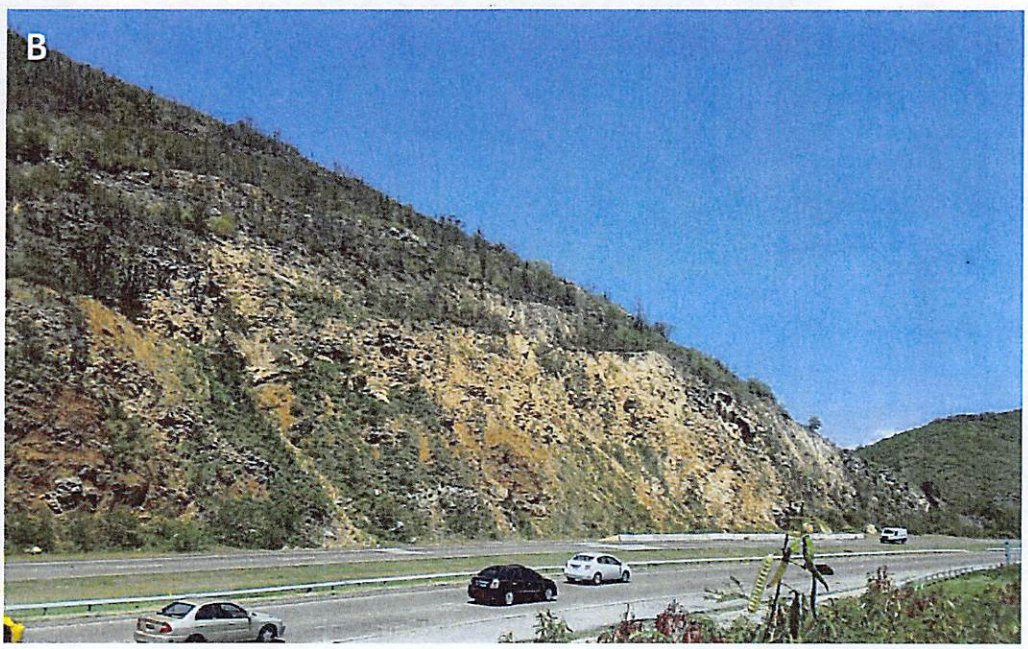
Stop #4 – PR-52 Km 68.3 Salinas

Aerial photographs show that this slope was cut as early as 1971. The material extracted from the site was used as fill in the construction of other sections of highway PR-52



Photographs A and B show a view of the slope towards the west and towards the east, respectively. Figure 19 shows that the slope was already inventoried and assigned a preliminary rating of A.

Figure 20 shows that the slope is composed of Cuevas Limestone, and close to several faults, including the Esmeralda Fault, which belongs to the great southern Puerto Rico fault zone



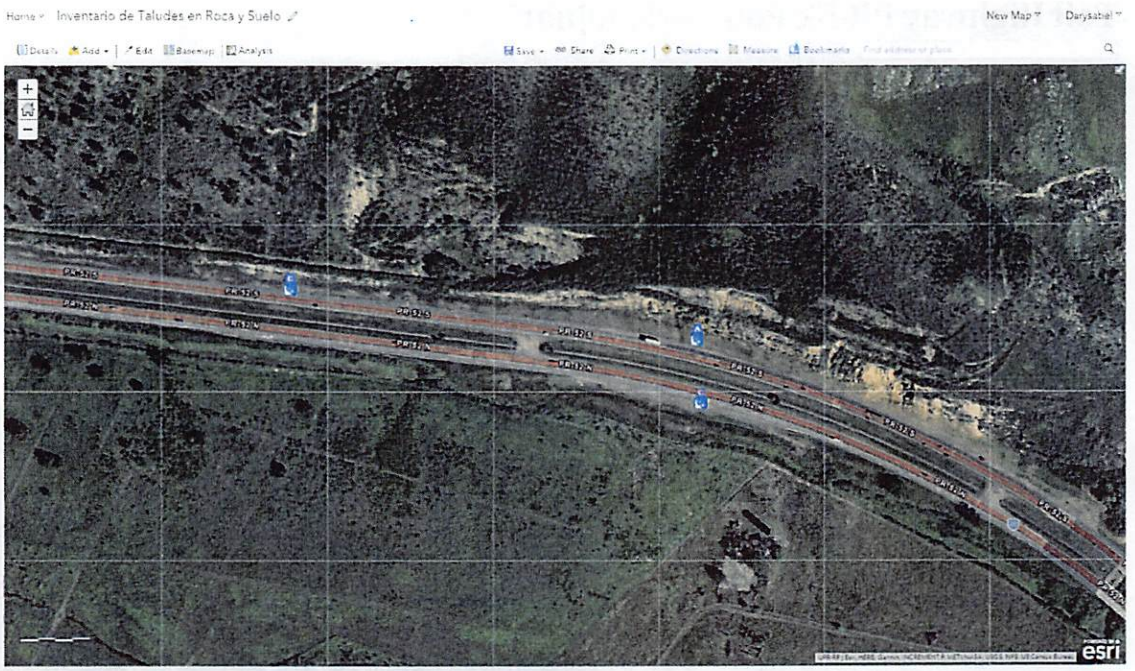


Figure 19. Inventoried slopes at PR-52 Km 68.3, Salinas. (Stop #4)

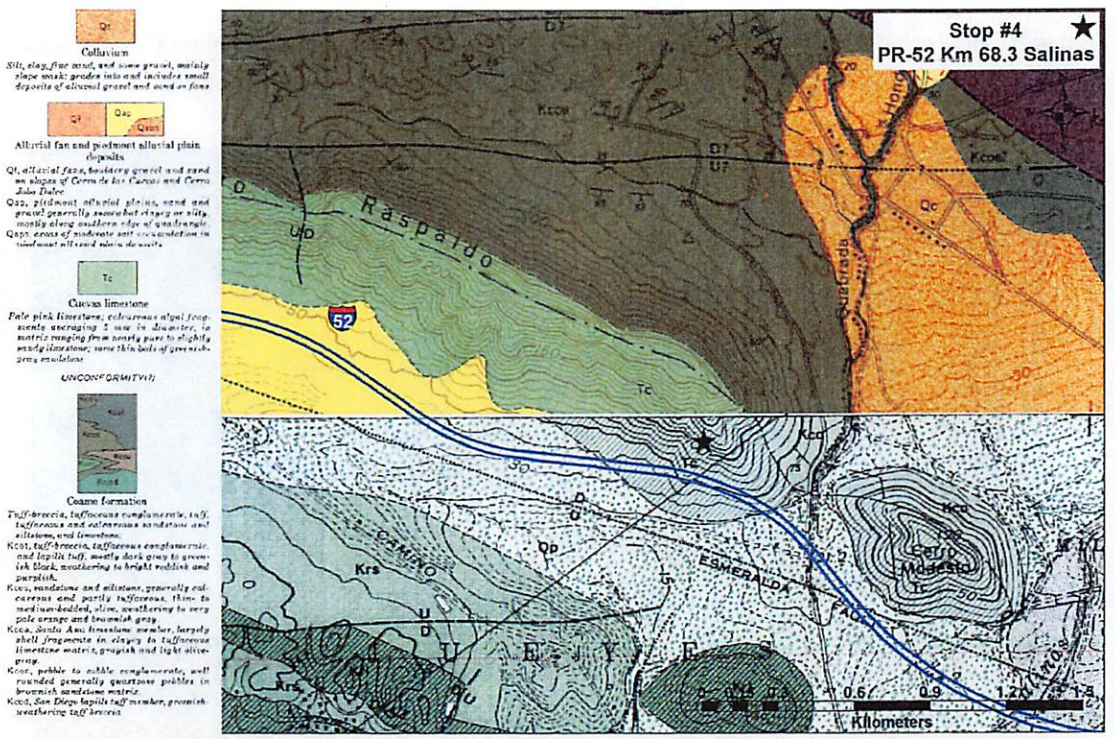


Figure 20. Geologic map of the Salinas and Coamo Quadrangles, PR-52 Km 68.3, Salinas. (Stop #4)

Stop #5 - PR-52 Km 52.3 Salinas

This rock slope (Fig. 22) has a total height of approximately 130 meters, including the rock cut and the natural slope above. And variable slope of 60° to 80°. The geology of the slope is composed of andesitic volcanic breccias (Kcvb) and flows (Kcf) of Formation C. (See figure 21)

This site poses many challenges including old steel mesh curtains of undetermined age that may require reinforcement or replacement. Multiple loose rocks can be seen stuck behind the steel mesh curtain and the natural slope above the cut is littered with loose rocks. There is virtually no rockfall catchment area.

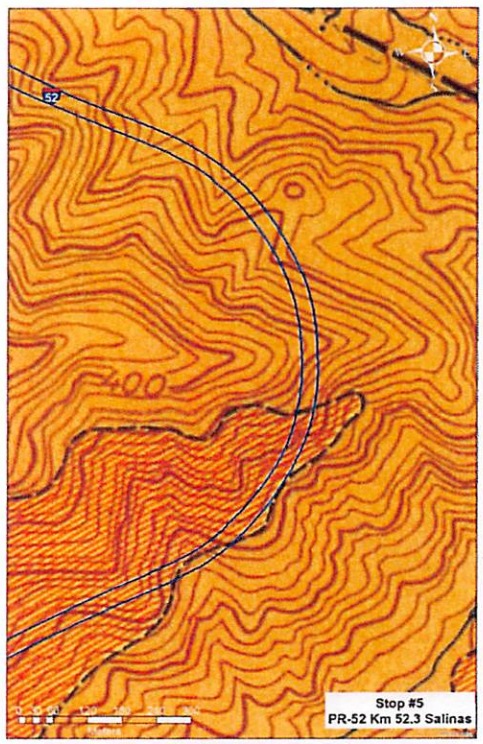


Figure 21. Geologic map of the Cayey Quadrangle, PR-52 Km 52.3, Salinas. (Stop #5)

Figure 22. Rock slope and rockfalls at PR-52 Km 52.3, Salinas. (Stop #5)