INTRODUCTION

Landslides in Puerto Rico have caused considerable damage to property and some loss of life. The industrial development of the island since 1950 has necessitated excavation of slopes that has produced many potentially dangerous areas. Landslides are relatively common in a variety of rock types. The largest slides, several hundred cubic meters in volume, happen where limestone rests on clay that becomes plastic when wet; mudflows and rockfalls, on the other hand, are common in areas of deeply weatherd volcanic and intrusive rock.

Puerto Rico is a tropical island, elongate east-west and lying between the Caribbean Sea and the Atlantic Ocean. A central mountainous upland is composed of extrusive and intrusive igneous rocks and minor amounts of limestone, sandstone, and conglomerate of Early Cretaceous to Eocene age. The upland separates belts of limestone of middle Tertiary age cropping out near the southern and northern coasts. Along the coasts, relatively narrow coastal plains (fig. 1) are made up of beaches, swamps, sand dunes, alluvial plains, and alluvial fans; these features consist of sand, gravel, and clay.

Different rock types and unconsolidated materials have different weathering characteristics. The alluvium, in general, is completely weathered to sand and clay. Limestone is dissolved in acid rainwater, and the impurities in the rock remain as a residuum of clay. Commonly the residual cover developed on limestone is washed away during heavy showers, leaving bare rock exposed. This exposed limestone is soon case hardened (Monroe, 1976, p. 17, 44), and further solution and weathering is retarded. The intrusive rocks, largely granodiorite and quartz diorite, weather very rapidly into ferruginous sandy clay, which is subject to rapid gullying; where the natural slope has been disturbed, small landslides occur. Residual boulders and corestones on much of the quartz diorite terrane are likely to move downhill during rainy periods. Corestones also form on some thicker lava and some tuffaceous sandstone. Most of the other rocks, such as lava, volcanic breccia, tuffaceous sandstone, claystone, siltstone, and conglomerate made up of volcanic debris, weather into tough clay that resists gullying. In the central mountainous portion of the island, the weathered material has been eroded into deep canyons; the walls of the canyons slump in massive landslides.

INCIDENCE OF LANDSLIDES

The term "landslide" is broadly defined as any "downward and outward movement of slope-forming materials composed of natural rock, soils, artificial fills, or combinations of these materials. The moving mass may proceed in any one of three principal types of movement: falling, sliding, or flowing, or by their combinations" (Varnes, 1958, p. 20). Landslides and areas susceptible to landsliding are common in many parts of Puerto Rico. An index map (fig. 2) shows names and authors of 27 published geologic maps of quadrangles that include mapped landslides, mudflows, and "colluvium." In some other quadrangles, landslides are present but were not mapped. Landslides in Puerto

[COL1B]

[COL2]

Areas of moderate susceptibility.—Most of the area mapped as having moderate susceptibility can be considered stable except where it is disturbed by steep-sided excavations; it also includes many unstable slopes that are near faults but are too small to map at the present scale. Because of the local complexity of the geology in the "moderate" area, detailed geologic maps and accompanying tables (Briggs, 1971; Pease and Briggs, 1960; and Briggs and Gelabert, 1962) should be consulted before beginning excavations in any part of the area.

Many natural slopes in the "moderate" category are unlikely to be unstable, but may slide if steepened by excavating. In this category is the slope of Rio Piedras Siltstone (Pease and Monroe, 1977) that collapsed and destroyed several houses at the foot of an east-west ridge about 4 km east southeast of Rio Piedras in 1970. Usually the Rio Piedras is stable except for soil creep, but the excavation for streets and houses created a steep slope that moved as a combination landslide and mudflow after a heavy rain.

Areas in which the rocks have been weathered to soil or to saprolite, which at places is more than 30 m thick, may be stable until excavation disturbs the stability (Briggs, 1971). Then heavy rainfall will nearly always cause minor sliding into road cuts; in some areas, heavy rainfall will cause entire roads to slide downhill, as happened at one place on Puerto Rico Route 157, 4.5 km west northwest of Orocovis (Briggs, 1971); this road is not shown on accompanying map. Shattering of the rocks along the Damien Arriba fault led to development of a thick plastic soil that in itself is unstable; excavation for a highway made the slopes too steep to stand, and the highway slipped several times into a nearby steep-sided valley. A somewhat similar situation on a new road from Caguas to Cidra in the east-central part of Puerto Rico caused successive slides that stopped only after several road relocations resulted in a gentler grade.

Rockfalls (too small to map) are hazards on almost all slopes steeper than 75 percent in the area of moderate susceptibility, and they are almost impossible to foresee. They are especially common where steep slopes are overlain by corestones formed by weathering of intrusive rocks and of some lava beds. Conditions leading to movement of corestones can be anticipated, and warnings of the danger of falling rock on roads along the sides or bottoms of canyons is practicable. Rockfalls on Puerto Rico Route 167, along the Río de La Plata between Bayamón and Comerío, have destroyed cars and have killed the drivers.

Areas of low susceptibility.—The areas of low susceptibility to landsliding are nearly flat or are underlain by unweathered stable rock. Most of the alluvium, the coastal deposits, such as beach deposits, swamp deposits, and the very wide alluvial fans along the southern coast of Puerto Rico are so flat that there is little need to make large excavations for highways and other structures. Most of the materials are unconsolidated and have such low stability that any deep excavation is likely to cave in. Included in the "low" category along the Atlantic coast are extensive deposits of dune sand and eolianite, both of which have steep slopes. Excavations into these materials may lead to slides. Because the deposits are thin, collapse generally does not involve structures, but there is a slight danger that people could be buried by collapse of deep road cuts.

The most stable rock in Puerto Rico is unweathered limestone. Along the northern and southern coasts, large areas are underlain by limestone of Oligocene and Miocene age, and in the interior there are several deposits of Cretaceous and Eocene limestone. Most deep road cuts do not collapse or slough off because after a few months the limestone becomes case hardened by solution and immediate reprecipitation in place (Monroe, 1976, p. 17, 44). Although the limestone itself is not subject to landsliding, limestone blocks are involved in the large active slides where limestone rests on clay that becomes plastic when wet. In some large sinks having nearly vertical sides, limestone spalls off the walls, and excavations in such places may be hazardous. The only sink of this type that has been excavated is at the Arecibo Ionospheric Observatory, 14 km south of Arecibo, but to date there have been no rockfalls into the bowl.

Offshore islands.—Most of the small islands around Puerto Rico have slopes that are either too gentle to offer much danger from landslides or that have been so beaten by heavy storms that highly weathered material has been eroded away. The exceptions are Culebra and Vieques, east of Puerto Rico, and Isla de Mona west of Puerto Rico. All three islands have relatively little rainfall.

Isla de Mona (Briggs and Seiders, 1972) is composed of limestone and dolomite, except on the southern side where there is a narrow sandy coastal plain. On the eastern, northern, and western coasts nearly vertical cliffs of dolomite and limestone rise about 20–80 m directly out of the sea. Erosion

[COL4]

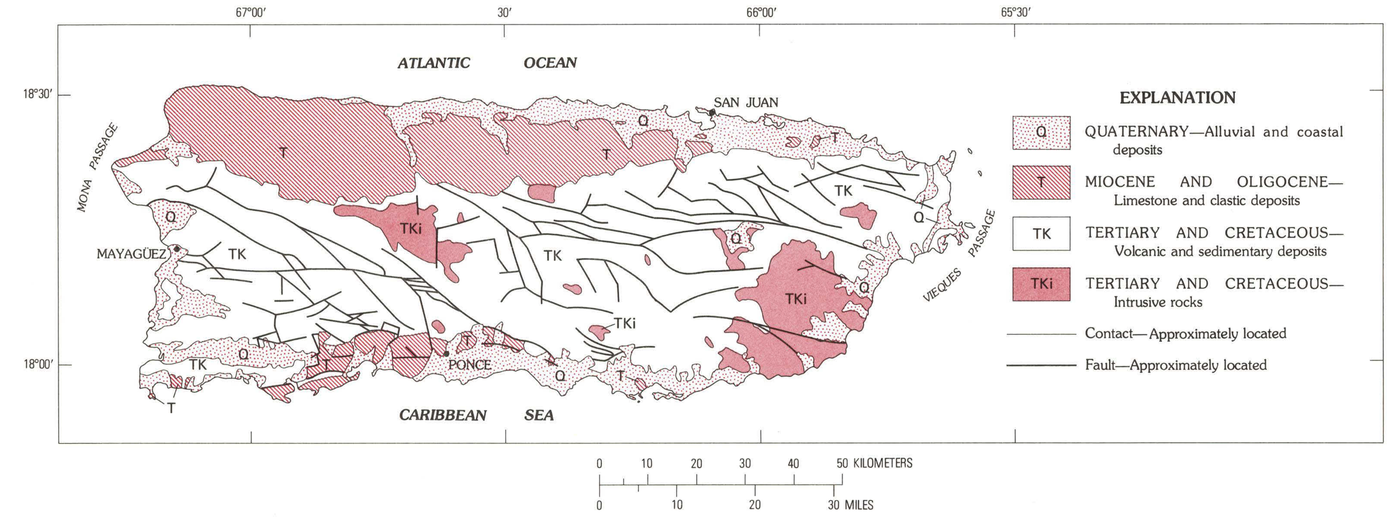

FIGURE 1—GENERALIZED GEOLOGIC MAP OF PUERTO RICO

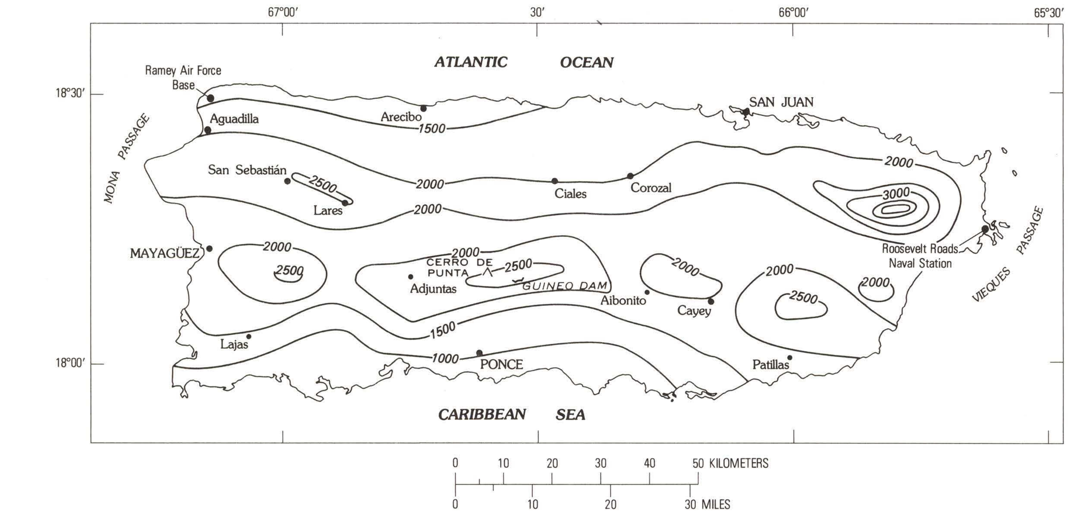

FIGURE 3— MAP SHOWING ANNUAL RAINFALL IN PUERTO RICO, CONTOURED IN MILLIMETERS. (Data from U.S. National Weather Service)

FIGURE 2—MAP OF PUERTO RICO SHOWING 7½ MINUTE QUADRANGLES. (Geologic maps of quadrangles in which landslides are mapped, are referenced)

Base from U.S. Geological Survey, 1952

Map compiled by W. H. Monroe, 1977

MAP SHOWING LANDSLIDES AND AREAS OF SUSCEPTIBILITY TO LANDSLIDING IN PUERTO RICO

By

Watson H. Monroe

1979

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