CHAPTER 3 AFFECTED ENVIRONMENT

3.1 INTRODUCTION

According to the National Environmental Policy Act (NEPA) (40 Code of Federal Regulations [CFR] § 1502.15) "the Environmental Impact Statement shall succinctly describe the environment of the area(s) to be affected or created by the alternatives under consideration." Potential impacts cannot be determined without first understanding the existing conditions in the affected environment. For this reason, the impact analysis process involves two steps—identifying the affected environment and detailing the potential environmental consequences resulting from the alternatives. The geographic extent of the affected environment is determined by the potential for impacts to affect components of the human, natural, and cultural environment. From this point forward, these human, natural, and cultural components are referred to collectively as resource categories. Depending on the resource category, the extent of the affected environment/region of influence may differ. For instance, the proposed action may have impacts on soils within specific areas of the Military Lease Area; however, air pollutants generated by the proposed action would include areas downwind of the proposed action and could possibly influence the regional air quality. Following the affected environment discussion, Chapter 4 details the magnitude of potential impacts or "environmental consequences" of the proposed action on the resource categories.

3.2 GEOLOGY AND SOILS

Section 3.2 describes the geology and soils in the region of influence for the proposed action. The geology and soils of the islands of Tinian and Pagan including the adjacent marine geology and sediments (out to a distance of 1,000 feet [300 meters]) comprise the region of influence for this resource. This distance from shore for marine geology and sediments is based on the footprint of amphibious training under the proposed action. Geology and soils include the natural physical characteristics of the land forms (topography), the underlying soils and rocks (structural geology), and any associated geologic hazards.

3.2.1 Definition

The discussion of this resource includes an overall description of the regional geological setting as well as a description of the topography, geology (geologic units and hazards), and soils associated with the region of influence (i.e., Tinian and Pagan). These terms are defined below.

- ***Topography*** - the natural and man-made features of a place or region that show relative positions and elevations at the earth's surface.
- ***Geology*** - the bedrock materials, mineral deposits, and fossil remains of an area.
- ***Geologic Unit*** - a volume of rock of identifiable origin or age that is defined by the distinctive, dominant, easily mapped, and recognizable physical characteristics and features that characterize it.

- ***Geologic Hazards*** - one of several types of adverse geologic conditions capable of causing damage or loss of property and life. This includes adverse results of seismic activity (e.g., earthquakes or fault ruptures), liquefaction, volcanic activity, landslides, tsunamis, and sinkholes.
- ***Soils*** - unconsolidated earthen materials overlying rock.
- ***Erodibility*** - it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff.
- ***Runoff Rate*** - speed at which water that is not absorbed by the soil travels over and off the surface.
- ***Impervious Surfaces*** - surfaces covered or compacted to the point that water cannot be absorbed by the soil.
- ***Karst*** - landscape underlain by limestone that has been eroded by dissolution, producing ridges, towers, fissures, sinkholes, and other characteristic landforms.
- ***Sink Hole*** - a depression or hole in the ground caused by some form of collapse of the surface layer.

3.2.2 Regulatory Framework

The regulatory framework governing geologic and soil resources is listed below. A complete listing of applicable regulations is provided in Appendix E, *Applicable Federal and Local Regulations*. The United States (U.S.) Army Corps of Engineers and the U.S. Environmental Protection Agency are the primary federal agencies with jurisdiction over geological and soil resources. Within the Commonwealth of the Northern Mariana Islands (CNMI), the CNMI Bureau of Environmental and Coastal Quality is the administrative authority for the Clean Water Act. The U.S. Department of Agriculture is the regulatory entity with oversight of the Farmland Protection Policy Act. The Department of Defense adheres to Unified Facility Criteria 3-310-04 which provide planning, design, construction, sustainment, restoration, and modernization criteria. Federal and local regulations and codes that serve to protect, conserve, and manage geological and soil resources are listed below.

3.2.2.1 Federal Regulations and Codes

- Clean Water Act
- Farmland Protection Policy Act, 7 U.S. Code § 4201 regulated by the U. S. Department of Agriculture
- Unified Facility Criteria 3-310-04

3.2.2.2 CNMI Regulation

- CNMI Earthmoving and Erosion Control Regulations
- Water Quality Standards
- Drinking Water Regulations
- Well Drilling and Well Operation Regulations

3.2.3 Methodology

Reports, studies, and data sets prepared by or for the federal government, the CNMI government, and independent researchers which address natural resources (e.g., geology, soils, groundwater) and infrastructure (e.g., utilities) on Tinian and Pagan were reviewed for information related to the existing condition of geological and soil resources. All topography, geologic units, geologic hazards, and soils identified during literature review which could be potentially affected by the proposed action are described below. Federal and CNMI regulations were reviewed for regulations that serve to protect, conserve, and manage geological and soil resources.

3.2.4 Regional Geologic Setting

The islands of Tinian and Pagan are located on a volcanic arc adjacent to the Mariana Trench subduction boundary where tectonic plates converge. "Tectonic plates" are massive pieces of the earth's crust and upper mantle that move and come in contact with each other on the Earth's surface. A "subduction boundary" occurs where the edge of a denser plate moves under a less dense tectonic plate. The Mariana Trench and the Mariana Islands are part of an active subduction zone where the more dense Pacific Oceanic (tectonic) Plate, moving northwest, passes beneath the less dense Philippine Plate, moving west-northwest (Figure 3.2-1). These plates are constantly moving, resulting in many geologic phenomena (i.e., earthquakes, tsunamis, and volcanic activity) that originate where the moving plates encounter each other. During the past century, more than 40 earthquakes of magnitude 6.5 to 8.1 on the Richter Scale have occurred in the Mariana Trench region (Trusdell et al. 2006) and several of the islands feature active volcanoes.

The geology of individual islands in the Mariana Islands is largely dependent on the degree of volcanic activity present. The older, southern islands, including Tinian, generally consist of a volcanic core that was covered by coralline limestone in layers up to several hundred feet thick, which formed as the volcanic core was exposed above the ocean surface. Uplifting of the Philippine Plate resulted in the limestone caps being pushed several hundred feet above sea level. In some locations, the volcanic cores of these southern islands are exposed by the results of either volcanic activities or erosion of the limestone. The younger (northern) islands, including Pagan, generally consist of exposed volcanic cones (i.e., conical hill produced by volcanic eruptions) and calderas (i.e., large crater formed by volcanic explosion or collapse).

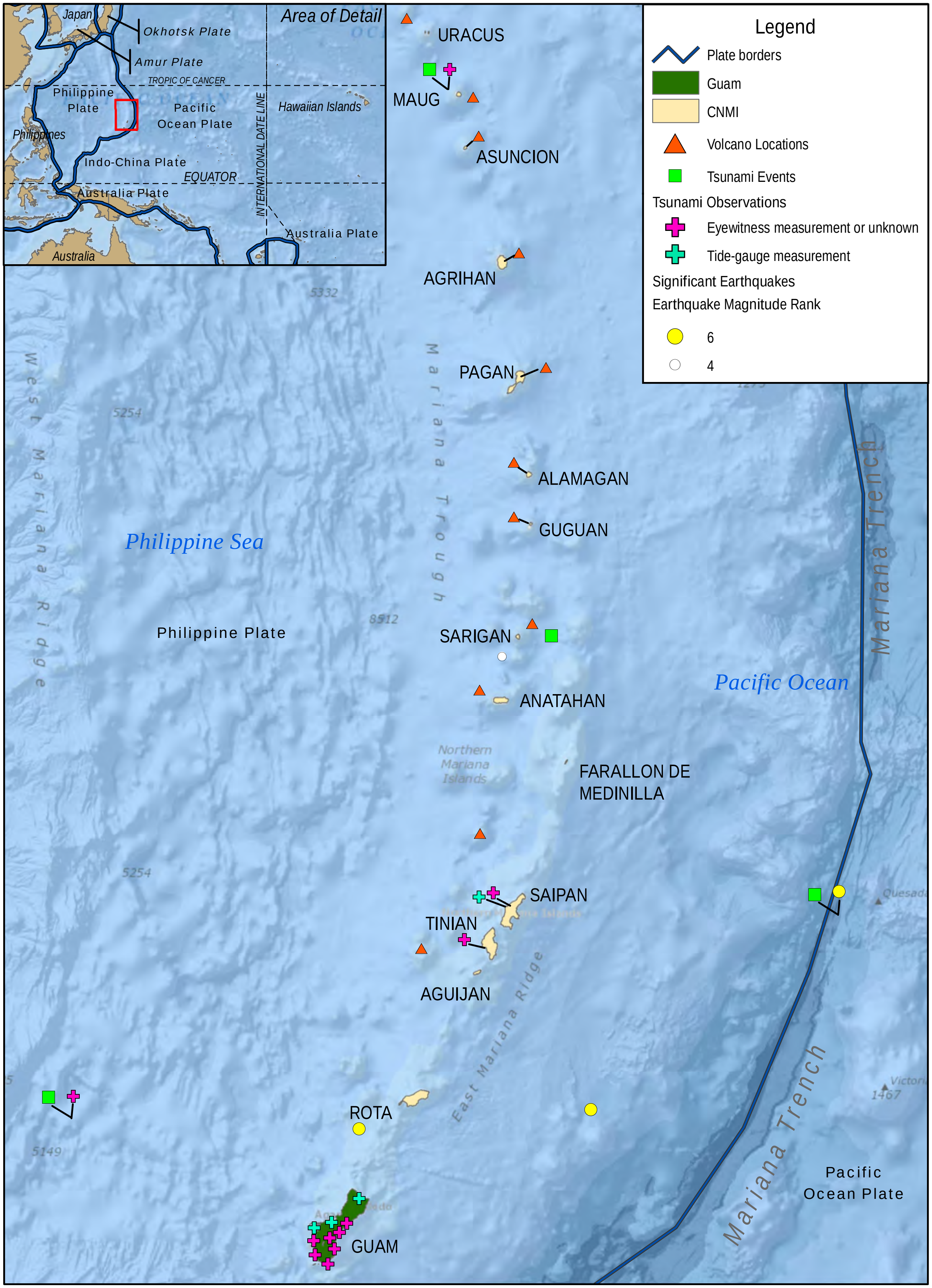

Figure 3.2-1

Regional Geologic Map of the Mariana Islands

Source: National Oceanic and Atmospheric Administration National Geophysical Data Center 2013

3.2.5 Tinian

3.2.5.1 Topography

Tinian is about 12 miles (19 kilometers) long and 6 miles (10 kilometers) wide. It is composed of a series of limestone plateaus separated by steep slopes and cliffs (Young 1989). The surface landforms can be divided into five major physiographic areas described below and shown on Figure 3.2-2 (Doan et al. 1960; Gingerich 2002).

- **Southeastern Ridge:** This land feature is the southernmost topographic feature on the island and includes Mount Kastiyu, the highest part of the island at 614 feet (187 meters). It has steep slopes and cliffs as high as 500 feet (150 meters).
- **Median (Marpo) Valley:** A low, broad depression located north of the Southeastern Ridge, this area has a maximum elevation of 150 feet (46 meters). This area includes San Jose Village.
- **Central Plateau:** This land area extends northward from Marpo Valley and includes all of central Tinian and portions of northern Tinian. The plateau is broad and gently sloping with the majority of the vertical relief at its southern and northern boundaries. This area includes the Tinian International Airport and portions of the Military Lease Area.
- **North-Central Highland:** This land area is located within the northern part of the Central Plateau and midway between the east and west coasts of the island. The maximum elevation is 545 feet (166 meters) at Mount Lasso.
- **North Lowland:** This land area is located at the very northern part of the island. It is generally flat with an average elevation of about 100 feet (30 meters), except for Lake Hagoi, where the elevation is approximately at sea level.

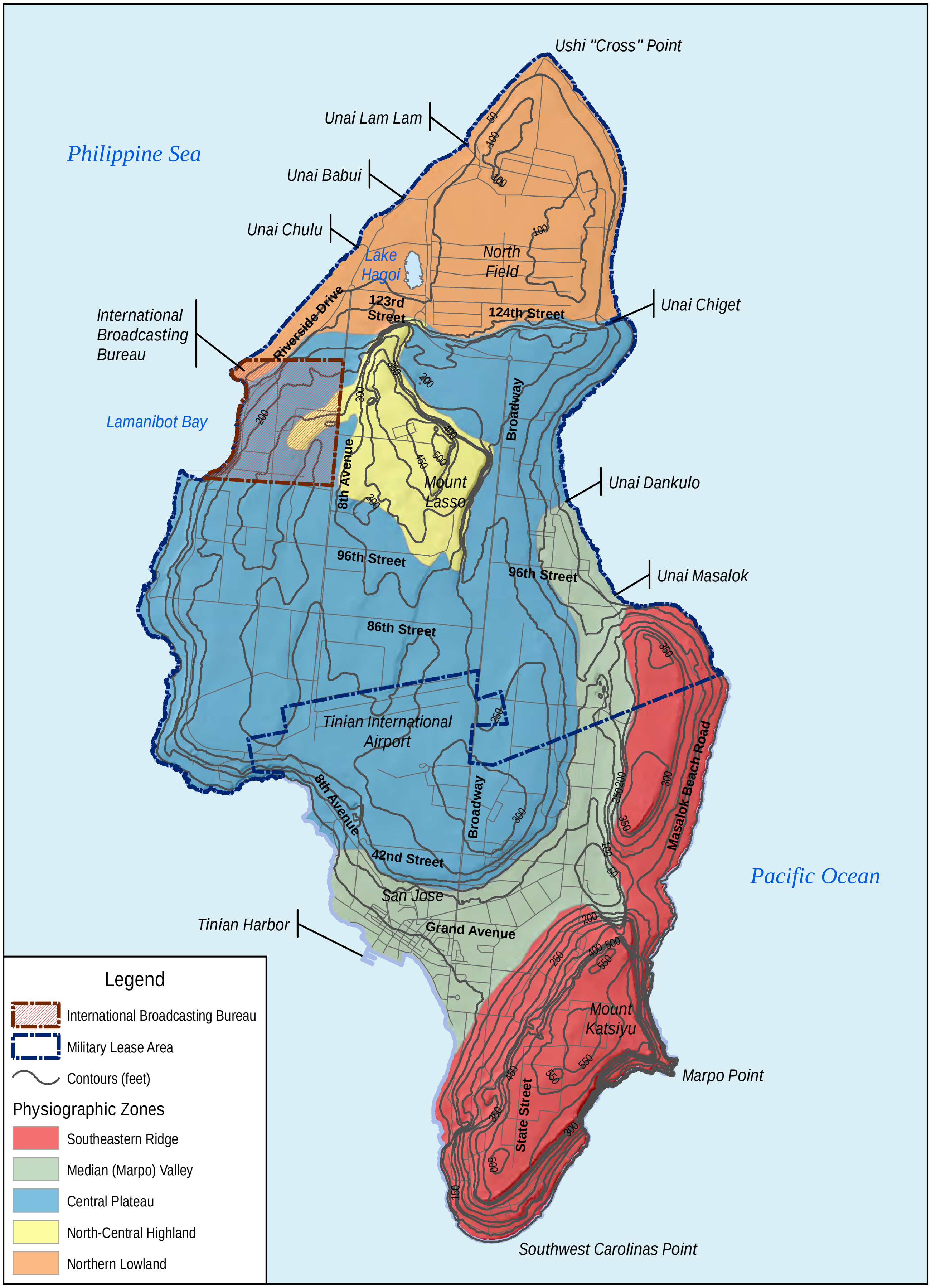

Figure 3.2-2
Tinian Physiographic and Topographic Map

Source: Gingerich 2002

3.2.5.2 Geology

3.2.5.2.1 Geologic Units

Tinian represents an extinct volcanic core (greater than 38 million years old) covered by younger limestone formations (5 to 23 million years old) and recent beach and reef deposits. The island is composed mainly of coralline and algal limestone overlying volcanic rock. The volcanic rock is only observable at ground surface in two localized areas in the vicinity of Mount Lasso (Figure 3.2-3) (Gingerich 2002). The limestone is highly porous, so water easily flows through it (Gingerich 2002). The raised limestone plateaus that characterize the island are evidence of uplifting caused by movement along high-angle normal faults. Figure 3.2-3 shows the four major geologic units that comprise Tinian. They are explained below.

- **Tinian Pyroclastic (volcanic) Rock:** These fine-grained to coarse-grained ash and angular fragments represent volcanic explosive materials ejected from an ancient (extinct) volcano that forms the core of the island. These rocks are exposed on the North-Central Highland and Southeastern Ridge and cover about 2 percent (%) of the surface of the island. These materials are generally highly weathered and are altered to clay in surface exposures. Because of its texture and density, this rock unit has low permeability (i.e., water does not flow easily through it).

- **Tagpochau Limestone:** These rocks are exposed on approximately 15% of the island's surface, generally in the North-Central Highland and the southern part of the Southeastern Ridge. This formation reaches thicknesses of up to 600 feet (180 meters). It is composed of fine to coarse-grained, partially recrystallized broken limestone fragments and approximately 5% reworked volcanic fragments and clays. This formation is very porous and water flows easily through it.

- **Mariana Limestone:** This formation covers approximately 80% of the island's surface, forming nearly all of the North Lowlands, the Central Plateau, and the Marpo Valley. This formation reaches thicknesses up to 450 feet (140 meters). It is composed of fine to coarse-grained fragmented limestone, with some fossil and algal remains, and small amounts of clay particles. Small voids and caverns are common in surface exposures. The Mariana Limestone has a higher coral content than the Tagpochau Limestone but is similarly porous, allowing water to readily flow through it.

- **Beach Deposits, Alluvium, Colluvium, and Marsh:** These deposits cover less than 1% of the island's surface and reach a thickness of up to 15 feet (5 meters). The deposits are made up of poorly consolidated sediments, mostly sand and gravel deposited by waves. However, they do contain clays and silt deposited inland at Lake Hagoi and Makpo Marsh, as well as loose soil and rock material found at the base of slopes.

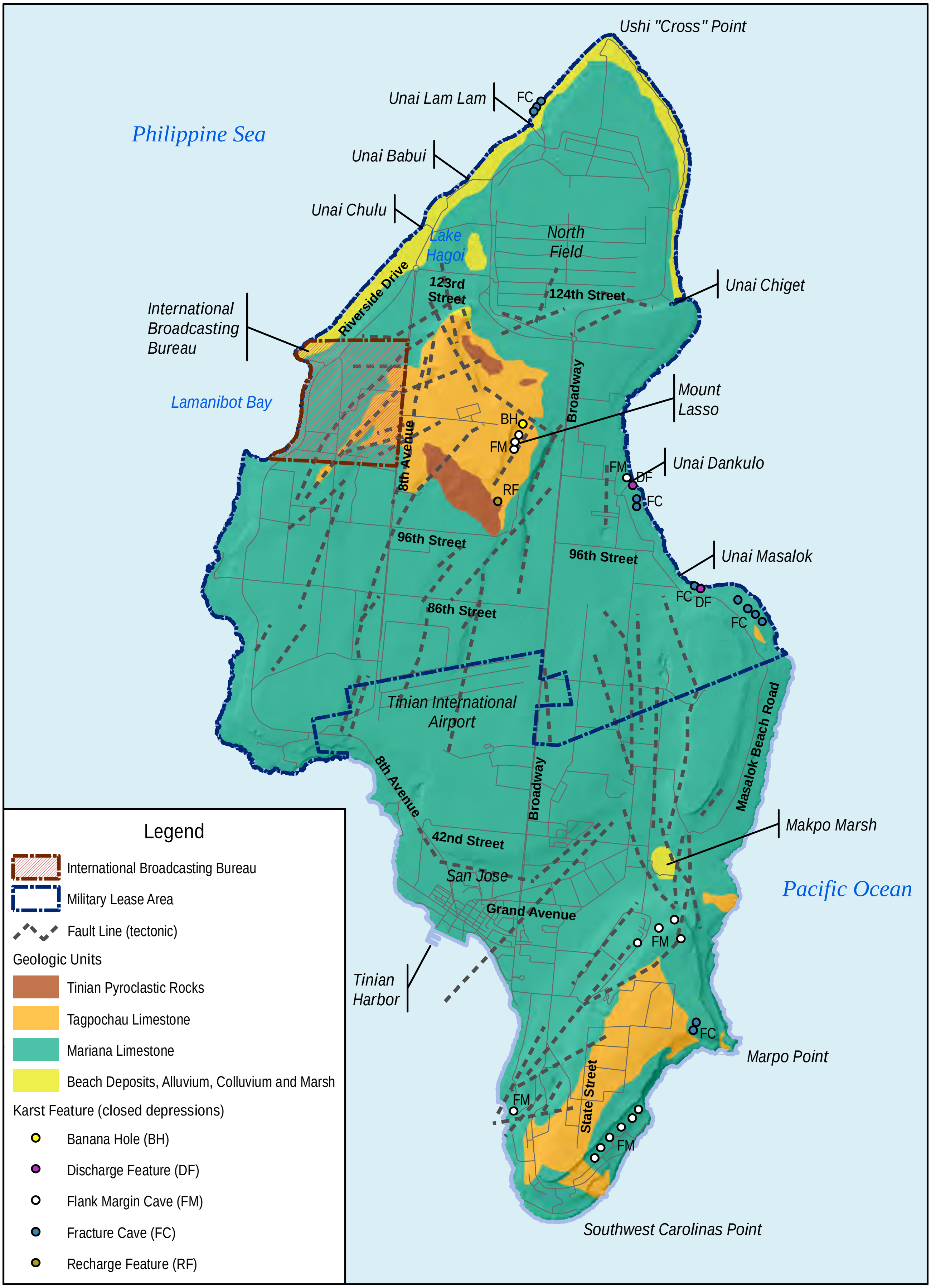

Figure 3.2-3
Tinian Geologic Units

Sources: Gingerich 2002; Water and Environmental Research Institute 2002

3.2.5.2.1.1 Coastal Geology

Photo 3.2-1. View of typical Tinian coastline with limestone cliffs

The majority of the Tinian coastline is characterized by limestone cliffs (Photo 3.2-1) with sea-level caverns, notches, cuts, and slumped materials (i.e., materials that have collapsed or fallen) commonly bordered by intertidal limestone benches (elevated flat areas). Beach deposits are mostly medium-to-coarse grain calcareous sands, gravels, and rubble interspersed over exposed limestone. Submarine topography is characterized by limestone with interspersed coral colonies and occasional submerged boulders. A more thorough discussion of the coral reef is presented in Section 3.10, *Marine Biology*.

There are four beaches proposed for different types of amphibious training (see Section 2.4.1.3.6), all of which are located within the Military Lease Area. They are described below, depicted on Figure 3.2-4, and further described in Section 3.10, *Marine Biology*.

- **Unai Babui:** Located on the leeward (western) side of the island, it is approximately 200 feet (60 meters) long with a land area of approximately 0.08 acre (0.03 hectare).
- **Unai Chulu**: Located on the leeward (western) side of the island, it is approximately 790 feet (240 meters) long with a land area of approximately 3 acres (1 hectare).
- **Unai Lam Lam:** Located on the leeward (western) side of the island, it is approximately 55 feet (17 meters) long with a land area of approximately 0.1 acre (0.04 hectare).
- **Unai Masalok:** Located on the windward (eastern) side of the island, it comprises three beaches covering a distance of 1,600 feet (370 meters) and 0.2 acre (0.1 hectare).

3.2.5.2.1.2 Karst Geology

Karst is a distinctive landscape formed when water dissolves rocks. This creates large voids, such as sinkholes and caves, as well as smaller features characterized by rough surfaces, little soil, and small cavities known as epikarst. The epikarst commonly acts as a conduit for surface water (such as rainfall) to the underlying groundwater aquifer by percolation or channelization through connected subsurface voids or cavities.

Figure 3.2-4
Proposed Amphibious Training Beaches on Tinian

Epikarst that is not ordinarily saturated by groundwater or surface water may provide a large amount of water storage in voids and cavities. The fast flow of water through the joints and channels of epikarst does not allow for adsorption (by soil), uptake (by plants), or microbial processes to occur that would ordinarily remove pollutants contained in surface waters before they reach groundwater (Islam 2005). Karst geology on Tinian includes epikarst, closed depressions (e.g., sinkholes), caves, and freshwater discharge features (Stafford et al. 2005). Epikarst is present in all of the limestone rock formations on Tinian and its characteristics vary based on proximity to the coast. Coastal epikarst is jagged as result of the effects of sea spray, while inland epikarst surface features become less extreme (Stafford et al. 2005). Sinkholes, a type of epikarst, can occur naturally or as a result of excavation, change in drainage patterns, or lowering of the groundwater table (Islam 2005); sinkholes can occur anywhere within the limestone formations on Tinian. Caves can form in limestone deposits in the mixing zone of the salty groundwater and fresh groundwater lens. These caves are present along portions of Tinian's coast.

There are three main types of closed depressions on Tinian: (1) dissolutional (when water dissolves rock); (2) constructional (caused by faulting or certain rock formations); and (3) man-made or modified (e.g., excavations such as quarries, borrow pits, or landfills). Twenty closed depressions were identified during the 2005 karst survey (Stafford et al. 2005), in both inland and nearshore locations on Tinian: 7 of them were identified as dissolutional, 8 constructional, and 5 man-made or modified. Figure 3.2-3 provides the locations of the closed depressions identified in the karst survey.

3.2.5.2.2 Geologic Hazards

Potential geologic hazards on Tinian include seismic activity (e.g., earthquakes along faults), liquefaction, landslides, tsunamis, and karst features (e.g., sinkholes). Additional information on these hazards is provided in the following sub-sections.

3.2.5.2.2.1 Seismic Activity

An earthquake is caused by the sudden slip of a fault that results in ground shaking and radiated seismic energy caused by the slip; volcanic or magmatic activity; or other sudden stress change in the earth's crust (U.S. Geological Survey 2013). Faults on Tinian are shown in Figure 3.2-3. In addition, there are several nearby faults along the ocean floor that could potentially cause significant earthquakes felt on Tinian. There have been 13 destructive earthquakes in the Mariana Islands during the past two centuries (Mueller et al. 2013) with the majority of the recorded impacts (i.e., property damage, injuries) felt on Guam (approximately 130 miles [225 kilometers] to the south).

3.2.5.2.2.2 Liquefaction

When loose sand and silt is saturated or partially saturated with water and shaken by an earthquake it can behave like a liquid; this is known as earthquake liquefaction. The soil can lose its ability to support structures, flow down gentle slopes, and erupt to the ground surface to form sand boils (i.e., upward movement of sand). This can cause damage to buildings, roads, and pipelines. Three factors are required for liquefaction to occur: (1) loose, granular sediment is present; (2) the sediment is saturated or partially saturated by groundwater (i.e., water fills the spaces between sand and silt grains); and (3) strong shaking occurs (i.e., from a strong earthquake). Typically, liquefaction occurs in areas where there are loose soils with poor drainage. On Tinian, these conditions could be present on fill land located near the coast (e.g., Port of Tinian).

3.2.5.2.2.3 Landslides

The term landslide includes a wide range of ground movement such as rock falls, deep failure of slopes, and shallow debris flows. Earthquakes of magnitude 4.0 and greater are known to trigger landslides (U.S. Geological Survey 2013). Tinian has numerous fault scarps depicted as "fault lines" on Figure 3.2-3. These are related to the uplift of the limestone formations as a result of tectonic activity in the region. In general, the consolidated nature of the limestone and volcanic units reduce the potential for slope failure; however, there is a potential for slope failure to occur due to wet tropical weather on Tinian combined with weathered rock and steep cliffs along the island's perimeter, and areas of land disturbance.

3.2.5.2.2.4 Tsunamis

A tsunami is a sea wave that can result from large-scale seafloor displacements associated with large earthquakes, major submarine landslides, or volcanic eruptions. The Mariana Islands have had recorded tsunami events dating back to 1700 (Uslu et al. 2013). Doan et al. (1960) notes that Tinian is not likely to be vulnerable to tsunamis originating from distant earthquakes or landslides due to the geographic location and the close proximity to Saipan. However, Tinian may be vulnerable to those generated by disturbances along the volcanic axis (Mariana Islands) associated with the subduction zone at the Mariana Trench. Shocks emanating from this region have the potential to generate tsunamis capable of impacting the Tinian Harbor area and the low-lying Median Valley, or other areas not protected by coastal cliffs. On March 11, 2011, evacuations were ordered for low-lying areas in the CNMI in response to the earthquake and ensuing tsunami in Japan, no damage was reported.

3.2.5.2.2.5 Karst Features

Tinian exhibits several different types of karst features including naturally formed dissolution-type closed depressions or sinkholes, human modified depressions, and limestone caves. Figure 3.2-3 illustrates the location of karst features on Tinian mapped by Stafford et al. (2004). Due to the porous nature of the limestone formations that underlie much of the island, other unmapped karst features are likely to be present. These include sinkholes, caves, recharge features (i.e., voids in the rock that allow water to seep into the subsurface), and discharge features (i.e., voids in the rock where groundwater seeps out of the subsurface).

3.2.5.3 Soils

Soil classes across Tinian were identified by the U.S. Department of Agriculture Soil Conservation Service in 1985 (Young 1989). Figure 3.2-5 shows the horizontal distribution of these soil classes and Table 3.2-1 describes the soil characteristics within the affected environment (i.e., Military Lease Area, Tinian International Airport, and Tinian Harbor). Appendix F, *Geology and Soils Technical Memo* provides a detailed table and map showing the soil units associated with the soil classifications.

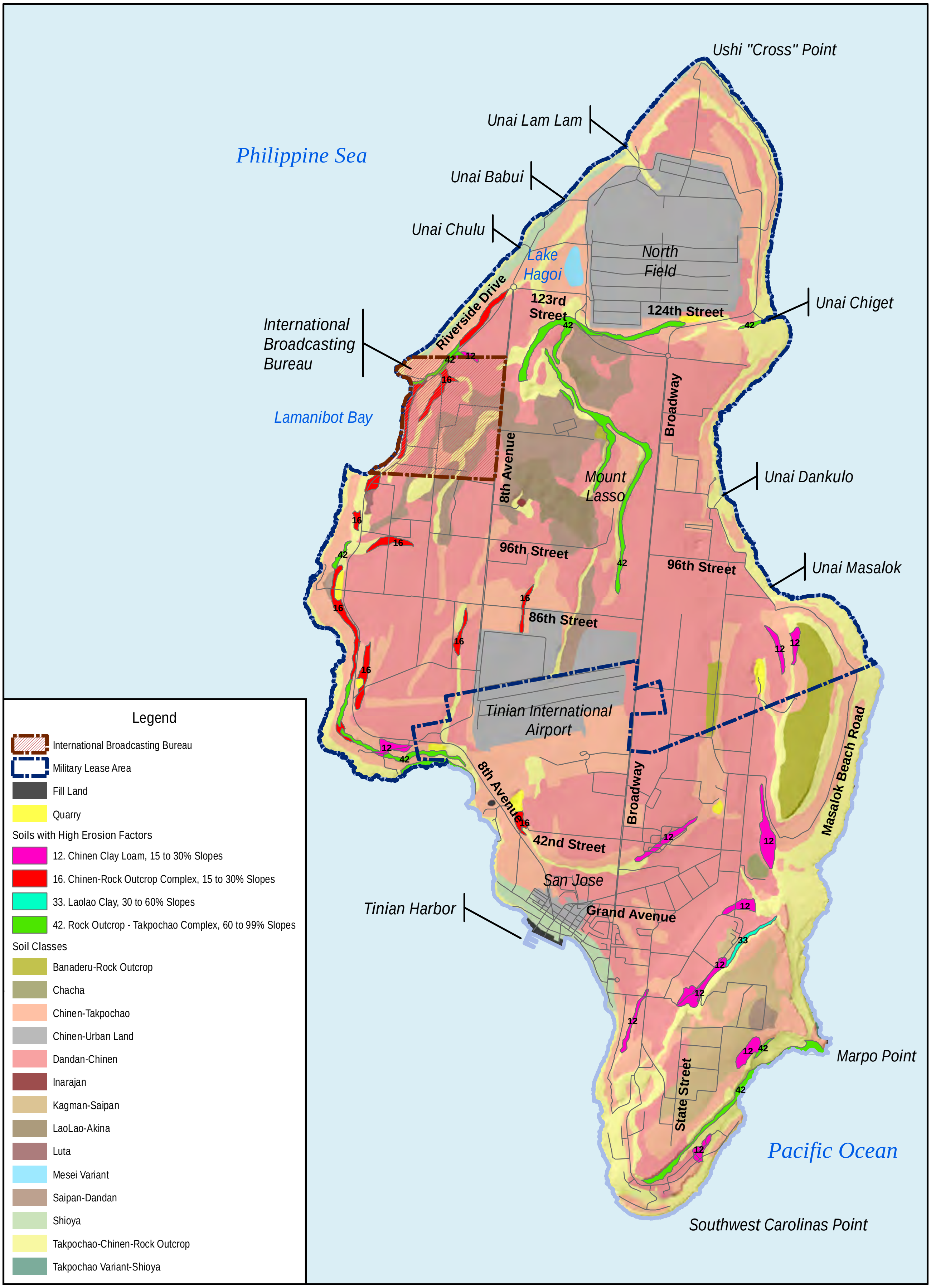

Figure 3.2-5
Tinian Soil Classes
Associated with the Affected Environment

Source: Young 1989

Table 3.2-1. Soil Classifications Associated with the Affected Environment

Soil Class	*Soil Description*	*Location*
Banaderu-Rock Outcrop	Shallow, well drained, nearly level, to moderately steep soils, and rock outcrop.	Limestone Plateaus
Chacha	Shallow and deep, and poorly drained, and found on steep slopes, plateaus, and hills.	Limestone Uplands
Chinen-Takpochao	Very shallow and shallow, well drained, nearly level to strongly sloping soils; on plateaus and side slopes.	Limestone Plateaus
Chinen-Urban Land	Shallow, well-drained, nearly level soils and urban areas.	Limestone Plateaus
Dandan-Chinen	Shallow and moderately deep, well drained, nearly level to strongly sloping soils.	Limestone Plateaus
Inarajan	Very deep, poorly drained soils.	Valley Bottoms and Coastal Plains
Kagman-Saipan	Deep and very deep, well drained, nearly level to strongly sloping soils.	Limestone Plateaus
Laolao-Akina	Moderately deep, well drained, strongly sloping to steep soils; on volcanic uplands.	Uplands
Luta	Very shallow, well drained, nearly level to strongly sloping soils.	Limestone Plateaus
Mesei Variant	Moderately deep, very poorly drained, level soils.	Depressional Areas
Rock Outcrop-Takpochao-Luta	Shallow and very shallow, well drained, strongly sloping to extremely steep soils and rock outcrop; on limestone escarpments.	Uplands
Saipan-Dandan	Moderately deep and very deep, well drained, nearly level to gently sloping soils.	Limestone Plateaus
Shioya	Very deep, excessively drained, level to nearly level soils; on coastal strands.	Coastal Limestone Sands
Takpochao-Chinen-Rock Outcrop	Shallow, well drained, strongly sloping to extremely steep soils and rock outcrop; on limestone escarpments and plateaus.	Uplands
Takpochao variant-Shioya	Very shallow to very deep excessively drained, levels to gently sloping soils; on coastal stands and plateaus.	Lowlands

Source: Young 1989.

Soil types and characteristics affect the potential for soils to erode. The U.S. Department of Agriculture defines soil erosion as the "removal of material from the surface soil, which is the part of the soil having an abundance of nutrients and organic material vital to plant growth." Natural causes of soil erosion include wind and water. Human and wildlife activities can accelerate soil erosion (Muckel 2004). There are several soil units in the vicinity of the proposed action (i.e., Military Lease Area, Tinian International Airport, and Tinian Harbor) that are characterized as having the greatest susceptibility for soil erosion. These soil units are generally located in areas with steep slopes and include the following: (1) Chinen Clay Loam (15-30% slopes); (2) Chinen-Rock Outcrop Complex (15-30% slopes); (3) Laolao Clay (30-60% slopes); and (4) Rock Outcrop-Takpochao Complex (60-99% slopes). These soil units are shown in Figure 3.2-5 and are further described in Appendix F, *Geology and Soils Technical Memo*.

Most of the soil units located in the vicinity of the proposed action are characterized by slow water runoff or the potential for water to pond. These characteristics can cause issues with flooding or problems with construction if adequate grading and drainage are not provided for structures and roads. These soil types are largely located on relatively gentle slopes. Their locations and further description are provided in Appendix F, *Geology and Soils Technical Memo*.

Prime farmland soils are soils that are best suited to producing sustained high yields of crops (Young 1989). Two prime farmland soil units have been identified in the vicinity of the proposed action (Figure 3.2-6): (1) Dandan-Saipan clays, (0-5% slope) and (2) Saipan clay (0-5% slope). Appendix F, *Geology and Soils Technical Memo* provides a description of these soil units.

3.2.6 Pagan

3.2.6.1 Topography

Pagan is about 10 miles (16 kilometers) long and 4 miles (6 kilometers) wide. The island consists of two stratovolcanoes joined by an isthmus (narrow strip of land) with a width of 1,980 feet (660 meters). Pagan's main topographic features are Mount Pagan (or North Pagan Volcano), 1,870 feet (570 meters) above mean sea level (MSL) (Photo 3.2-2) and South Pagan Volcano, 1,771 feet (540 meters) above MSL (Figure 3.2-7) which are connected by the narrow isthmus. There are two lakes situated on the west side of Mount Pagan: Upper Lake or Laguna Sanhalom and Lower Lake or Laguna Sanhiyon. Figure 3.2-7 provides a topographic map of Pagan with four slope classes: (1) 0-5%; (2) 6-15%; (3) 16-30%; and (4) greater than 30%. The steepest slopes are located at Mount Pagan (sloping to the west towards the two lakes), along the isthmus leading to South Pagan Volcano, and around much of South Pagan Volcano. The gentlest slopes are located immediately south and southwest of Mount Pagan.

Photo 3.2-2. View of Mount Pagan

A well-defined valley system exists but there are no streams associated with these valleys. These valley systems were most likely developed during torrential downpours or soon after volcanic eruptions (Corwin et al. 1957). Most large valleys are directed down original volcanic slopes in a radial pattern. Terrain features described by Corwin et al. (1957) include plains and basin floors, lava fields, caldera backslopes, dissected ridges, cinder cones, volcanoes, rugged highlands, and major escarpments.

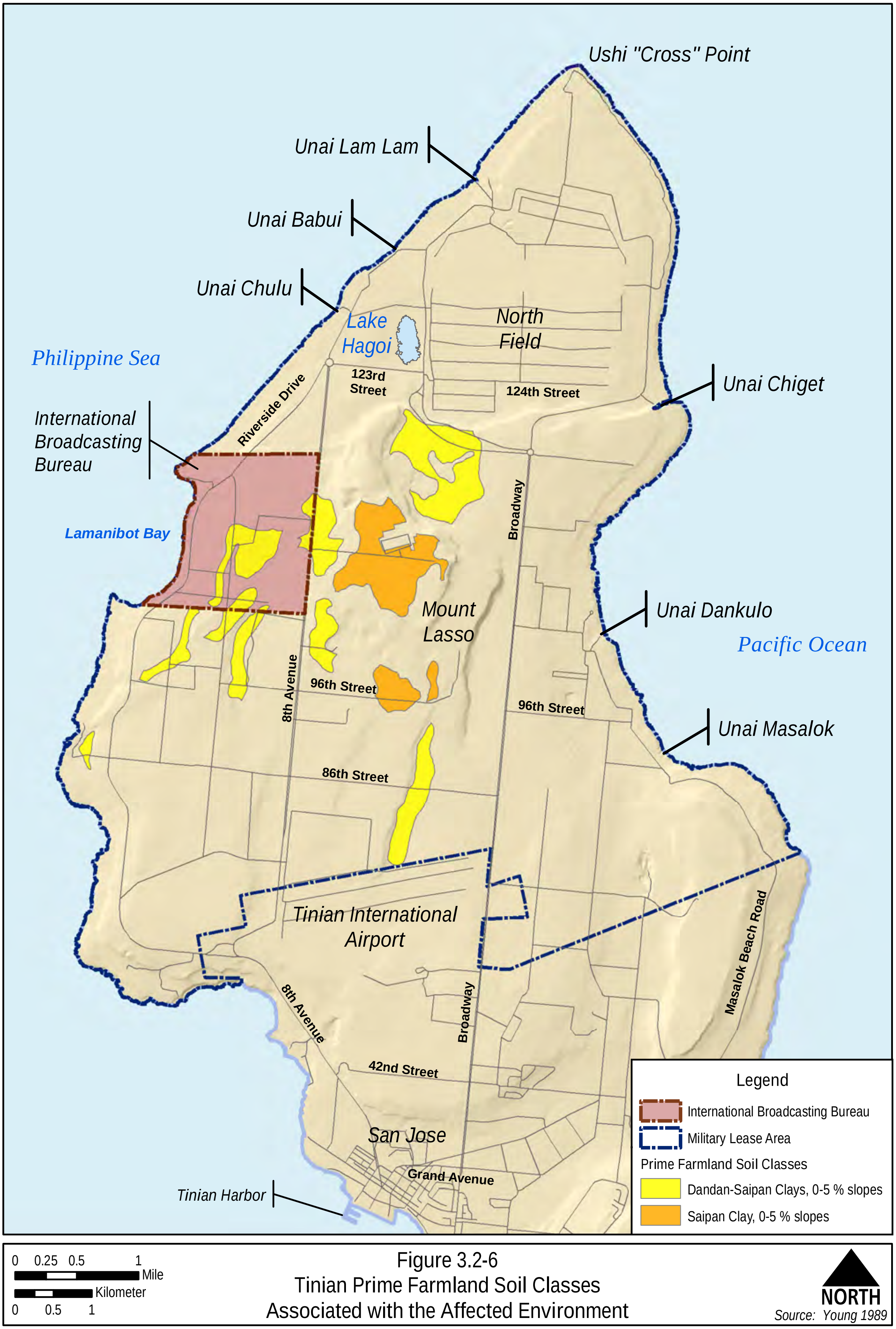

Figure 3.2-6
Tinian Prime Farmland Soil Classes
Associated with the Affected Environment

Source: Young 1989

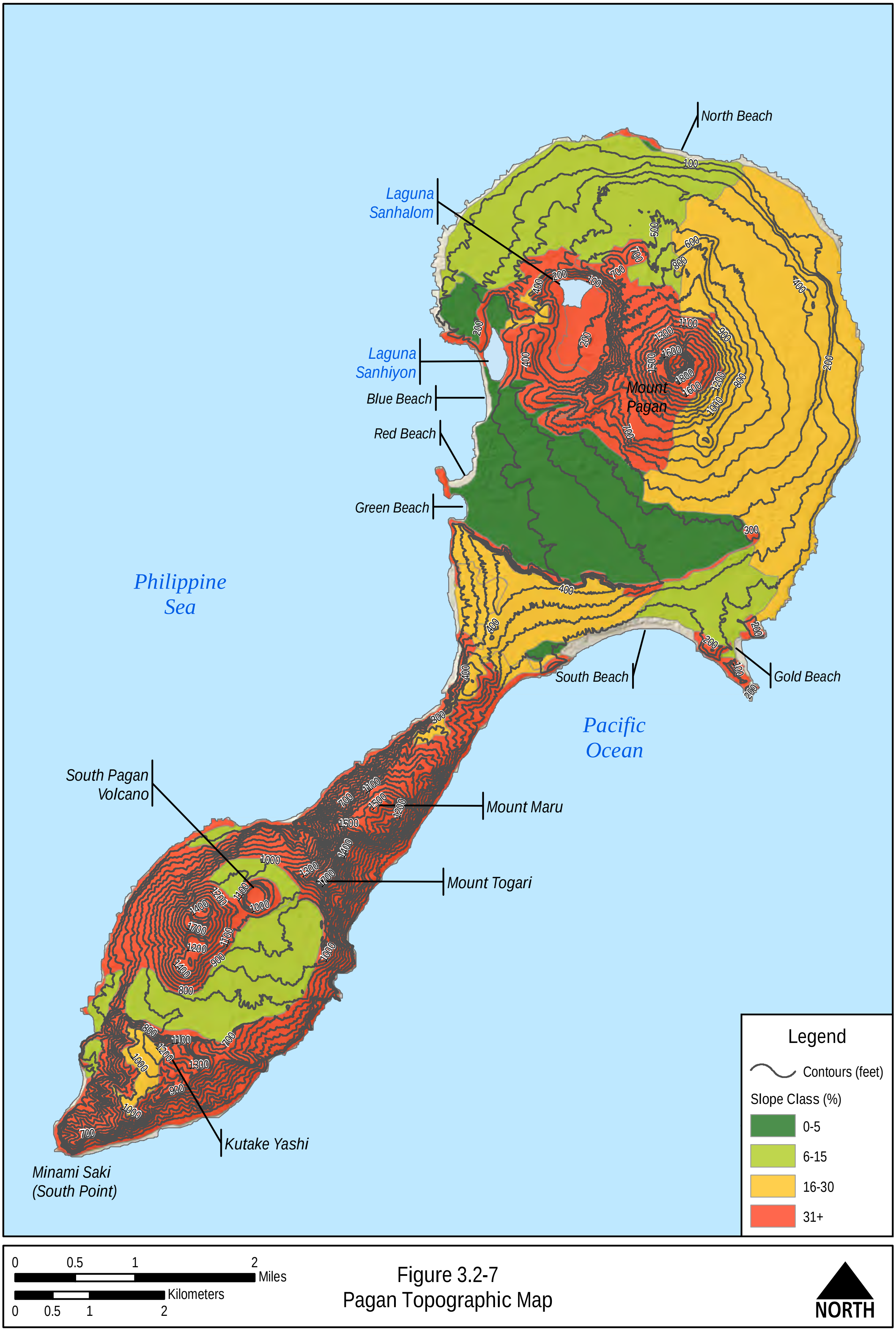

Figure 3.2-7
Pagan Topographic Map

3.2.6.2 Geology

Mount Pagan and South Pagan Volcano are exposed volcanic cones formed within the calderas of two ancient stratovolcanoes (Banks et al. 1984) (Figure 3.2-8). A stratovolcano, also known as a composite volcano, is a conical volcano built up by many layers (strata) of hardened lava and pyroclastic materials such as volcanic ash. The structure of the two stratovolcanoes is located primarily beneath the ocean surface (i.e., submarine flanks). The northern portion of the island where Mount Pagan is located is a partially collapsed caldera. Mount Pagan is the larger and more active of the two exposed volcanoes (Banks et al. 1984). Few detailed studies of the geology and historic eruption activities of Pagan have been done. The oldest exposed lava flows on Pagan appear to be less than 700,000 years old (Banks et al. 1984). Trusdell et al. (2006) notes reports of eruptions in the 1600s, 1872-73, the 1920s, and on May 15, 1981. On May 15, 1981, a large eruption occurred from Mount Pagan that sent columns of gas and volcanic ash 8 miles (13 kilometers) into the stratosphere. As a result of this explosive eruption and continuing volcanic activity, Pagan residents were evacuated from the island and it has not been resettled. Since 1981, a number of eruptions, ash, and low-level gas and steam plumes have been confirmed from Mount Pagan in 1987, 1988, 1992, 1993, 1996, 2006, 2010, 2011, and 2012 (Smithsonian Institution National Museum of Natural History 2014).

3.2.6.2.1 Geologic Units

Photo 3.2-3. View of *a'a* lava just north of the Pagan airfield

A generalized geologic map was prepared by Corwin et al. (1957) (Figure 3.2-8) which shows geologic units on Pagan. Geologic units mapped included Quaternary-age lavas and ash deposits that pre-date and post-date the existing Mount Pagan and South Pagan Volcano. Limited portions of the shoreline included recent raised reef deposits (i.e., shown as sedimentary deposits in Figure 3.2-8). A more recent effort by the U.S. Geological Survey (Trusdell et al. 2006) mapped and conducted age-dating of various deposits on the northern portion of the island. All units and surface deposits of Mount Pagan are basalt, andesite, or a combination of the two. Rock outcrops include cinder or spatter cones, lava flows (*a'a* which is jagged or pahoehoe which is smooth) (Photo 3.2-3), or consolidated or unconsolidated pyroclastic (ash) deposits. In these deposits, pozzolan, a siliceous and aluminous material is found. Pozzolan, like that found on Pagan, is a material used in cement and concrete. The pozzolan deposits on Pagan were mapped by the U.S. Geological Survey in 2006 (Trusdell et al. 2006) and revised in 2007 (Ding and Wilson 2007). The pozzolan deposits found on Pagan are depicted by thickness contours on Figure 3.2-9 (Ding and Wilson 2007). The estimated volume of pozzolan is described in Section 3.15, *Socioeconomics and Environmental Justice*.

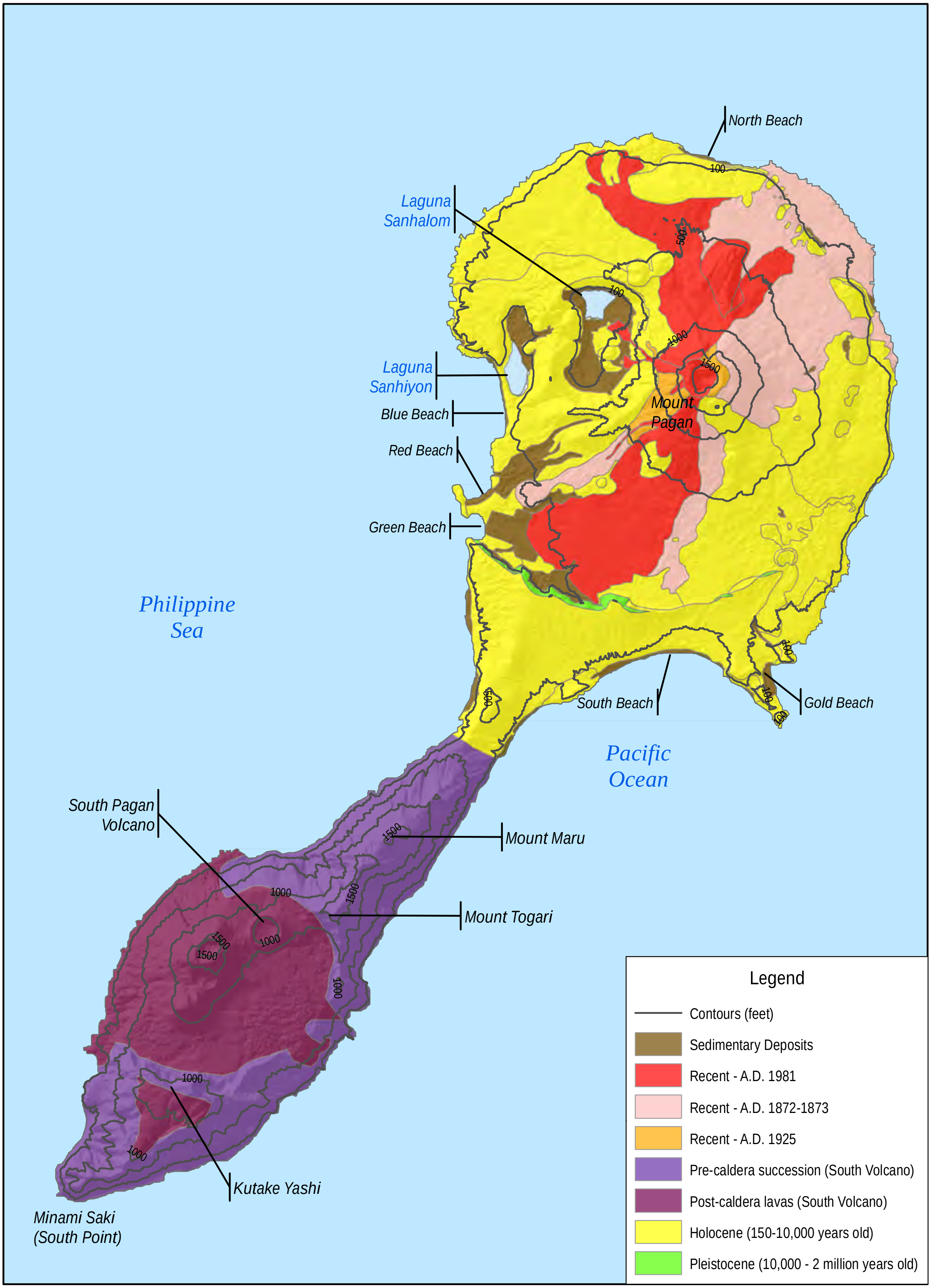

Figure 3.2-8
Pagan Generalized Geologic Map

Source: Corwin et al. 1957; Trusdell et al. 2006

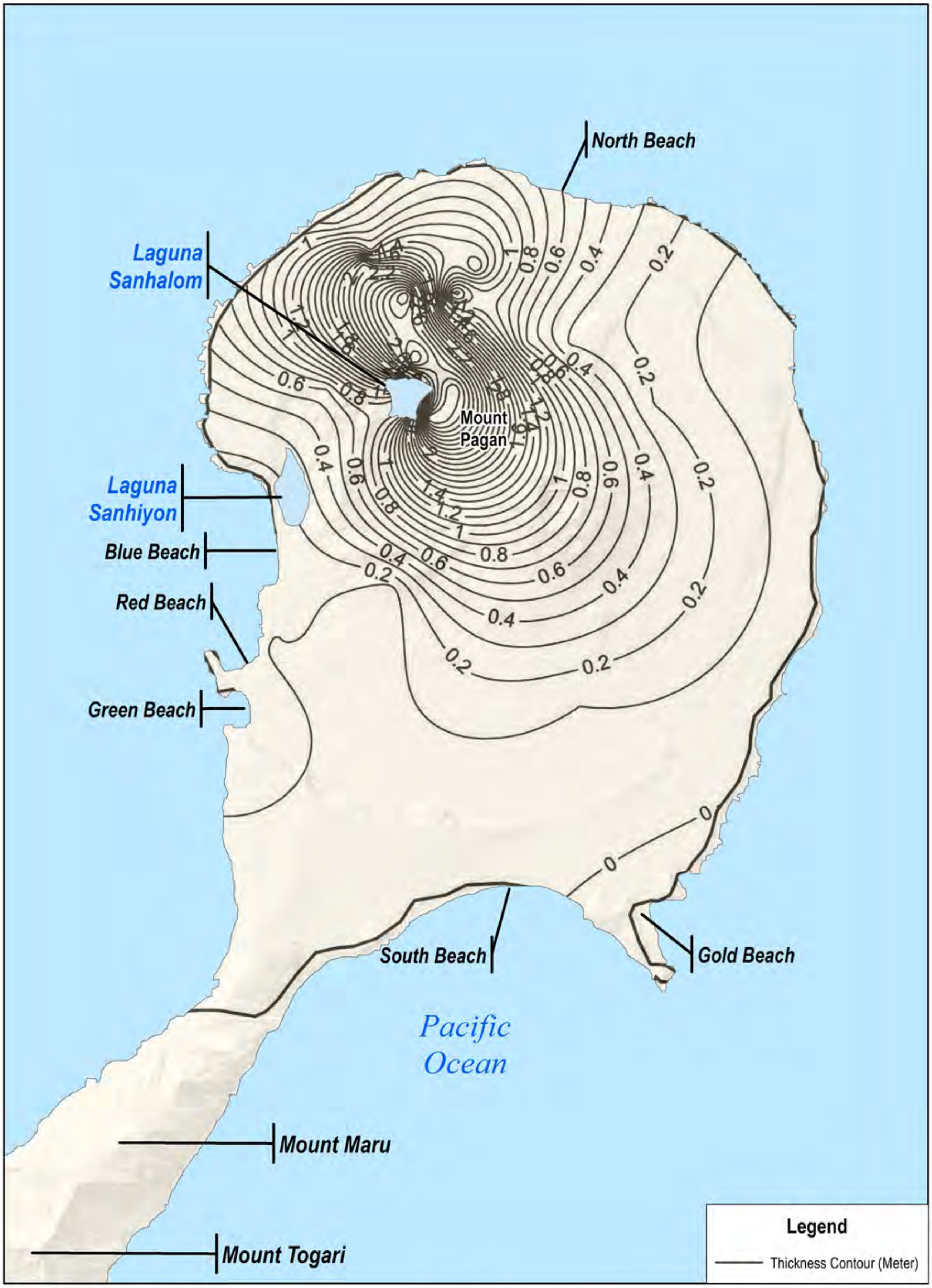

Figure 3.2-9
Pagan Pozzolan Deposits

Source: Wilson & Ding 2007

3.2.6.2.2 Geologic Hazards

Geologic hazards of concern for Pagan include the possibility of seismic activity (e.g., earthquakes), volcanic activity, landslides, and tsunamis. These concerns are addressed in the following sub-sections.

3.2.6.2.2.1 Seismic Activity

Seismic activity on Pagan can be attributed to its close proximity to the Mariana Trench subduction zone (see Section 3.2.4, *Regional Geologic Setting*), and the presence of two active volcanoes on the island. Seismic activity from low magnitude earthquake swarms has been documented and high magnitude earthquakes are possible. Months prior to the major explosive eruption of Mount Pagan in 1981, a number of locally felt earthquakes occurred, as described in the following section. On the day of the eruption, a swarm of small earthquakes occurred followed by a loud boom (Trusdell et al. 2006). These earthquakes are thought to have been the result of shifting underground magma (molten lava).

Other types of earthquake-generating activity in the region are the same as those described for Tinian. Pagan is not currently monitored with ground-based geophysical instrumentation to monitor seismic activity.

3.2.6.2.2.2 Volcanic Activity

Six of the northern Mariana Islands (i.e., Anatahan, Guguan, Pagan, Agrihan, Asuncion, and Uracus) have stratovolcanoes that have erupted in the past century (Trusdell et al. 2006). Lava flows erupted at stratovolcanoes are typically slow moving, thick, viscous flows (U.S. Geological Survey 2014); however, they can be fluid and fast-moving depending upon the energy of the eruption, topography, and the composition of the magma. It is possible for stratovolcanoes to have violent and prolonged eruptions. Eruptive materials associated with stratovolcanoes can include ash clouds; density currents of volcanic debris and hot gas (termed pyroclastic flows); falling rock blocks (termed volcanic bombs); and muddy debris floods (termed lahars). Other volcanic activity includes phreatic eruptions (water magma interactions) that can produce ash, steam, and gas. Agrihan, the highest of the Mariana arc volcanoes and located immediately north of Pagan, had a significant eruptive event in 1917 that sent large blocks of rock into the air and resulted in the deposition of approximately 10 feet (3 meters) of ash and lapilii (i.e., small stones ejected into the air from the volcano) on a former village on the southeast coast of Agrihan (U.S. Geological Survey 2014). Recent eruptions from Anatahan deposited in excess of 20 feet (6 meters) of volcanic ash on Anatahan, disrupted numerous flights, and closed Saipan International Airport (Quick n.d.). As previously described in Section 3.2.6.2, *Geology*, Pagan is home to two active stratovolcanoes with historic eruptions and continued volcanic activity through 2012.

As stated earlier, Pagan is not currently monitored with ground-based geophysical instrumentation. The only current source of information is satellite observation as noted in the *Volcano Hazards Program Report* (U.S. Geological Survey 2014). Land deformation may occur within the crater on Pagan such as swelling, shrinking, and topographical changes to the surface due to magma movement underneath the surface. Ground deformation may also be accompanied by temperature changes in the rock and water around it. Gases and particulates are released into the atmosphere as a result of volcanic activity of Mount Pagan. As magma moves up in the crust, pressure decreases and gases are released. Magma produces sulfur dioxide, carbon monoxide, carbon dioxide, hydrogen sulfide, hydrogen chloride, and hydrogen fluoride. These gases behave according to their properties and can accumulate, migrate, and be emitted in various areas depending on changing volcanic activity, subsurface conditions, and weather conditions. The hazard that these gases pose is that they are acids and can also cause asphyxia (a decrease in the concentration of oxygen and an increase in the concentration of carbon dioxide in the body which can lead to loss of consciousness and death). Particulates and solids can also become projectiles in sizes ranging from ash to objects more than 20 inches (50 centimeters) in diameter and present physical hazards. Gases may also be accompanied by temperature changes in the rock and water around it (The International Volcanic Health Hazard Network n.d.). Low level hazardous conditions continue to occur and minor gas and steam plumes continue to be observed at Mount Pagan in satellite data.

Volcanic activity can also produce noise ranging from soft hissing to deafening explosions accompanied by shockwaves. While the volcano is building up pressure prior to an eruption, sounds have been captured by acoustic recording devices and can sound like a rumble, roar, or sound coming from a jet engine. During blasts and explosions, impulsive, broad frequency band acoustic signals are created which are the highest amplitude or loudest sounds created by volcanoes. Consequentially, these loud booms and cracks travel the furthest and energy from these blasts can travel across ocean basins being recorded by pressure recorders thousands of kilometers away (Oregon State University n.d.; Hotovec et al. 2013).

3.2.6.2.2.3 Landslides

Rock falls, failure of slopes, and shallow debris flows (all forms of landslides) are possible due to the volcanic and seismic activity on Pagan. Evidence of collapse structures and debris flows have been reported on Pagan (Corwin et al. 1957; Trusdell et al. 2006).

3.2.6.2.2.4 Tsunamis

Tsunamis are generated when significant volumes of water are displaced by explosive eruptions or landslides of volcanic flanks. The National Oceanic and Atmospheric Administration does not have records of tsunamis occurring on Pagan. Tsunami inundation modelling has not been undertaken for Pagan (CNMI Coastal Resources Management Office, personal communication, 2013). However, the potential for tsunami generation resulting from movement of magma, submarine landslides, and seismic activity exists on Pagan and could result in significant, localized tsunamis with little warning. Modeling of 0.25 cubic mile (1.0 cubic kilometer) landslide from the south flank of Anatahan (an island in the northern Mariana Islands) volcano produces a calculated tsunami amplitude of 2 to 3 feet (0.6 to 0.9 meter) on Saipan; however, the presence of large calderas on Anatahan, Pagan, and Maug indicate that there is the potential for Mariana volcanoes to produce very large explosive eruptions, which could displace much greater volumes of water and thus generate a dangerous tsunami on Pagan (Quick n.d.).

3.2.6.3 Soils

Photo 3.2-4. View of volcanic cinder sand along the west coast of Pagan (facing south) with South Pagan Volcano in the background

Detailed soil survey data for Pagan is unavailable. As described earlier, surface soil and rock conditions range from alluvium (soil created from eroded rock), residuum (soil created from rock weathered in place), volcanic ash, raised coral reef deposits, volcanic cinder (Photo 3.2-4), and spatter deposits, as well as sharp (*a'a*) (see Photo 3.2-3) and smooth (pahoehoe) basalt, andesite, or basaltic andesite lava flows. Soils on the island are thin and largely confined to gentle slopes with a maximum depth seldom greater than 2 feet (0.6 meter). The best-developed soils are found in the inner basin, south of Lake Sanhalom, and the area north of the central plateau (Pangelinan and Kapileo 1970).

Anecdotal observations indicate that there are portions of soil (either alluvium or residuum) that are highly eroded. Surveys in 2000 and 2010 (Cruz et al. 2000; Kessler 2011) found the island's forests and grasslands "severely overgrazed" due to the abundance of feral cattle, goats, and pigs that have done considerable damage to island vegetation. This overgrazing has resulted in large open areas susceptible to soil erosion. Erosion has not been as prominent on Pagan as it has been on some other islands in the chain, perhaps due to the many lava flows and a lower abundance of loose pyroclastic materials. However, localized erosion has been prominent in large drainages that head on the western upper flank of Mount Pagan and flow southwestward into the central plateau (Trusdell et al. 2006).