National Park Service
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Natural Resource Program Center

# National Park of American Samoa

## *Geologic Resource Evaluation Report*

Natural Resource Report NPS/NRPC/GRD/NRR—2008/025

THIS PAGE:
Surgeonfish and butterflyfish on coral reefs at National Park of American Samoa

ON THE COVER:
Fringing coral reefs at Ofu Island in American Samoa

Photos by: Peter Craig, National Park of American Samoa

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Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
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# Executive Summary

*This report accompanies the digital geologic map for National Park of American Samoa in American Samoa, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research.*

National Park of American Samoa is the only National Park Service unit south of the equator. It comprises parts of four separate islands and harbors lush rainforests, steep terrain, diverse coral communities, lagoons, and beaches. Habitats at the park include shoreline wetlands, cloud forests, and littoral forests.

Geology is fundamental to the creation of the islands and to the environments of American Samoa. Geology influences surface water flow, and it contributes to climate, weather, hydrology, and topography. Geologic units and structures provide the framework for the craggy, eroded volcanic island peaks blanketed by rainforests, for beaches, lagoons, and pristine reef areas in the South Pacific Ocean.

The islands of American Samoa rise thousands of feet from the Pacific Ocean floor as a series of broad shield volcanoes. These volcanoes formed as the Pacific plate moved over a stationary hotspot deep in the earth. Alternating lava flows and airfall (pyroclastic) debris that hardened into tuff, volcanic breccia, lapilli, and cinder layers form these volcanoes. Although the initial volcanism that created these islands has ceased, the tectonically complex setting of American Samoa—near the junction of the Pacific and Australian plates—means that volcanoes may again become active on any Samoan island.

Although the islands of American Samoa are geologically young (<2 Ma), after active volcanism ceased intense weathering and erosion produced today's extremely steep topography. Wind, water, and slope processes carved through the deeply weathered volcanoes to produce steep slopes, amphitheater valleys, beaches and volcanic soils that now support rainforests. Fringing several parts of the islands of Tutuila, Ofu, Olosega, and Ta'u are coral reefs of great biodiversity and resilience.

Samoa has been occupied by humans for more than 3,000 years. Early inhabitants may have used the islands as a base for exploring and settling Polynesia. Since that time, a human presence and concomitant development has steadily increased in American Samoa, especially on the island of Tutuila. Given the limited natural resources available to island inhabitants, the sustainability of this development is now in question.

Because tourism has become a major industry, it is increasingly important to maintain island beaches and reefs in a natural state. Optimal beach management can be hindered by riprap, jetties, and other nearshore structures adjacent to park lands. Loss of sand to erosion and sand mining reduces sand supply to beaches, which are shrinking. Geologic hazards such as debris flows and landslides threaten the growing populated areas. The following four topics of concern to park management have geological underpinnings:

- Ocean temperatures and reef health. Surface water temperatures in the South Pacific are rising. Coral species in American Samoa are the current subject of much study because some species are able to withstand extreme temperatures. However, slight increases in ocean temperature can cause other corals to "bleach" or expel their symbiotic zooxanthellae algae and, if the high temperature is prolonged, coral polyps can die.

  Excess nutrients and pollutants also harm the reefs. Transplanting resistant coral species to vulnerable areas may be a way to preserve the reefs at American Samoa and elsewhere throughout the Pacific.
- Sea level rise. Sea level is likely to rise in the near future. Global climate changes are warming and expanding surface waters within the South Pacific Ocean Basin, and melting ice caps shed water into the oceans. Rising sea level may force changes in the reefs, park infrastructure, and park management.
- Increased human development. The increasing population of American Samoa is placing demands on the available space, building materials, fresh water, and natural areas of the islands. It also increases air and water pollution. Because private lands surround several park units within National Park of American Samoa, cooperation between resource managers at the park and adjacent landowners is essential in reducing potential harm to park resources.
- Seismicity and mass wasting. American Samoa lies in a tectonically active area. The Pacific plate subducts beneath the Australian plate along the Kermadec-Tonga trench. At the northern end of this trench, the plate is being torn laterally along an east- west-trending transform zone. This region produces many seismic events each year. Although most are small, even small earthquakes can trigger landslides, submarine debris flows (potentially leading to tsunamis), and other mass wasting along the steep island slopes. Seasonal rains and cyclones cause wind and wave damage and create flashfloods and mass wasting. Slope vulnerability assessments and geologic hazards maps are needed data sets for park resource management.

# Introduction

*The following section briefly describes the National Park Service Geologic Resource Evaluation Program and the regional geologic setting of National Park of American Samoa.*

### Purpose of the Geologic Resource Evaluation Program

The Geologic Resource Evaluation (GRE) Program is one of 12 inventories funded under the NPS Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort from the development of digital geologic maps to providing park staff with a geologic report tailored to a park's specific geologic resource issues. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRE team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRE products.

The goal of the GRE Program is to increase understanding of the geologic processes at work in parks and provide sound geologic information for use in park decision making. Sound park stewardship relies on understanding natural resources and their role in the ecosystem. Geology is the foundation of park ecosystems. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS- 75, Natural Resources Inventory and Monitoring Guideline.

To realize this goal, the GRE team is systematically working towards providing each of the identified 270 natural area parks with a geologic scoping meeting, a digital geologic map, and a geologic report. These products support the stewardship of park resources and are designed for non- geoscientists. During scoping meetings the GRE team brings together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes. Scoping meetings are usually held for individual parks and on occasion for an entire Vital Signs Monitoring Network. The GRE mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their innovative Geographic Information Systems (GIS) Data Model. These digital data sets bring an exciting interactive dimension to traditional paper maps by providing geologic data for use in park GIS and facilitating the incorporation of geologic considerations into a wide range of resource management applications. The newest maps come complete with interactive help files. As a companion to the digital geologic maps, the GRE team prepares a park- specific geologic report that aids in use of the maps and provides park managers with an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and up to date GRE contact information please refer to the Geologic Resource Evaluation Web site (http://www2.nature.nps.gov/geology/inventory/).

### Geographic Setting

The National Park of American Samoa is the only National Park Service unit in the southern hemisphere. It is located in the South Pacific more than 4,200 kilometers (km) (2,600 miles [mi]) southwest of Hawaii and 2,900 km (1,800 mi) northwest of New Zealand, near the International Date Line (between 13° and 15° south latitude). The park was authorized on October 31, 1988, and since the land is non- federal a 50- year lease was signed on September 9, 1993. The park covers 9,000 acres (2,500 acres submerged) in the Samoa Archipelago on four volcanic islands (of seven in American Samoa): T'au, Ofu, Olesega, and Tutuila (fig. 1). The islands are remote, isolated, and undeveloped.

### Geologic Setting

The Samoa Archipelago is part of a physiographic area known as Polynesia, a triangular area bounded by the Hawaiian Islands, New Zealand, and Easter Island (fig. 2). Within Polynesia, many volcanic island chains intersect. The western edge of the Samoan chain terminates in a region known as the northern Melanesian borderland. This complex region contains island arcs (such as Tonga and Lau Islands), Peggy Ridge, and other volcanic features such as the Samoa Ridge near the convergent margin of the Pacific plate and the Fiji Plateau, west of the Tonga trench (fig.3). The northern boundary between the Fiji Plateau and the Pacific plate is a transverse boundary which is being sheared in a west- to- east trend north of the Tonga trench (also called the Kermadec- Tonga trench). The Tonga trench is a west- dipping subduction zone located less than 200 km (120 mi) south of Samoa. This extensive crustal intersection is 7,000 to 9,000 meters (m) (23,000 to 29,500 feet [ft]) below the ocean floor.

Much like the islands of Hawai'i, the Samoan Islands were formed as a result of a crustal plate (the Pacific plate) moving slowly over a stationary hotspot. Hotspots are localized areas where hot mantle material wells up towards the surface of the earth. Crustal regions over these hotspots may experience volcanic eruptions and geothermal activity, such as the volcanic activity at Yellowstone National Park. As volcanic material is extruded or ejected over the hotspot, masses of lava may accumulate on the ocean floor.

A 3,444 - meter (11,300 ft) high submerged, active volcano is located 43 km (27 mi) east of the island of Ta'u. This feature (named Vailulu'u) still lies some 610 m (2,000 ft) below the ocean's surface. Eventually, if enough lava accumulates, the lava pile will break the ocean surface to become an island. Once subaerially exposed, the new island is susceptible to weathering and erosion. Thus, the longer an island is exposed, the more heavily eroded it becomes.

In the Samoa Archipelago, the Pacific plate is moving westward across a hotspot; thus, the easternmost Samoan Islands are the youngest, least eroded islands of the chain. The entire Samoan chain stretches east to west along the crest of the Samoa Ridge for more than 485 km (300 mi) of high volcanic islands, atolls, seamounts, and submerged reef banks. The western islands compose the Independent State of Samoa (formerly Western Samoa) and are the largest, oldest, and most heavily weathered islands of the archipelago. The American Samoa islands are approximately 1 million years younger than those of the Independent State of Samoa. These islands are host to developed fringing coral reefs and climax wet, tropical forests.

### Tutuila Island

The long, narrow island of Tutuila is the largest of the seven islands that compose American Samoa (fig. 4*A*). Volcanic activity is responsible for the shape and depth of Pago Pago harbor, one of the largest natural harbors in the south Pacific. The harbor, which formed in a collapsed caldera that cuts deeply into the south- central coast of Tutuila, almost divides the island in two.

A steep ridge runs from east to west along the 32 km (20 mi) length of the island. This ridge is interrupted by summits such as Matafao Peak (the tallest at 653 m, [2,142 ft]), North Pioa Mountain, and Mount Alava, which mark the southern boundary of the park area on the island (fig. 5). Approximately 200 closely spaced streams create numerous steep slopes and gorges separated by narrow ridges. Drowned valleys form embayments such as Pago Pago, Fagaitua, Afono, Fagasa, Vatia, and Nua Seetaga Bays. Prominent craters on Tutuila include Oloava, Fogama'a, and Fagatele craters. Approximately 1.6 km (1 mi) southeast of the southern tip of Tutuila is the tiny island of Aunu'u. The island has scenic beaches and an extinct crater that contains Pala Lake, a unique expanse of fiery red quicksand.

### Ta'u, Ofu, and Olosega Islands (Manu'a Islands)

The remaining three islands of National Park of American Samoa are T'au, Ofu, and Olosega islands, which are collectively referred to as the Manu'a Islands. This group of islands lies 100 km (60 mi) east of Tutuila. The tallest peak in American Samoa, Lata Mountain (a shield volcano), rises 966 m (3,170 ft) above Ta'u. The southeastern half of Ta'u lies within the national park. The island has numerous volcanic cones, thin lava flows, and tuff beds. The southern shore of the island contains sea cliffs rising more than 610 m (2,000 ft) above the ocean. Ofu has a sandy beach area and a pristine coral reef; a bridge connects it to Olosega. These two small islands are the remnants of an eroded large volcano that may have once been a double caldera. Lava flows, pyroclastic beds, and dikes characterize the volcanic rocks exposed on the slopes of the islands. The shorelines present steep cliffs more than 100 m (330 ft) high on the east side of Olosega and on the west side of Ofu (figs. 4*B*, 4*C* ).

## Ancient Samoan History

The word Samoa is derived from the native Samoan name, *sa ia moa*. This name refers to a legend describing the volcanic origin of the land itself. As described in the legend, the rocks "cried to the Earth," and the Earth became pregnant. Salevao, the god of rocks, observed motion in the moa, or center of the Earth. A child was born and named sa ia Moa, from the place where it was seen moving. Salevao said he would become loose stones, and that everything which grew would be sa ia Moa or "sacred to Moa." This sacred name is abbreviated as Samoa (Keating 1992).

Evidence suggests that people have lived on the islands for more than 3,500 years. An archaeological site (the To'aga archaeological sequence) on Ofu dates ~3,000 years ago (Dickinson 2001). Samoa may have been the base of settlement expeditions throughout Polynesia. Adzes (a primitive stone tool) made from Tutuila basalts have been found throughout the Pacific.

Inland quarries, streambed tool fabrication areas, and agricultural sites dating back 1,000 years have been recognized on Tutuila (Addison 2002; Arthur 2002). Fine- grained, dense basalt, suitable for tool making, is not a common resource on most Pacific islands. For this reason, it appears the basalt of Tutuila was prized and widely traded (Arthur 2002).

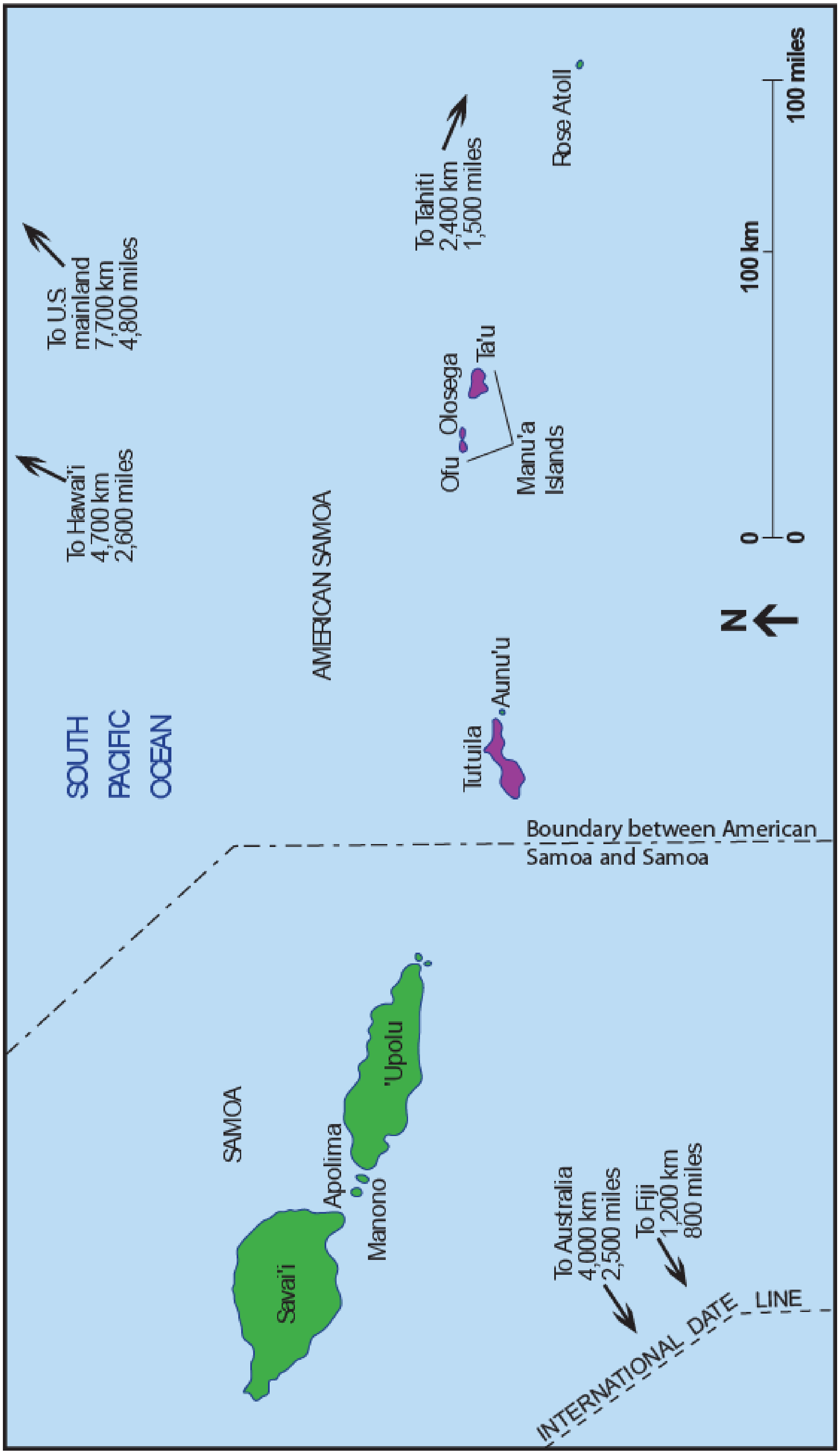


**Figure 1. Location of American Samoa with islands containing NPS lands highlighted in purple. Original map at http://www.lib.utexas.edu/maps/australia/samoa_islands_2002.gif (accessed May, 10, 2006). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).**

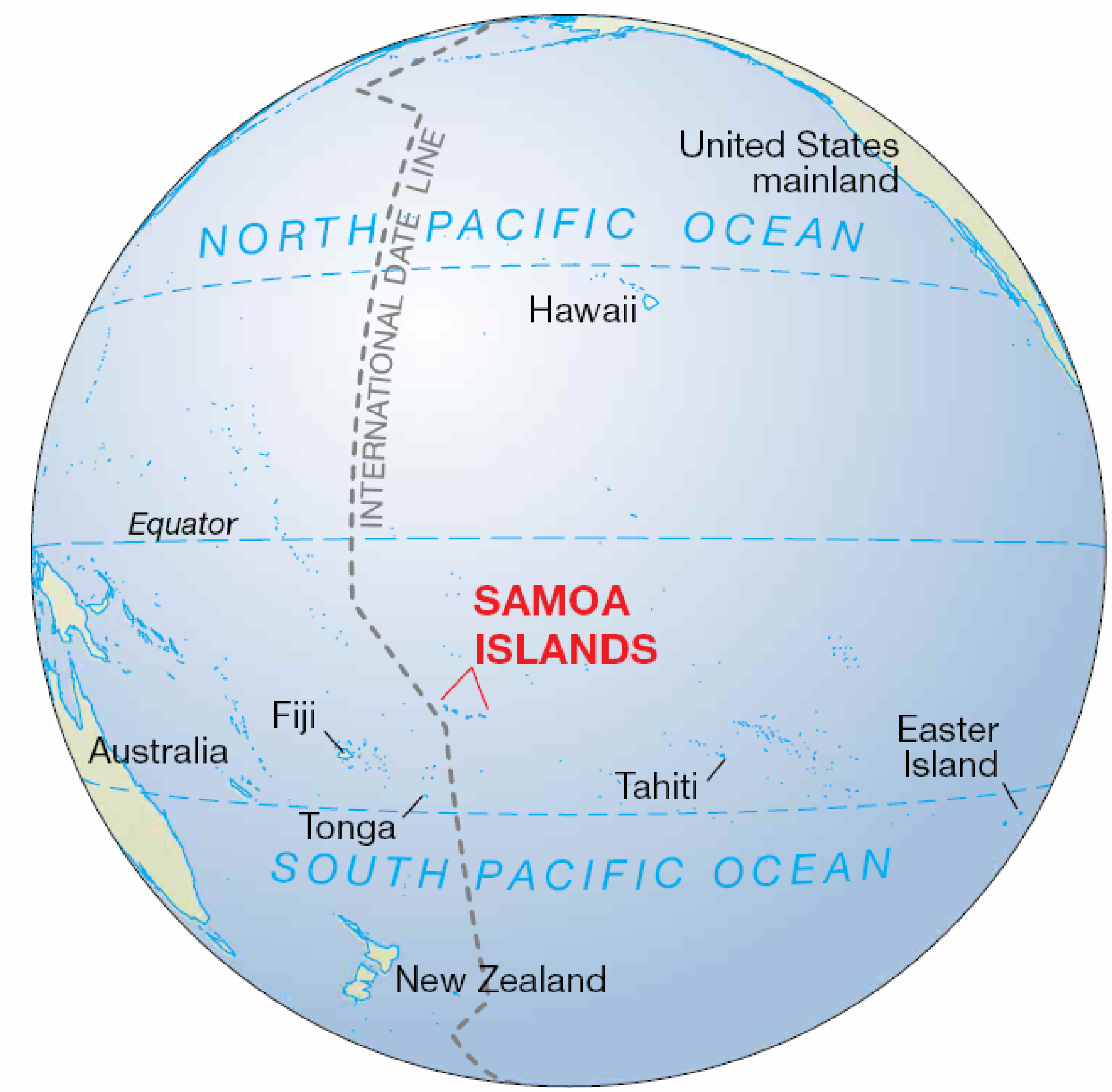


**Figure 2. Location of Samoa Islands in the South Pacific. Graphic courtesy of the National Park Service at http://www.lib.utexas.edu/maps/american_samoa.html (accessed March 17, 2007).**

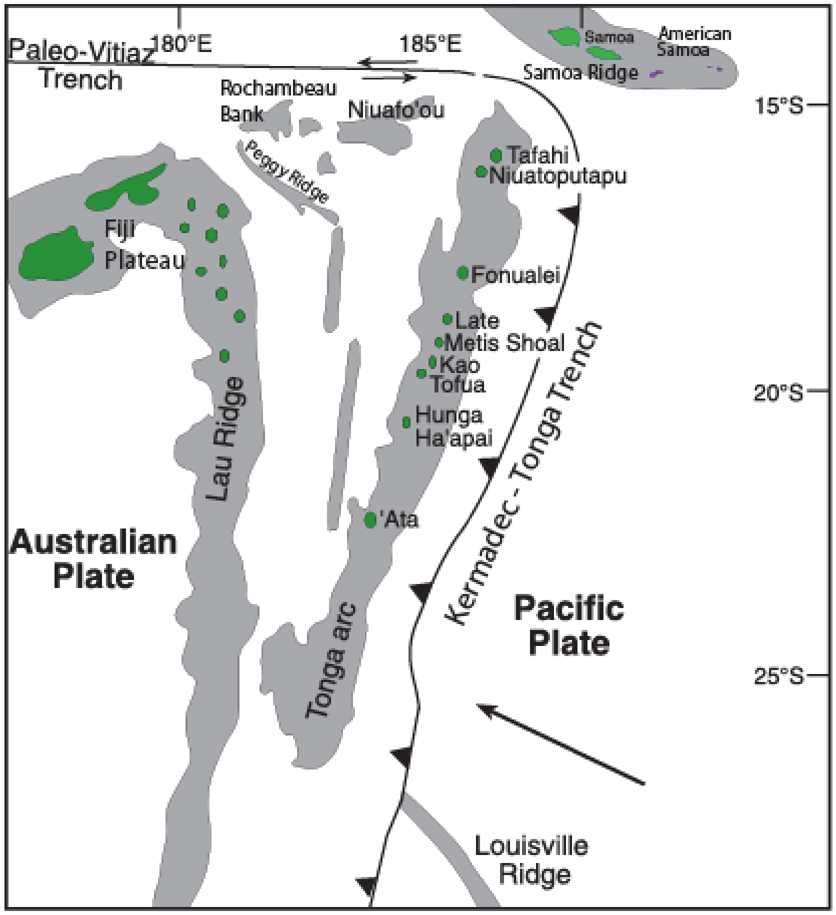


**Figure 3. Features within the Melanesian Borderland. Graphic adapted from figure 1 from Turner and Hawkesworth (1998) by Trista L. Thornberry-Ehrlich (Colorado State University).**

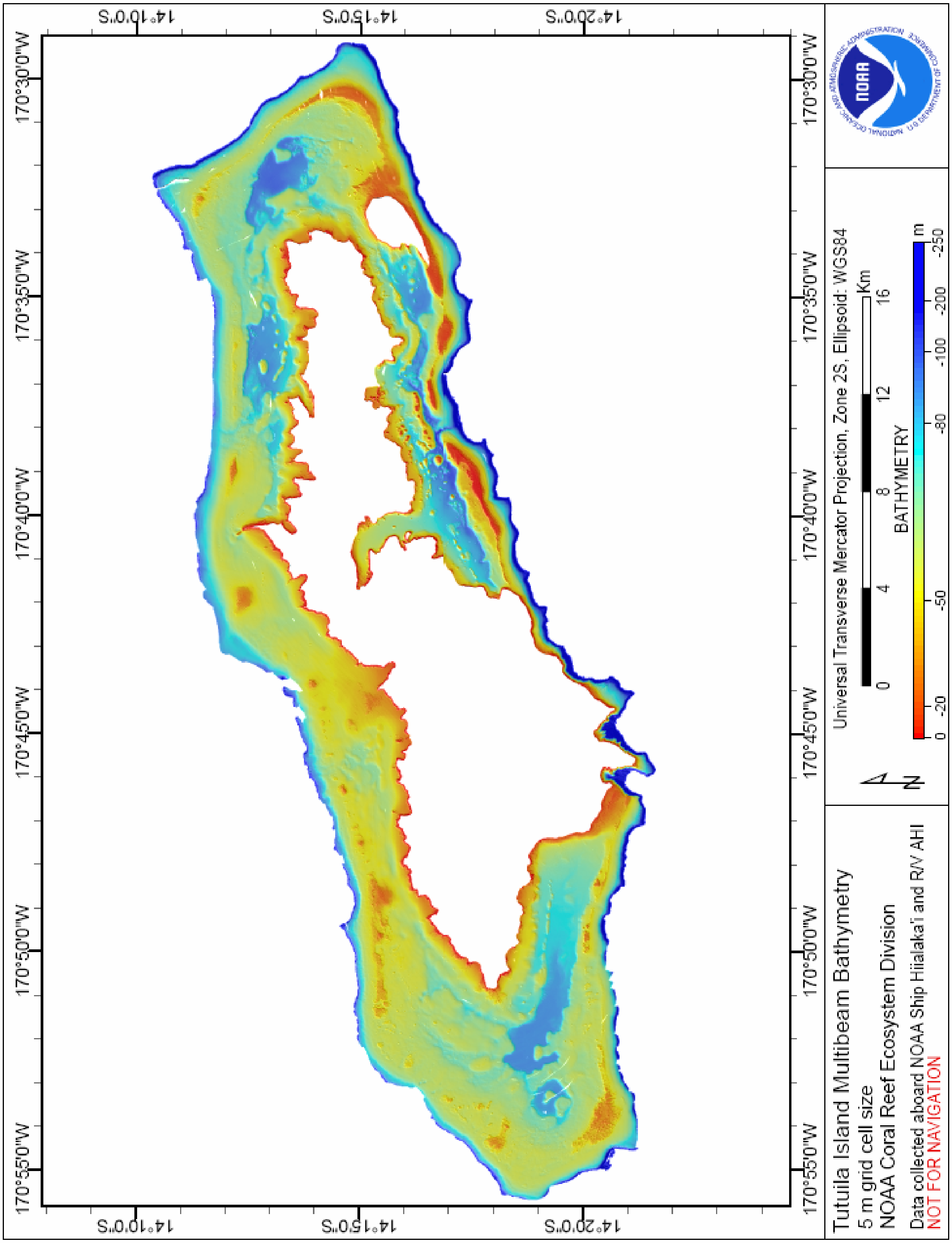


**Figure 4*A*. Bathymetry surrounding the island of Tutuila at 5 m resolution. Data from National Oceanic and Atmospheric Administration Coral Reef Ecosystem Division. Graphic downloaded from http://www.soest.hawaii.edu/pibhmc/pibhmc_AmSamoa.htm (accessed March 17, 2006).**

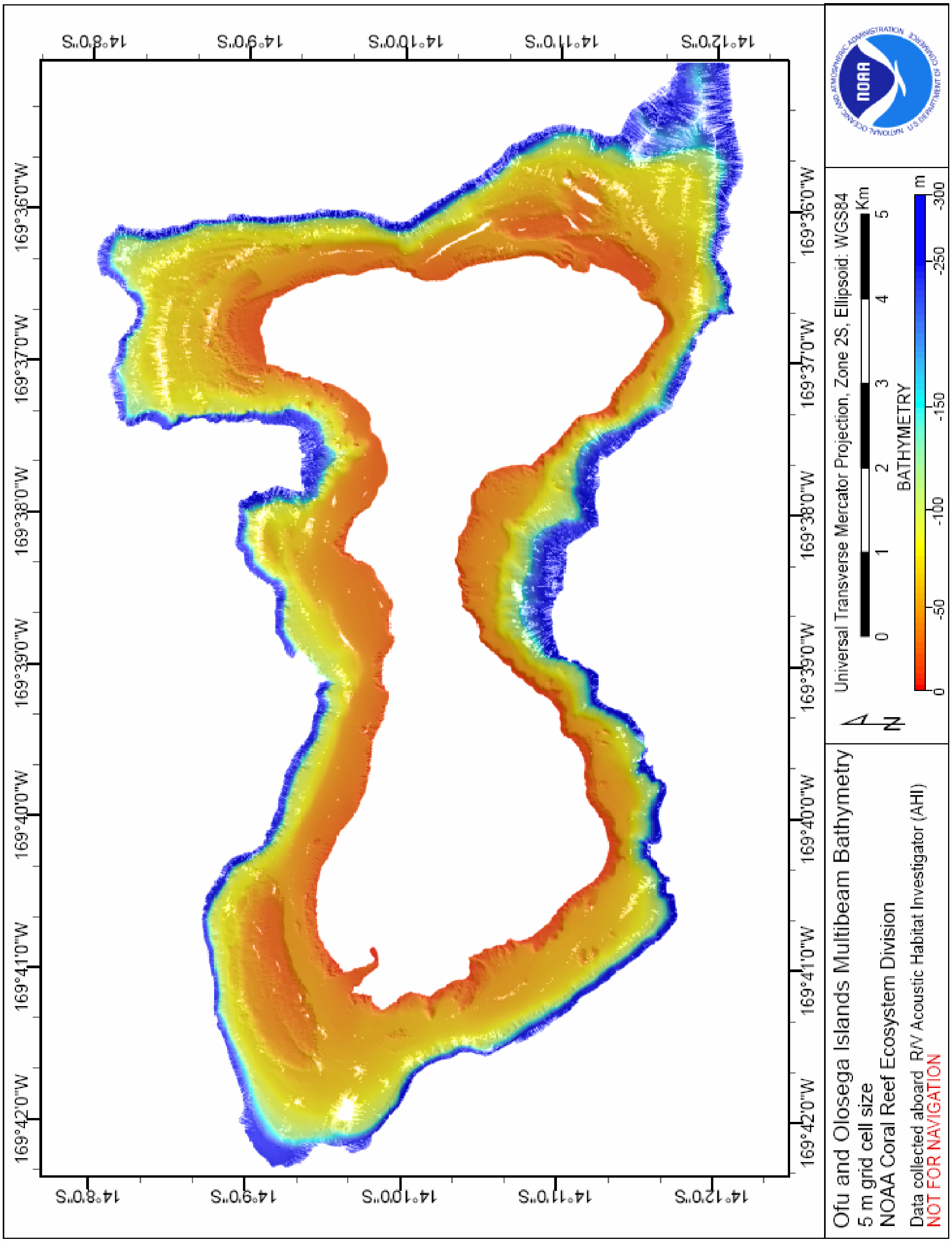


**Figure 4*B*. Bathymetry surrounding the islands of Ofu-Olosega at 5 m resolution. Data from National Oceanic and Atmospheric Administration Coral Reef Ecosystem Division. Graphic downloaded from http://www.soest.hawaii.edu/pibhmc/pibhmc_AmSamoa.htm (accessed March 17, 2006).**

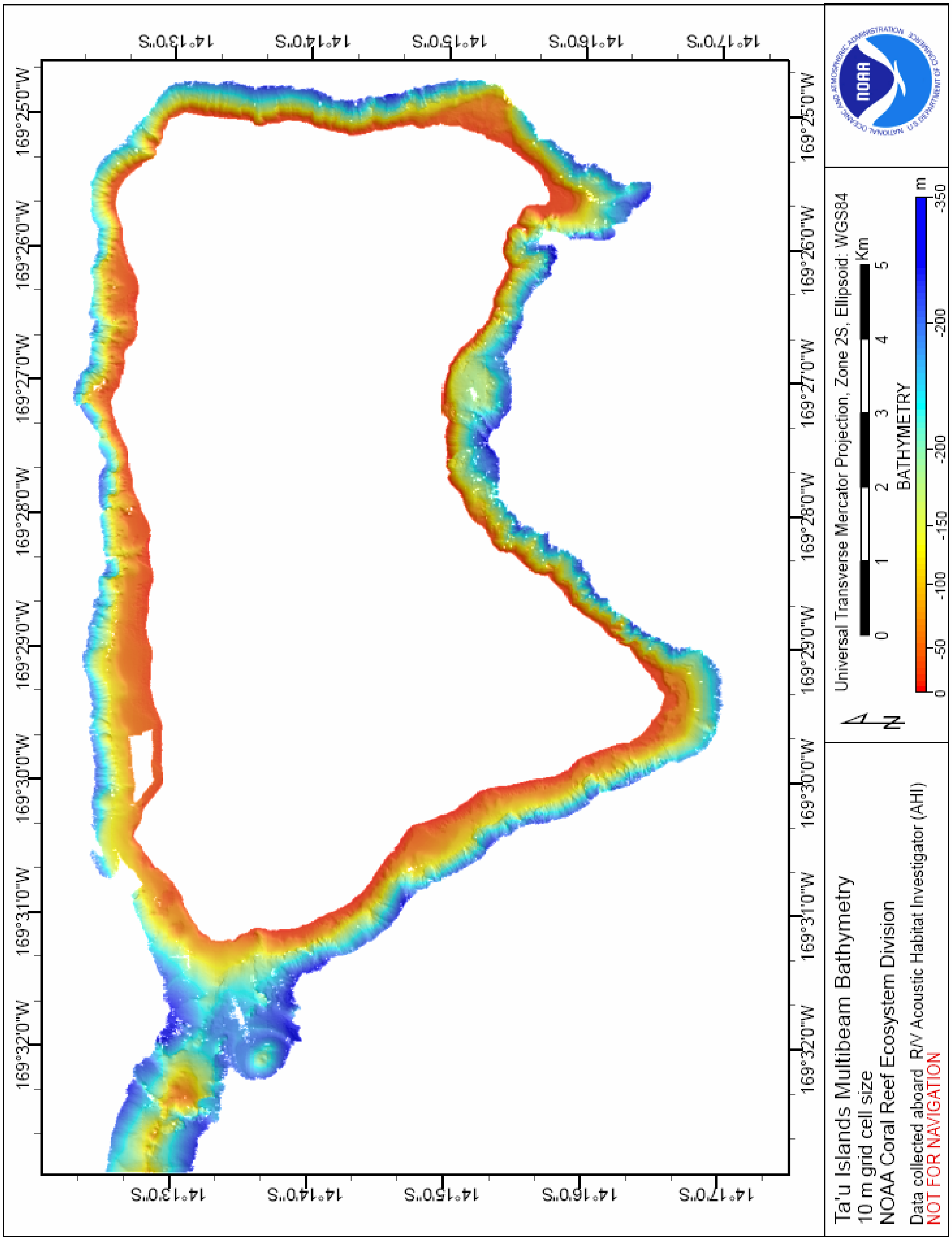


**Figure 4C. Bathymetry surrounding the island of T'au at 10 m resolution. Data from National Oceanic and Atmospheric Administration Coral Reef Ecosystem Division. Graphic downloaded from http://www.soest.hawaii.edu/pibhmc/pibhmc_AmSamoa.htm (accessed March 17, 2006).**

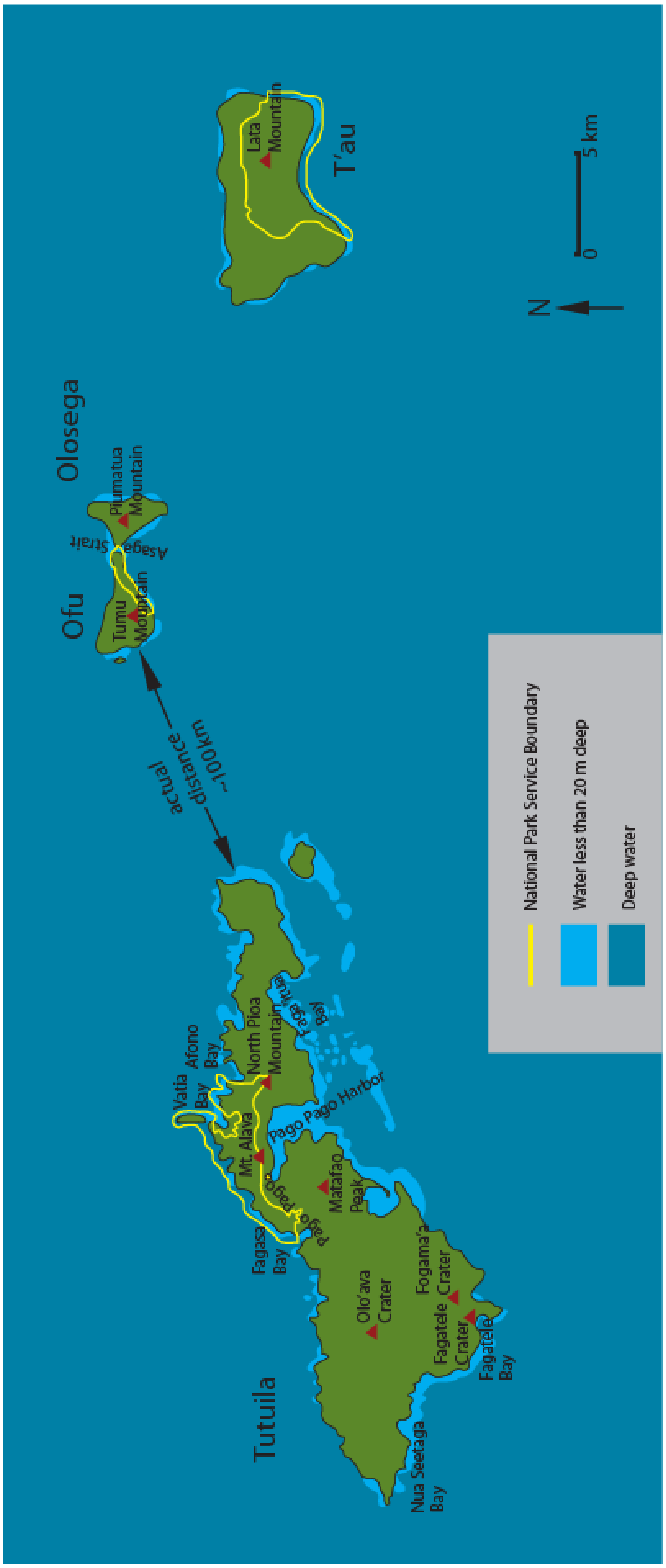


**Figure 5. Shallow water areas around American Samoa and locations mentioned in the text. Information from National Oceanic and Atmospheric Administration (2007); graphic by Trista L. Thornberry-Ehrlich (Colorado State University).**

# Geologic Issues

*A Geologic Resource Evaluation scoping session for National Park of American Samoa was held on March 20- 21, 2003, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. The following section synthesizes the scoping results, in particular those issues that may require attention from resource managers.*

This section discusses the management of natural resources. The most critical topics are listed first. Potential research projects and other topics of scientific interest are presented at the end of this section.

## Reef and Ecosystem Health

### Coral Reefs

Coral reefs are an important resource at National Park of American Samoa. The reefs are an integral part of Samoan culture and a source of food for local villages. They protect shorelines from wave action, especially during seasonal storms (NOAA 2007). In addition, the reefs attract visitors and researchers from around the world. Most of the beach sediment fringing the islands is derived from the adjacent coral reefs (Richmond 1995).

The high geothermal gradient in the Samoan region and active volcanism produces a large hydrothermal vent system currently active at the Vailulu'u seamount (Staudigel et al. 2004). This and other smaller vents associated with rejuvenated volcanism may have far-reaching consequences for the park. Although these vents are located outside the park, tides and oceanic currents disperse warmer, mineral- laden (dense) vent water around the area. The higher- than- usual ocean-water turbidity, density, and temperature may harm the park's coral reefs. At this time (2007), it is unclear whether venting has in fact harmed the shallow reefs (Bruce Richmond, written comm. 2007).

Sea level is likely to rise in the near future. Global climate changes are warming and expanding surface waters within the South Pacific Ocean Basin, and melting ice caps shed water into the oceans. Rising sea level may force changes in the reefs. American Samoa corals are renowned for their resilience to extreme environmental stress. The corals have survived four hurricanes in the past 18 years, a predatory starfish invasion (*Acanthaster planci*), and high temperatures (NOAA 2007).

Although resilient, Samoan corals are not indestructible. Slight increases in ocean temperature (1- 2 days at temperature elevations of 3- 4°F or several weeks of temperature elevations of only 1- 2°F) can cause the corals to "bleach" or turn pure white.

Plant- like cells (zooxanthellae) living in coral tissues are released at higher temperatures depriving the coral of symbiotic nutrient exchange. If the zooxanthellae are not recovered, the coral will die. Once coral die, they can become covered with slimy mats of green algae (Craig 2006). Algae overgrowth can stunt coral recovery efforts, which are already slow.

Human- induced changes also threaten the current state of the reefs. Fishing pressure has reduced the overall health of the reef ecosystem. Rapid population growth threatens the reef environment with coastal alterations, loss of wetlands, soil erosion, coastal sedimentation, solid and hazardous waste disposal, water contamination and air pollution (NOAA 2007).

The coral reefs of National Park of American Samoa can serve as an indicator of changes in the seas of the region. According to estimates, approximately 30% of the world's coral reefs are severely damaged and as much as 60% may perish by the year 2030 (Piniak et al. 2004). At American Samoa, temperatures in some pools reach 35.5°C and can fluctuate as much as 6°C degrees in a single day. Such high temperature fluctuations would kill most corals. Factors associated with this resiliency include acclimatization, chemical properties, types of symbiotic zooxanthellae, adaptation, evolution of larvae, and susceptibility to disease. Careful study of these factors is necessary in order to apply the results to other reefs (Piniak et al. 2004).

Baseline studies and inventories followed by careful monitoring of reef conditions are vital to reef management and to the understanding of coral reef response to ocean changes.

### Backreef Moats

Shallow lagoonal areas (backreef moats) are on the landward side of several fringing reefs of American Samoa. These moats may be typical of fringing reef zones—shoreline, lagoonal moat (with or without patch reef), reef flat, reef crest (area exposed at low tide), and the upper and lower reef slopes. Moats typically range from 1 m (3 ft) to about 10 m (30 ft) deep and may contain rocky substrates in addition to the predominantly sandy bottom. Where hard substrate exists, coral growth can be elaborate, and patch reefs may extend in mushroom-shaped bulbs from the sea floor (Kirda 1998).

Backreef moat areas are important as natural buffers along the shoreline of the Samoa Islands. They collect sediment, support coral colonies, and act as nursery areas for local fisheries. Existing backreef areas need protection from human influences and degradation within the National Park of American Samoa. Formation of further backreef moats by creation of offshore ridges may extend these unique and invaluable habitats.

On the island Ofu, the backreef moat supports a diverse coral community including reef- building corals. A continuous reef crest separates and protects this area from the open ocean. It contains several interconnected pools about 1- 2 m (3- 6 ft) deep. No streams enter the moat so it is only slightly influenced by adjacent land. Temperatures in the moat frequently are more than 3°C above the average summer water temperature, 32- 34°C. As part of the protected National Park of American Samoa, this moat offers research opportunities uncompromised by most human influences (Smith 2004).

#### Ecosystem Conservation

Ecosystems in National Park of American Samoa range from lagoon, coral reef, and littoral strand to tropical rain forest to montane, ridge top, mountaintop scrub, and cloud forest (www.nps.gov/npsa). All of these ecosystems are built on geologic substrates and by geologic processes. Those processes influence how ecosystems respond to climate change, seasonal storms and droughts, and human intervention. The isolation of the islands means biodiversity is somewhat limited. Thirty- two percent of the local plant species are endemic however, endemic marine species have yet to be investigated (Craig 2006). These geographically isolated ecosystems yield abundant opportunities to study global changes in climate, ocean conditions, and air quality in a relatively undisturbed environment.

#### Inventory, Monitoring, and Research Needs for Reef and Ecosystem Health

- Complete baseline inventories and characterize present reef conditions. Locate areas targeted for monitoring of ocean change and the consequences of any change.
- Monitor sea level changes and ocean temperatures at various locations around coral reefs. Note changes in water turbidity and density.
- Cooperate as part of the Coral Reef Advisory Group in NOAA's Coral Reef Ecosystem Research Plan http://coris.noaa.gov/activities/coral_research_plan/pdfs/american_samoa.pdf (accessed March 17, 2007).
- Measure amounts of dissolved solids in ocean water and correlate with oceanic currents to determine potential source areas (such as active hydrothermal centers, submarine volcanoes).
- Continue to cooperate with multidisciplinary studies of coral persistence in American Samoa (Piniak et al. 2004).
- Support plans to responsibly manage village- based fisheries.
- Support legislation that strengthens penalties for malicious coral bleaching (fishing with chlorine bleach), dumping waste in waterways, releasing sewage from piggeries onto the reefs, or improper land- use activities that release excess sediments.
- Identify, protect, and nurture naturally resistant corals for possible use in re- seeding areas affected by coral bleaching.
- Continue to support backreef moat characterization studies that involve transplanting corals into backreef areas most likely to sustain long- term growth (Smith 2004).
- Research the possibility of building onto fringing reefs or creating artificial reefs to expand backreef moat habitat.
- Investigate placing restrictions on access to especially fragile and sensitive backreef moat areas.
- Promote studies that emphasize the role of geology as the foundation for the ecosystems at National Park of American Samoa.
- Create interpretive programs and exhibits highlighting the role of geology in ecosystem development.

### Water and Energy Resources

A population growth in American Samoa of 2.1 % per year strains the natural resources available on these isolated islands. Chief among these resources is fresh, potable water for drinking and municipal use. Freshwater from precipitation that is neither discharged by streams, evaporated, nor used by plants is stored in the subsurface to recharge groundwater. Many of the volcanic rocks that form American Samoa are highly permeable and fractured and have a low hydraulic gradient; however, volcanic dikes may act as impermeable barriers to groundwater movement.

Near the coast, lighter freshwater floats on top of a saltwater aquifer. The fresh water percolating into the ground depresses the salt water beneath an island forming a profile that has the appearance of a lens referred to as the Ghyben- Herzberg lens. For every foot of fresh water above sea level on dry land, an estimated 12 m (40 ft) of fresh water lies below sea level floating in the lens. The division between fresh and salt water is not sharp, and coastal areas near the lens contain brackish water unsuitable for drinking (Keating 1992).

Because the islands of American Samoa are underlain by many rock types, hydrogeologic properties can change in a short distance. Younger lavas in general are more permeable than older volcanic rocks and alluvial deposits. Wells in younger, permeable lavas sustained yields of up to 300 gallons per minute (Keating 1992). On American Samoa, volcanic rocks outside of calderas locally produce water. However, volcanic rocks within calderas are not productive because of their limited subaerial collection area. Zones of local permeability and productivity are associated with fractures, faults, volcanic ejecta, and boundaries between distinct flow units (Keating 1992).

It is estimated that 23 million gallons per day of groundwater recharges the aquifer in the highly permeable volcanic rocks of the Leone peninsula (fig. 6) (Keating 1992). Given the spatial variation in permeability, even productive wells may have limited recharge potential. Thus, it is essential for park resource management to understand the nature of the hydrogeologic system at American Samoa at a fine scale.

Human activities continue to degrade air and water quality at National Park of American Samoa. Pre-industrial contaminants generally were limited to dust and to natural volcanic gases. Today, lead is of major concern. Lead is carried to the islands as industrially produced carbonaceous aerosols that are recycled as sea spray salt, and then deposited on plant leaf surfaces. These lead- rich aerosols are then reintroduced into the air as plant aerosols (Settle and Patterson 1991).

As human development increases in American Samoa, importing goods, supplies, and energy sources will become more expensive. A new airport at Ofu is requiring massive amounts of fill dirt. Increased development also increases the need for rocks, cement, aggregate, lumber, and other building materials.

Geothermal energy may reduce the islands' reliance on imported petroleum products. Geothermal energy is relatively nonpolluting and can be developed in small areas (Olson 1987). The geothermal gradient around Samoa is relatively high, and a hydrothermal plume in the Pacific Ocean may be economically feasible to exploit (Lupton et al. 2004).

#### Inventory, Monitoring, and Research Needs for Water and Energy Resources

- Monitor air quality (in particular, lead and particulate matter) and correlate with local volcanic activity to separate fluctuations from background levels; initiate a record of local air change.
- Investigate alternative energy sources, such as geothermal, wind, and solar, for use at park facilities (Olson 1987).

### Geologic Hazards

The particular combination of tectonic setting and climate in American Samoa creates several geologic hazards: earthquakes, volcanic eruptions, tsunamis, slope failures (rapid mass wasting), cyclones, drought and flooding.

#### Earthquakes

Seismic events are common in Samoa and the potential for future earthquakes is high. The largest earthquake recorded in Samoa (since recording began in 1917) was a magnitude 8.3 on the Richter scale in 1917. A magnitude 8.0 earthquake occurred in 1995 (Tavoi et al 2001). Average events are magnitude 4.5–5. Most larger earthquakes occur to the southwest and are associated with the Tonga arc (fig. 3) (Tavoi et al 2001; Leavasa 2004).

Near Vailulu'u, active volcanism produces as many as 40 small earthquakes in a single day (Konter et al. 2002; Konter et al. 2004) as brittle rock fails during redistribution of magma movement and in the magma chambers below the seamount (Konter et al. 2004).

Subduction of the Pacific plate into the Tonga trench (figs. 17, 19) has led to high seismicity and deep earthquakes. Another system of seismic activity, trending east- west through Fiji west to the New Hebrides (Vanuatu), also contributes to the earthquake potential in the area. Earthquakes east and north of the trench are at shallower depths (less than 70 km, 43 mi) and are usually the result of internal deformation of the Pacific plate or subsurface movement of magma accompanying volcanism (Hill and Tiffin 1993; Leavasa 2004). In the area south of American Samoa, the Pacific plate is cut by small- scale normal and thrust faults striking north-south and dipping westward. This orientation is in response to the bending of the plate into the Tonga trench and to longitudinal compressive stresses within the plate. In addition, the tearing of the Pacific plate, associated with the junction of the subduction zone and the transverse boundary north of the trench, causes earthquakes in the area (Hill and Tiffin 1993).

#### Volcanic hazards

The Samoa Islands are part of a volcanic archipelago located along the crest of the Samoa Ridge overlying the stationary Samoa hotspot. In general, isotopic dating of dredge basalts from along the entire trend of the Samoan lineament indicates that Samoan volcanism is older to the west (Hart et al. 2004). The trend in dates is consistent with the velocity of the Pacific plate movement listed below (Hart et al. 2004). However, as discussed below in the Geologic History section, a strictly plume- driven hotspot model is not necessarily consistent with the volcanic activity of the Samoan Islands. On the westernmost and oldest (~5 million years old) Samoan island of Savai'i, voluminous young volcanic rock indicates rejuvenated volcanic activity whereas on Upolu, the second oldest island, there is little to no rejuvenated volcanic activity (Hart et al. 2004; McDougall 1985).

Rejuvenated volcanic activity along the Samoan Ridge may be explained by the unique tectonic setting of the Samoan archipelago close to the junction of the Pacific plate and the Australian- Indian plate (Hart et al. 2004). At this point, the Pacific plate is tearing laterally in a pattern propagating eastward at the northern end of the Tonga arc (Hart et al. 2004). The nature of this boundary produces earthquakes, as described above, and may also be responsible for some renewed volcanic activity in the area, including that on Savai'i (Keating 1992; Hart et al. 2004). Crustal tearing may facilitate volcanic rejuvenation extraneous to the Samoan hotspot.

Volcanic activity and associated hazards are still a very real possibility at National Park of American Samoa. Resource management at National Park of American Samoa can assume future volcanism may occur in areas distant from the present hotspot location beneath Vailulu'u. As recently as 1866, subaqueous eruptions and earthquakes spewed clouds of pumice, volcanic ash, and steam for several months in the Manu'a islands (Keating 1992; Craig 2006). In 1905, lava flows from several large eruptions destroyed villages in Savai'i, Samoa (Craig 2006). Recent volcanic events such as these pose hazards of lava flow destruction, emission of noxious gases and fumes, mantling ash falls and pyroclastic flows, and direct blast damage.

#### Mass wasting

The flanks of Samoan volcanoes are thickly mantled by coarse debris flows, especially offshore. Both large and small slump blocks are common in these locations (Keating and Karogodina 1990). In sea floor images taken in western Samoa, debris avalanche deposits extend from the island slope onto the adjacent abyssal plains, covering areas of more than 20,000 $km^2$ (7,700 $mi^2$) (Hill and Tiffin 1993). This debris may have been transported as sheet flows, semi- coherent blocks, or chaotic flows (Keating et al. 2000). Triggered by seismicity associated with volcanism or the local tectonic setting near the Kermadec- Tonga trench (fig. 3), catastrophic failure of these submarine debris slopes (perhaps triggered by a tectonic shift in the seafloor) could displace the water column enough to produce a tsunami.

In addition to submarine debris flows, mass wasting on land produces catastrophic landslides, rockfalls, and slumps in most coastal and upland areas of American Samoa. Severe rockfalls have killed people on Tutuila.

Torrential tropical rains and cyclones increase the potential for flash floods and mass wasting on island slopes. Slopes underlain by weakly cemented or unconsolidated volcanic ejecta or by heterogeneous layers such as basalt flows, tuffs, and lapilli tend to fail when undercut. Moreover, cyclones usually coincide with elevated water levels owing to storm surge and winds that affect all coasts of the islands (Richmond 1995). These conditions, when combined with the seismic potential for the area, create a considerable safety hazard for National Park of American Samoa visitors, staff, and facilities.

#### Inventory, Monitoring, and Research Needs Geologic Hazards

- Set up a GIS database that incorporates geology, meteorology, seafloor mapping, seismic monitoring, volcanic monitoring, bathymetry, physiography, engineering, geomorphology, population distribution, and land- use patterns; this information can be used to assess the risks of a given hazard in specific geographic areas of the park (Shorten 2001).
- Refer to the Pacific Disaster Center website for hazard maps, vulnerability assessments, and mitigation plans for geologic hazards at American Samoa http://www.pdc.org/iweb/pdchome.html (accessed March 17, 2007).
- Improve seismic hazard maps and analyses at a finer scale, especially those pertaining to park facilities, future development, and visitor- use areas (McCue 1999).
- Cooperate with the U.S. Geological Survey, the Ministry of Agriculture, Forestry, Fisheries, and Meteorology, and the Global Seismological Network to improve seismic monitoring throughout Samoa, to standardize seismic monitoring, and to increase the number of seismograph recording stations (Leavasa 2004).
- Identify areas susceptible to mass wasting and debris flows, and map landslide scars. Monitor slide- prone areas and measure distance of slope movement, visible cracks, slumps, and scars.

### Coastal Erosion and Beach Loss

#### Beaches

Sand beaches are present only in limited areas of the coastline of Tutuila. Coastal plains, which are underlain by a mixture of terrigenous and marine sediments and support beaches, wetlands, stream valleys, alluvial fans, and mangrove forests, are separated by headlands of volcanic rocks (Richmond 1995). Beaches fringe approximately 20% of the island's coastline. Beach features include pocket beaches, barrier spits, tombolos, and small flood- deltas at the mouths of stream valleys (Richmond 1995). Beaches are an important and limited natural resource to American Samoa and are not desirable sources for sand and gravel. Sand mining on coastal beaches would severely degrade the resource and affect the sediment budget for the entire coastal system.

The sands of the shoreline are present as loose, fine to coarse grains and as moderately lithified beach rock. Sediment type depends on the material available and the energy regime associated with deposition. Higher energy conditions during deposition yield coarser sediment deposits (Richmond 1995).

The composition of Tutuila sand is primarily calcareous fragments of coral, shells, and algal mat remnants (Keating 1992). In most areas of American Samoa, lagoonal sediments are fine- grained and friable. Lagoons help to protect the coast during storms (Lewis 1989). Coastal deposits contain sand and gravel eroded from Holocene basalts and carbonaceous sediments. These deposits are present only locally at the ends of lava fields in alluvial deltaic settings near coastal lagoons. These areas may support seagrass beds that act as nurseries for reef fisheries (Lewis 1989) but are too fragile for mineral extraction.

Because of the isolation of American Samoa, construction materials are both expensive and difficult to import. Thus, careful management is essential to protect the islands' indigenous resources. Colluvium and alluvium add silt, clay, loam, silty clay, boulders, gravels, and sand to the natural resources of American Samoa (Keating 1992). Crushed dense volcanic rock, such as that at the Pago caldera complex, is suitable for concrete aggregate and road material. Cinder deposits are also used for road surfaces. These deposits are found at the Futiga and Mapusaga cones.

### Coastal Engineering

The islands of American Samoa are slowly subsiding into the sea. Because these are now extinct volcanoes, subsidence occurs due to the lack of thermal uplift associated with active volcanism, deflation of vacated magma chambers below the islands, and the weight of the mass of volcanic rock on the ocean floor (see Volcanoes and Volcanism section below). As an island subsides, coastal, low- lying areas are slowly submerged, changing shoreline dynamics.

Structures intended to reduce erosion along one stretch of beach often cause beach loss further along the direction of longshore transport. For instance, the majority of villages and island infrastructure are located on the coastal plains of Tutuila. Where erosion threatens villages, buildings, or roads, engineering structures such as riprap, revetments, groins, or seawalls are typically constructed to prevent coastal erosion (Richmond 1995). Riprap is composed of large, loose blocks (concrete, rock, asphalt or other resistant material) placed to stabilize and armor a coastline susceptible to erosion. Riprap is placed below slopes and along sandy beaches to reduce sediment movement and to decrease erosion and undercutting of the coastline.

Shoreline armoring has severely reduced the amount of beach available for traditional recreational uses and has degraded the natural state of Tutuila beaches. The shoreline is prevented from normal migration in response to storm surges and cyclones (Richmond 1995). Water that ponds behind the riprap allows sand to accumulate, whereas water scours the ocean- facing side, which is starved of sand and thus preferentially erodes. The more extensive the riprap structure, the more the erosional effect further down (down- current) the shoreline.

This erosion, combined with island subsidence, sand extraction, and structures designed to buffer against waves, is causing significant coastal disturbance in the park and throughout the Samoa Islands (Richmond 1992a).

### Inventory, Monitoring, and Research Needs for Coastsal Erosion and Beach Loss

- Refer to U.S. Army Corps of Engineers shoreline inventories from 1980 and 1989, which describe the developed shoreline emphasizing engineering structures and erosion. Incorporate this information into the park GIS.
- Research recycled sand alternatives including crushed building material (such as old concrete or asphalt).
- Focus an interpretive program on the origin, distribution, and movement of sand supply.
- Discourage the use of beach sand as construction material.
- Cooperate with local developers to reduce the amount of riprap in areas adjacent to park beaches.
- Create education programs that depict the consequences of riprap along beaches. Highlight the natural processes of sand supply and movement, longshore drift, and erosion.
- Research alternatives to riprap that will stabilize surrounding beach areas for adequate recreation.

# Geologic Features and Processes

*This section describes the most prominent and distinctive geologic features and processes in National Park of American Samoa.*

### Volcanoes and Volcanism

The volcanic features at National Park of American Samoa range from broad, gently sloping, eroded shield volcanoes to steep, slightly weathered, cinder- cone deposits. Many craters are present throughout the islands (Keating 1992). Samoan shield volcanoes erupt from fissures and along the flanks, rather than exclusively from summit craters and most are lava flows rather than airfall debris (Hawkins 1987)

On Tutuila, the largest (approximately 32 km (20 mi) long and 9 km (5.5 mi) wide) and oldest island in the park, the landscape is dominated by the eroded Pago shield volcano. This volcano's maximum elevation is 653 m (2,142 ft) at Matafao Peak (fig. 6). Based on the dip of post- caldera lavas, the mountain once may have risen as high as 1,200 m (3,937 ft) above present sea level (Keating 1992). Rugged terrain with steep, narrow valleys and deeply embayed coastlines characterize the island. Several overlapping basaltic shield volcanoes underlie the island along a rift zone that strikes N. 70° E. at an angle to the overall west- east trend of the Samoan chain. Among the larger volcanic centers on the island are Olomoana, Alofau, Pago, and Taputapu (fig. 6). Most lavas are present as shallow dipping flows 1 to 10 m (3 to 33 ft) thick composed of olivine basalt and hawaiite (McDougall 1985).

Dikes of similar composition that strike parallel to the Samoan chain are common in the Pago volcano. Today, only the northern half of the Pago shield remains; the rest was removed during the formation of Pago caldera (now drowned and forms Pago Pago Harbor). Other shield volcanoes erupted at about the same time as the Pago volcano. The Olomoana and Taputapu volcanoes were built on eastern and western extensions, respectively, of the same rift zone. Recent reactivation of volcanism at Tutuila produced the cinder cones, ash, and tuff of the Leone volcanic rocks. These rocks dominate a broad plain in the southwestern portion of the island (McDougall 1985), the only place on Tutuila where cones are concentrated (Keating 1992).

Volcanic cones are present at Tauga Point on the northwest tip of the island of Ofu. At Lemaga Point on the southeast tip of Olosega (fig. 6), another volcanic cone is exposed. The oldest rocks on Ofu- Olosega, the Asaga Formation, form volcanic breccia cones. Several large and small craters are scattered across the landscape of Ta'u. Red Lake, on Aunu'u Island (not part of the park) is a crater lake—a drowned volcanic crater (Keating 1992).

The volcanoes of American Samoa are considered classic examples of the plume- driven, age- progressive hotspot island chain (fig. 7), in part because of the geomorphology of the islands. The oldest volcanic islands are also the most weathered and eroded (fig. 8). The youthful, uneroded shield landscape at Ta'u is in sharp contrast to the deeply incised valleys of Tutuila (Hart et al. 2004). Recent studies show that island formation was more complex than simply a hotspot source of volcanism. The islands appear too limited in geographic scope and lack the oceanic basaltic plateaus necessary to strictly fit the deep- mantle plume, long-lived hotspot model (Clouard and Bonneville 2001).

Although the overriding trend is for volcanic islands in Samoa to increase in age from east to west, rejuvenated volcanism on older islands (such as Savai'I and Upolu) in the chain are putting this classic model into question (Hawkins 1987). Other hotspot island chains have intersecting lineaments that further complicate the hotspot model including the Tuvalu lineament and the lineaments from the Cook- Austral or Louisville hotspots (see fig. 16 below). The location of the Samoa Islands just north of the Kermadec- Tonga trench (fig. 3), where it swings westwards towards Fiji, may help explain the volcanic rejuvenation and complexity of island formation (Hawkins 1987).

### Coral Reefs and Sea Level Change

Coral reefs surround all islands of National Park of American Samoa. Corals thrive in warm, clear water, and framework- building corals grow at depths between the low- water level and no more than 20 m (66 ft) (Richmond 1995). Around Tutuila, the reefs display considerable spatial variation in the amount of development and distance to the island's shoreline. This variation may indicate the presence of a drowned reef forming a shelf around certain parts of the island at 58–72 m (190–236 ft) depth (Keating 1992). Off Tutuila, a narrow reef structure is formed by the coalescence of the fringing reef and barrier reef. This feature is only 10.5 m (34 ft) across (fig. 4*A*) (Keating 1992). Fringing reefs consist of a reef flat extending seaward from the shoreline and terminating in a reef crest beyond which a steep reef face forms the seaward margin (Richmond 1995). Reef development is limited around Ofu, Olosega, and Ta'u (Keating 1992), because submarine slopes around the islands are steep. Water reaches depths of 610 m (2,000 ft) within 0.8–3 km (0.5–2 mi) offshore (fig. 4*B-C*).

Corals are important to National Park of American Samoa for at least two reasons. First, they protect adjacent coastlines (Bruce Richmond, written comm. 2007). Coral organisms secrete carbonate minerals from their cells in successive layers and build widespread coral "rocks" that slowly add to island area (1.3–7.6 centimeters (cm)/year, 0.5–3.6 inches (in.)/year). These carbonate minerals form a solid structure that buffers the shoreline from large waves and storms. Coral and other reef organisms also supply much of the nonvolcanic sediment at American Samoa (Richmond 1995). Coral is used for building material and adds to the sands in the lagoons and beaches (www.nps.gov/npsa).

Coral reefs are also important because of their high degree of biodiversity. The number of coral species represented in the reefs of National Park of American Samoa is vast. Families may contain many species, such as Zoanthidae, Alcyoniidae, Actinodiscidae, Acroporidae, Pocilliporidae, Poritidae, Agariciidae, Siderastreidae, Fungiidae, Oculinidae, Pectiniidae, Mussidae, Faviidae, Merulinidae, Helioporidae, and Milleporidae (figs. 9–12). National Park of American Samoa maintains a coral inventory website (http://www.nps.gov/npsa/NPSAcorl/corlnamA.htm) (last accessed January 9, 2008) that is regularly revised as new species are documented.

Effective resource management at American Samoa National Park requires an understanding of global climate change. A small rise in sea level could drown the coral reefs and coastal plains of the islands. Previous sea level positions are recorded on the islands by drowned reefs, truncated ridges, wave- cut benches, and cliffs (Keating 1992). On Upolu (fig. 1), a positive sediment budget allowed mangrove swamps to develop; these swamps and larger fringing and barrier reefs may indicate a small relative sea- level lowering since the past 700- 1,000 years (Richmond 1992a; Goodwin and Grossman 2003).

Understanding the history of sea level changes, especially those during the most recent (Holocene) epoch, is important for constraining geodynamic theories of crustal flexure and plate tectonics, interpreting the environments of early human occupation sites, and predicting future environmental conditions, especially as they pertain to coral reefs and ecosystem health (Dickinson 2001). The overall pattern of Holocene sea level for the equatorial Pacific indicates a middle to late Holocene highstand (1–3 m above present average value) (Grossman et al. 1998). Subsequently, sea level lowered to present elevations.

In the Samoa Islands this drop in sea level stranded wave- cut benches, beach rock, caves, and coral reefs) on dry land (Dickinson 2001). This drop in sea level may also have coincided with early human migrations into island groups of the northwestern and southwestern Pacific Ocean Basin. The early settlers would have taken advantage of newly available coastal environments created by lowered sea level (Dickinson 2001).

#### Weathering and Erosion

The current landscape at National Park of American Samoa illustrates the contrasting forces of island building by volcanism and reef formation and the persistent forces of weathering and erosion that lower island elevation and reduce their size. On Tutuila, the Pago volcanic rocks that form the main caldera show amphitheatre- headed canyons and deep V- shaped valleys. Deeply incised canyons and valleys are also common in the Taputapu volcanic rocks. Erosion of the Alofau and Olomoana volcanic rocks is less pervasive. In these areas, only limited canyons and shallow gullies exist. The youngest rocks on Tutuila, those of the Leone volcanic rocks, possess weakly developed drainage patterns and little soil (Ollier 1988; Keating 1992).

Amphitheatre- headed canyons commonly form in response to local springs (Ollier 1988). Springs develop in volcanic rocks of high permeability and readily available groundwater. The flow from springs locally erode and undercut valley sides roughly along the elevation of the local water table. Streams are concentrated at the valley head, and landslides and mass wasting reduce the valley sides in short bursts. Relatively flat valley floors are commonly mantled with talus deposits. The intersection of the valley and the adjacent plateau is typically an abrupt cliff (Ollier 1988).

Perhaps the most dramatic erosional features at National Park of American Samoa are the numerous sea cliffs. These cliffs typically develop on a coast that lacks a buffering coral reef and thus is exposed to direct attack by waves. Such cliffs line the Leone peninsula on Tutuila and encircle the islands of Ofu and Olosega (Keating 1992). Erosional features at American Samoa such as sea-cut caves, benches, and ancient shorelines record variation in sea level during the past million years. Benches on Tutuila are 3–6 m (10–20 ft) above the present high tide level. Openings in sea- cut caves at Mataae Point and Fagaitua (fig. 6) are now 5 m (16 ft) above high tide (Keating 1992).

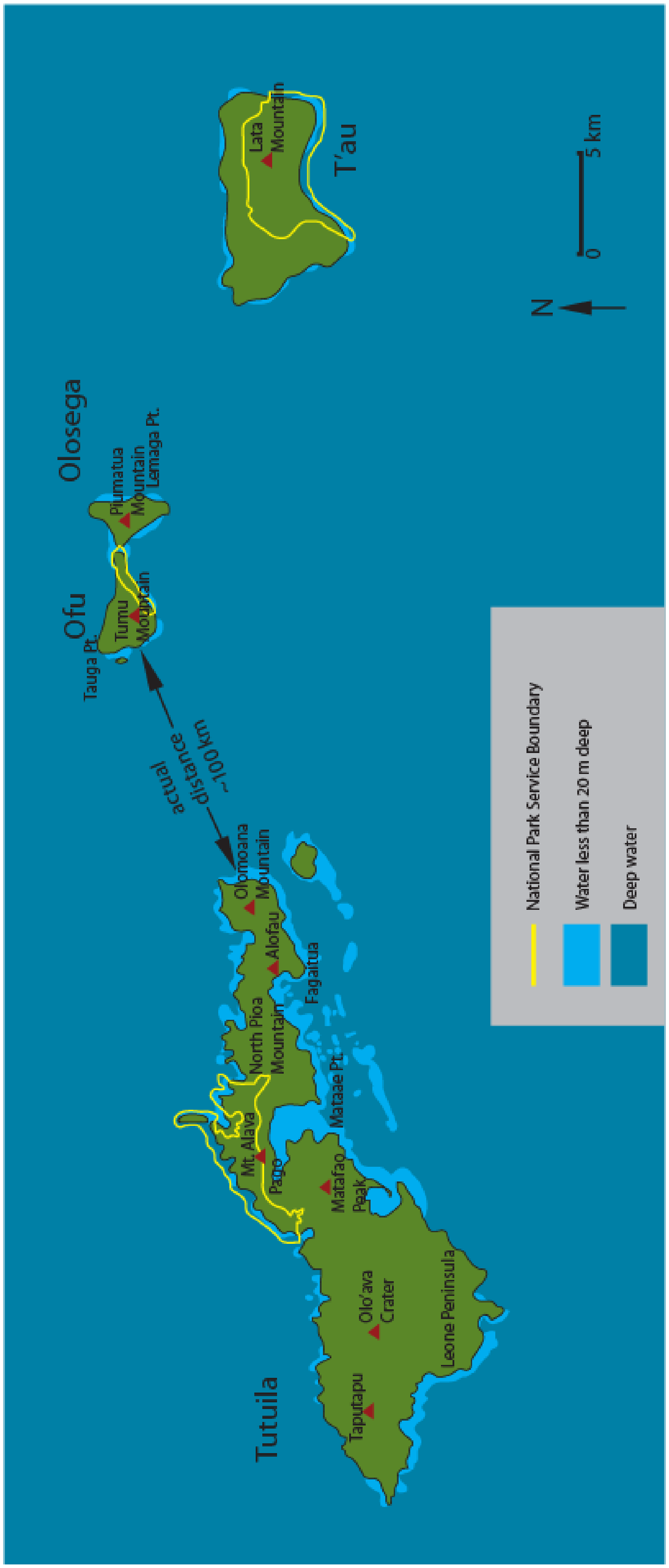


**Figure 6: Map showing features mentioned in the text. Information from National Oceanic and Atmospheric Administration (2007), and Keating (1992); graphic by Trista L. Thornberry-Ehrlich (Colorado State University).**

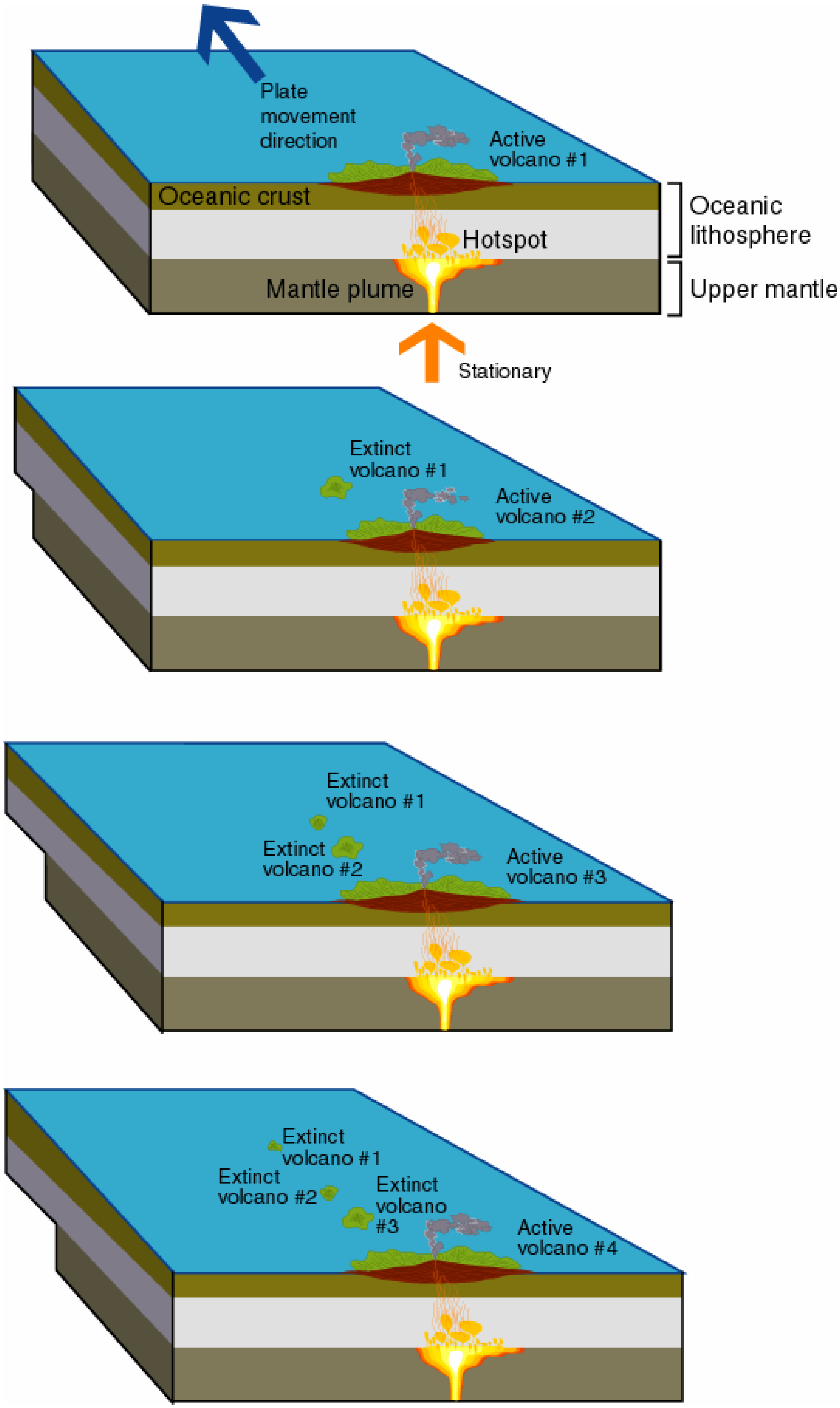


**Figure 7: Development of a volcanic island chain over a stationary hotspot in the mantle and lower lithosphere. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).**

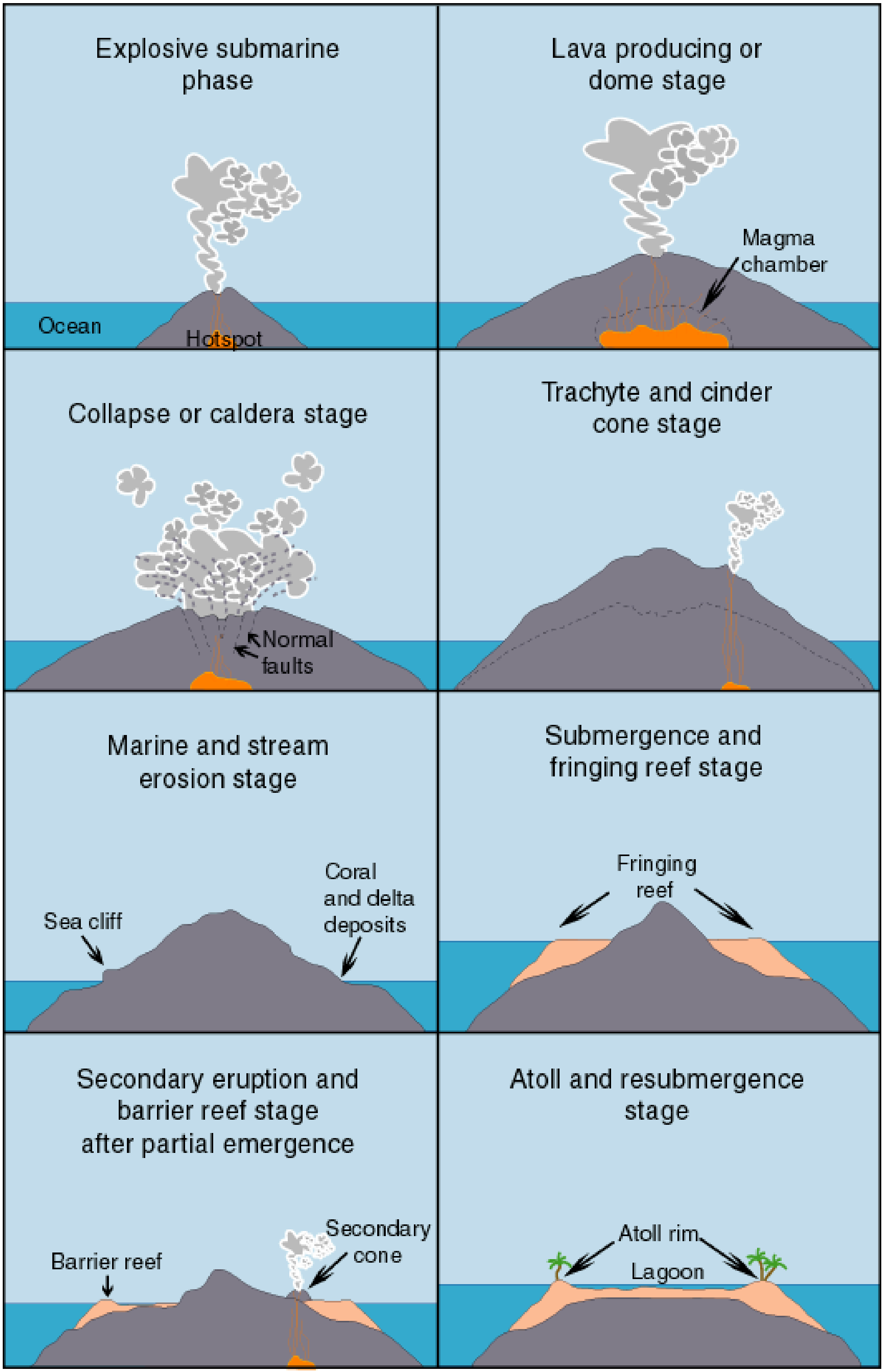


**Figure 8: Simplified stages of hotspot island volcanism. After volcanism ceases, erosion and subsidence slowly lower the island into the sea. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after figure 29 in Keating, 1992.**

**Figure 9:** ***Pocillopora eydouxi*** **Antler Coral. Photograph by Eva DiDonato (National Park Service).**

**Figure 10:** ***Acropora abrobanoides*****. Photograph by Eva DiDonato (National Park Service).**

**Figure 11: *Goniopora fruiticosa*. Photograph by Eva DiDonato (National Park Service).**

**Figure 12: *Gardineroseris planulata*. Photograph by Eva DiDonato (National Park Service).**

# Map Unit Properties

*This section identifies characteristics of map units that appear on the Geologic Resource Evaluation digital geologic map of National Park of American Samoa. The accompanying table is highly generalized and is provided for background purposes only. Ground- disturbing activities should not be permitted or denied on the basis of information in this table. More detailed map unit descriptions can be found in the help files that accompany the digital geologic map or by contacting the National Park Service Geologic Resources Division.*

Mapping of National Park of American Samoa is divided into three distinct island groups: Tutuila, Ta'u, and Ofu–Olosega. These islands sit on the Samoa Ridge, which is composed of thin- bedded pahoehoe basalt flows (or pillow lavas, if extruded under water). These flows built platforms 3- 5 km (2- 3 mi) high on the ocean floor that may rise above sea level (Wingert and Pereira 1981). The islands are composed almost entirely of volcanic rocks and their weathering products.

On Tutuila, the oldest rocks are from the Masefau dike complexes containing flows cut by basaltic dikes and talus breccias. Younger volcanic rocks include the Olomoana and, Alofau volcanic rocks, the Pago volcanic series, the Taputapu volcanic rocks, the 'Aunu'u tuff, and the Leone volcanic rocks. These eruptive rocks are from distinct volcanic episodes separated by quiescent erosional periods. Most of these units contain basalt, olivine basalt, picrite- basalt, and hawaiite flows; less common are volcanic breccias, cinder cone deposits, volcanic tuffs, and ash deposits (Wingert and Pereira 1981). The youngest map units on Tutuila are the loose calcareous beach sands, slope talus, and fluvial alluvium on the shores and valley floors of the island.

The Manu'a Islands (T'au, Ofu, and Olosega) are located along the crest of the easternmost portion of the Samoa Ridge (figs. 3, 19). The volcanic units of Ta'u contain, from oldest to youngest, the Lata, Tunoa, Luatele, and Fiti'uta Formations.

The geologic units on T'au are thick flows of a'a and pahoehoe nonporphyritic basalt, olivine basalt, and picrite- basalt. Deposits associated with caldera collapse include ponded lavas and pyroclastic deposits (Wingert and Pereira 1981).

On Ofu and Olosega, the oldest unit (the Asaga Formation) is composed of volcanic breccia, and composite and tuff cones. The Tuafanua Formation contains olivine basalt, basalt, picrite- basalt, and hawaiite flows with interbedded ash, tuff, and breccia beds. The Nu'u Formation contains lapilli tuff and hawaiite and olivine basalt flows. All Manu'a Islands are covered in part by younger, unconsolidated surficial units including noncalcareous alluvium, slope talus, marsh, and stream deposits as well as modern calcareous beach sand and beach rock (Wingert and Pereira 1981).

The following pages present a tabular view of the stratigraphic column and an itemized list of features of each map unit. This table specifies several properties of each unit in the stratigraphic column, such as name and map symbol, description, resistance to erosion, suitability for development, hazards, potential paleontologic resources, cultural resources and mineral occurrence, , recreational use, habitat and geologic significance.

# Map Unit Properties Table – Tutuila Map Units

| Age | Map Unit (Symbol) | Unit Description | Erosion Resistance | Suitability for Development | Hazards | Paleontologic Resources | Cultural Resources | Mineral Occurrence | Habitat | Recreation | Geologic Significance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| QUATERNARY - Recent | Sedimentary Rocks (Ra) | Unit consists of loose calcareous beach sand along coastal areas and may include slope talus at the foot of valley walls and river deposited alluvium on valley floors; units are a maximum of 60 m thick. | Very low | Development not recommended on this highly permeable, erodable, and fragile unit. | Mass wasting (landslides, rockfalls, slumps, slope creep, etc.); extreme beach erosion | Fragments of foraminifera, algae, shells, and corals | Sediments may contain pre- historic artifacts from local populations of indigenous peoples | Sand, gravel | Forms beach and near shore habitat vulnerable to degradation from coastal erosion | Unit is highly desirable for beach and shoreline recreation | Unit is derived from surrounding coral reef, thus an adequate supply of sand demands a healthy reef, unit indicates ecosystem health |
| QUATERNARY - Recent | Leone Volcanic: Leone Volcanic (Rll); stony ash(Rla); cinder cone (Rlc); lithic/vitric (Rlt) | Rll contains olivine pahoehoe basalt flows. Rla contains deposits of stony ash along the source fissure zone. Rlc consists of cinder cone deposits localized at the upper end of the source fissure. Rlt contains at least 2 thick tuff beds from Vailoatai, Fagatele, and Fogāma'a Craters with material from Fogāma'a Crater atop the Fagatele Crater volcanic deposits. | Moderate | Highly porous; may be unsuitable for waste treatment facility and unstable for building foundations | Ash and cinder cone deposits are unstable on slopes and pose mass wasting hazards | Plant and animal casts possible, fragments of drowned coral reef | Humans may have witnessed eruptions | Volcanic glass, ash, and cinders | Unit supports a barrier reef environment | Cinder cone deposits are unstable trail base | Basalt flows covered submerged barrier reef adding 21 square km of new land near Leone. |
| QUATERNARY - Recent | 'Aunu'u Tuff (Rat) | Unit comprises 'Aunu'u Island of lithic to vitric tuff deposits. Unit is more than 200 m thick. | Moderate | Highly porous; may be unsuitable for waste treatment facility and unstable for building foundations | Contains sharp, glassy fragments; may pose mass wasting hazards | Plant and animal casts possible | Volcanic glass may have provided tool material | Volcanic ash, glass | Unit supports a barrier reef environment | Unit may be unstable on slopes for trail base and other visitor use | Unit records resurgence of volcanic activity in the area following intense erosion, lava erupted below sea level and caused steam explosions |
| PLIOCENE – EARLIEST PLEISTOCENE | Trachyte Plugs and Dikes: Trachyte Plugs and Dikes (Pt); pumice deposits (Ptp) | Pt consists of 642 m of dense, cream- colored trachyte present in plugs and dikes. Plugs are weathered and exposed as conspicuous eroded bulbous domes which are younger than the surrounding volcanic rocks. Ptp is pumice deposits (highly porous lava) associated with the Vatia Plug. | Pt high; Ptp moderate | Pumice rich areas should be avoided for waste treatment facility development and trails | Rockfall and landslide hazards if undercut on a slope | None | Topographic high may have been attractive to indigenous peoples for rituals and settlers for strategic positions | Trachyte | Units form topographic highs for birds, and support montane, ridge top, mountain- top scrub, and cloud forest | Suitable for most use unless rich in friable pumice | Units record the latter stages of volcanic evolution |
| PLIOCENE – EARLIEST PLEISTOCENE | Taputapu Volcanics (Po) | Undifferentiated olivine basalts (2 to 15 m thick), dipping 5°- 10° from a rift zone parallel to the Samoan Ridge interlayered with thin- bedded cinder cone deposits, dikes, and thin vitric tuff beds. In some areas the volcanics are capped by thicker flows of porphyritic and nonporphyritic olivine poor basalts. Some red vitric tuff and cinders present locally. | Moderate | Abundance of unconsolidated or loosely consolidated cinder cone deposits may render unit unstable for foundations, avoid heavily fractured basalts | Fractured basalt flows, and cinder cone deposits are unstable on slopes and pose mass wasting hazards | None | Volcanic glass may have provided tool material | Olivine phenocrysts, volcanic glass; cinders | Unit supports a barrier reef environment | Unit attracts shoreline recreation in some areas | Subsidence and erosion of this unit gave rise to a fringing reef and gradually a barrier reef. |
| PLIOCENE – EARLIEST PLEISTOCENE | Pago Volcanic Series: Pago Volcanic Series (Ppe); andesite/basalt flows (Ppi); lithic/vitric tuff (Ppt) | The series comprised of extra- caldera volcanics of the largest shield forming Tutuila: upper member - basaltic and andesitic flows with associated cones, dikes, and trachyte plugs; lower member predates caldera formation of primitive basalt flows, and associated cones and dikes (1 to 15 m wide). Pisolitic beds present locally. Ppt is confined to within the 10- km wide Pago Caldera and consists of interbedded lithic to vitric tuffs. Flows are as much as 150 m thick. | Ppe moderate to high; Ppi and Ppt moderate | Heterogeneity of unit may render unit unstable for foundations; avoid development if highly fractured and/or degraded | Rockfall and landslide hazards if undercut on a slope, especially if highly fractured or heterogeneous | None | None documented | Crystalline quartz trachyte (Matafau, Pioa, and Papatele plugs) | Unit forms harbor, shoreline, and marine habitats | Unit attracts shoreline recreation in some areas | Unit eroded differentially as a result of weathering upon exposure to sulfuric gases and explosive eruptions, caldera now forms Pago Harbor. |
| PLIOCENE – EARLIEST PLEISTOCENE | Alofau Volcanics (Pa) | Thin- bedded pahoehoe basalt flows, some of which are primitive olivine- bearing associated with cones, vitric tuff beds, and numerous cross cutting dikes; unit forms a shield- shaped dome.; total thickness more than 962 m. | Moderate | Suitable for most development unless highly fractured or undercut on a slope. | Rockfall and landslide hazards if highly fractured and undercut on a slope | None | None documented | Olivine grains, dikes may contain phenocrysts | Unit supports evergreen forest and wet tropical climax vegetation | Suitable for most uses unless undercut on slope | Cross cutting dikes present dating opportunity for the volcanic evolution of the area |
| PLIOCENE – EARLIEST PLEISTOCENE | Olomoana Volcanics (Pol) | Areally restricted thin bedded primitive olivine basalt flows dipping 10° north; flows cap andesite deposits and associated cones, vitric tuff beds, and volcanic plugs. Locally trachyte lavas form domes. Some flows are interbedded with palagonitized vitric tuffs; thickness as much as 322 m. | Moderate to high; low to moderate for loose pumice rich material. | Unit suitable for most development unless highly fractured or undercut on a slope. | Rockfall and landslide hazards if tuffs are weathered out below more resistant trachyte on slopes | None | Pumice may have been used as tool material | Pumice, trachyte, basalt | Domes form topographic highs for birds and support montane, ridge top, mountain- top scrub, and cloud forest | Suitable for most use unless highly fractured | Succession of lava types from basalts to trachytes and andesites records evolution of Olomoana volcano |
| PLIOCENE – EARLIEST PLEISTOCENE | Masefau Dike Complex (Pm) | Narrow basaltic dikes (a few cm to 2 m wide) and associated intraformational slope talus breccia cut older thin, basaltic flows; dikes are vesicular and platy with local amygdaloidal textures. | Moderate to high where dikes are coarsely crystalline | Avoid areas where flows are underlain by slope talus breccia as instability may occur. | Rockfall and landslide hazards if undercut on slope | None | None documented | Vesicles may be filled with secondary minerals | Vesicles may provide nesting habitat or burrow type habitat | Suitable for most use unless highly vesicular rich in slope talus breccia | Cross cutting dikes and intervolcanic episode slope talus breccia present dating opportunity for the geologic evolution of the area |

# Map Unit Properties Table – Tau Map Units

| Age | Map Unit (Symbol) | Unit Description | Erosion Resistance | Suitability for Development | Hazards | Paleontologic Resources | Cultural Resources | Mineral Specimens | Mineral Resources | Habitat | Recreation | Global Significance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| QUATERNARY – RECENT | Calcareous Sediments (Qb) | Modern beach deposits consisting of unconsolidated fragments of shells and other marine organisms. May be present as coquina or beachrock. | Very low to low | Development not recommended on this highly permeable, erodable, and fragile unit. | Extreme beach erosion associated with this unit | Coral and shell fragments | Sediments may contain pre-historic artifacts from local populations of indigenous peoples | Coquina | sand | Unit forms beach and near shore habitat vulnerable to degradation from coastal erosion and sand mining | Unit is highly desirable for beach and shoreline recreation | Units contain benches at 4 and 1.5m above present sea level as past indicators of higher eustatic stands |
| QUATERNARY – RECENT | Noncalcareous Sediments: alluvium (Qa); marshes (Qm) | Units consist of noncalcareous alluvium, slope talus, and stream deposits. Marsh deposits are fine- grained with organic material and mud, located behind constructional beaches. | Very low | Development not recommended on this highly permeable, erodable, and fragile unit. | Mass wasting hazards (landslides, rockfalls, slumps, slope creep, etc.) associated with this unit | Plant and animal debris | Sediments may contain pre-historic artifacts from local populations of indigenous peoples | None documented | Sand, clay, gravel, peat | Units support riparian and marsh- wetland habitat | Marsh units should be avoided for recreational use | Units reflect weathering and geomorphological processes active on the islands |
| QUATERNARY – RECENT | Fiti'uta Formation: lava flows (Qfl); cinder cone (Qfc) | Qfl consists of basalt and olivine basalt lava flows that form a bench at Fiti'uta. Qfc is associated with Qfl as cinder cone deposits interrupting the sequence of basaltic lava flows. | Moderate | Where abundant cinder cone deposits exist, unit is highly porous and might prove unsuitable for waste treatment facility development | Bench of basalt may be susceptible to rockfall and landslides if undercut or sitting atop weathered cinder cone deposits on a slope. | Coral blocks interbedded in tuff layers, plant and animal casts possible | Humans may have witnessed eruptions | Dunite- bearing flows (olivine); dunite xenoliths and coral blocks | Basalts, cinders | Unit supports evergreen forest and wet tropical climax vegetation | Suitable for most use unless rich in friable, unstable cinder cone deposits | Unit contains tuffs with xenoliths and coral fragments indicating longstanding hiatuses between flows, buries a former sea cliff showing evolution of island shorelines |
| QUATERNARY – RECENT | Faleāsao Formation (Qft) | Unit contains undifferentiated tuff complex of palagonitized vitric- crystal lapilli tuff, volcanic breccia, and occasional, roughly horizontal lava flows from at least three cone centers at Faleāsao, To'a, and Fa'asamene Coves. | Moderate | Unit is highly porous and might prove unsuitable for waste treatment facility development, may be unstable for building foundations | Ash, tuff, and cinder cone deposits are unstable on slopes and pose mass wasting hazards. Some units also contain sharp, glassy fragments | Plant and animal casts possible | Humans may have witnessed eruptions | Volcanic glass | Basalt | Depressions may support wetland development and provide shelter | Units may contain sharp fragments unsuitable for trail base | Unit is limited by extensive erosional surface, indicating a long- term intervolcanic period |
| PLIOCENE | Luatele Formation: pahoehoe flows (Qlp); ponded lava flows (Qlc) | Qlp contains thin pahoehoe lava flows of olivine basalt and picrite- basalt. Unit forms the Luatele shield on the northeastern portion of the island of Tau. Qlc contain 300 m thick ponded lavas from flows which partly fill local depressions in the caldera. | Moderate | Unit is suitable for most development unless highly fractured or undercut on a slope. | Rockfall and landslide hazards associated with this unit if undercut on a slope | None | None documented | Olivine phenocrysts | Basalt | Depressions may support wetland development and provide shelter | Suitable for most use unless highly fractured | Following summit collapse, ponded lavas record the end of local volcanic activity. |
| PLIOCENE | Tûnoa Formation: lava flows (Qte); cinder cone (Qtec); volcanic deposits (Qtc); cinder cone (Qtcc) | Qtec contains cinder cone deposits from the Tunoa shield which is comprised of basalt and olivine basalt lava flows on the northwestern portion of Tau. Qtc is composed of volcanic deposits of red vitric and crystal ash, lapilli tuff, and associated olivine basalt lava flows, these units and associated cinder cone deposits partly fill the depression formed during the collapse of the volcanic shield. | Moderate | Heterogeneity of unit as well as abundance of unconsolidated or loosely consolidated cinder cone and lapilli deposits may render unit unstable for foundations | Ash and cinder cone deposits are unstable on slopes and pose mass wasting hazards. Some units also contain sharp, glassy fragments | None | None documented | Olivine phenocrysts, volcanic glass, lapilli, red crystal ash | Cinders, basalt | Collapse features provide shelter, subterranean habitat and may support marsh development | Suitable for most use unless rich in friable, unstable ash and cinder cone deposits | Unit records discrete volcanic episode at the Tunoa shield in the northwestern portion of Tau |
| PLIOCENE | Lata Formation: post-caldera (Qle); post-caldera cinder cone (Qlec); post- caldera lava flows (Qlel); inra- caldera (Qli); intra- caldera cinder cone (Qlic); intra- caldera lava flows (Qlil) | Formation is comprised of olivine basalts, picrite- basalts, basalts, and hawaiites present as flows, cinder cone deposits, and other eruptions associated with the caldera collapse on Tau. | Moderate | Unit is suitable for most development unless highly fractured, rich in cinder cone deposits or undercut on a slope. | Ash and cinder cone deposits as well as fractured basalt flows are unstable on slopes and pose mass wasting hazards | None | None documented | Olivine phenocrysts | Cinders, basalt | Unit supports evergreen forest and wet tropical climax vegetation | Unit is suited for light recreational use unless highly fractured and/or degraded | Units record the caldera collapse of Lata Mountain |
| PLIOCENE | Lata Formation: pre-caldera (Tle) | The pre- caldera member consists of interlayered lava flows of olivine basalt, picrite-basalt, basalt, feldspar- phyric basalt, and hawaiite. Occasional tuff beds are interlayered locally. | Moderate | Unit is suitable for most development unless highly fractured or undercut on a slope. | Rockfall and landslide hazards associated with this unit if undercut on a slope | None | Phenocrysts may have provided trade materials | Feldspar and olivine phenocrysts | Basalt | Unit supports montane, ridge top, mountain-top scrub, and cloud forest | Unit is suited for light recreational use unless highly fractured and/or degraded | Largest volcanic center along the crest of the easternmost portion of the Samoan Ridge, over 3600 m thick of volcanic layers at top of Lata Mountain |

# Map Unit Properties Table – Ofu and Olosega Map Units

| Age | Map Unit (Symbol) | Unit Description | Erosion Resistance | Suitability for Development | Hazards | Paleontologic Resources | Cultural Resources | Mineral Specimens | Mineral Resources | Habitat | Recreation | Global Significance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RECENT | Calcareous Sediments (Qb) | Modern beach deposits consisting of unconsolidated fragments of shells and other marine organisms. May be present as coquina or beachrock. | Very low to low | Development not recommended on this highly permeable, erodable, and fragile unit. | Extreme beach erosion associated with this unit | Coral and shell fragments | Sediments may contain pre- historic artifacts from local populations documenting 3,000 years of occupation of indigenous peoples | Coquina | sand | Units contain benches at 4 and 1.5m above present sea level as past indicators of higher eustatic stands | Units contain benches at 4 and 1.5m above present sea level as past indicators of higher eustatic stands | Units contain benches at 4 and 1.5m above present sea level as past indicators of higher eustatic stands |
| RECENT | Noncalcareous Sediments: alluvium (Qa); marshes (Qm) | Units consist of noncalcareous alluvium, slope talus, and stream deposits. Marsh deposits are fine-grained with organic material and mud, located behind constructional beaches. | Very low | Development not recommended on this highly permeable, erodable, and fragile unit. | Mass wasting hazards (landslides, rockfalls, slumps, slope creep, etc.) associated with this unit | Plant and animal debris | Sediments may contain pre- historic artifacts from 3,000 years of uninterrupted occupation of indigenous peoples | None documented | Sand, clay, gravel, peat? | Units support riparian and marsh- wetland habitat | Marsh units should be avoided for recreational use | Units reflect weathering and geomorphological processes active on the islands |
| RECENT - PLEISTOCENE | Nu'u Formation: tuff (Qnt); lava flows (Qnl) | Qnt is present as young palagonitized lapilli tuff forming Nu'utele and Nu'usilaelae islets. Qnl is present as flows of hawaiite and olivine basalt, unit also fills former eroded stream valleys on western Ofu. | Moderate | Unit is highly porous and might prove unsuitable for waste treatment facility development, may be unstable for building foundations | Ash and cinder cone deposits are unstable on slopes and pose mass wasting hazards. Some units also contain sharp, glassy fragments | Plant and animal casts possible | Humans may have witnessed eruptions from 3,000 years Bp | Ejected lapilli | Basalt | Unit supports evergreen forest and wet tropical climax vegetation | Units may contain sharp fragments unsuitable for trail base | Unit records renewed volcanic activity after prolonged period of quiescence and erosion, units comprise remnant islets |
| PLIOCENE | Tuafanua Formation: A'ofa shield (Ttae); Sili shield (Tts); A'ofa caldera volcanic deposits (Ttai) | Ttae is composed of coalescing shields (A'ofa) of pahoehoe and a'a olivine basalt, basalt, picrite- basalt, and hawaiite flows dipping 10- 20 degrees with interlayered ash, tuff, and breccia beds. Shields and the Fatuaga breccia cone are cut and intruded by numerous igneous dikes locally. Similarly, the Sili shield is comprised of coalescing layers of olivine basalt, picrite- basalt, basalt, and hawaiite flows with interbedded ash, tuff, and breccia layers. Ttai contains thick, ponded flows of olivine basalt, hawaiite, and ankaramite locally within the A'ofa Caldera deposits. | Moderate | Heterogeneity of unit as well as abundance of unconsolidated or loosely consolidated cinder cone and lapilli deposits may render unit unstable for foundations | Mass wasting hazards (landslides, rockfalls, slumps, slope creep, etc.) associated with this unit especially where flows are present above more easily eroded ash, tuff, and breccia layers | None | None documented | Olivine phenocrysts, ankaramite | Volcanic ash | Depressions may provide wetland habitat and shelter | Suitable for most recreation unless friable volcanic breccias are present | Units record volcanic evolution across several distinct shield areas and fissures. |
| PLIOCENE | Asaga Formation: Fatuaga Point breccia cone (Tafb); Fatuaga Point plug (Tafi); Toaga composite cone (Tat); Lemaga Point tuff cone (Tam); Samoi tuff cone (Tas); Taugā point cinder cone (Tac) | Tafb is volcanic breccia in a cone formation. Tafi is a volcanic plug associated with the volcanic flows at Fatuaga Point. Tat contains various volcanic ejecta in a composite cone. Tam is comprised of interlayered tuffs in a cone at Lemaga Point. Tas is also a tuff cone located at the west end of Samoi. Tac is composed of a series of older cinder cones oriented along the regional rift zone. | Tafi is moderate to high, Tafb, Tam, Tat, Tas, and Tac are moderate | Volcanic ejecta may be too permeable for waste treatment facility development and unconsolidated cone deposits may be unstable for building foundations | Ash and cinder cone deposits are unstable on slopes and pose mass wasting hazards. Some units also contain sharp, glassy fragments | None | None documented | Volcanic ejecta | Dense crystalline rock for building material, basalt, cinders | Unit supports evergreen forest and wet tropical climax vegetation | Suitable for most recreation unless friable volcanic breccias are present | Units cover older pyroclastic cones and now compose 3300 m thick shields of the islands. |

# Geologic History

*This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of National Park of American Samoa, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.*

In geologic terms, the rock units in National Park of American Samoa are young. Volcanism created most of these rocks beginning 23 million years ago (Ma)—compared to more than 4 billion years of Earth's history (fig. 13). Even so, the geologic setting and history of the Samoan archipelago is complex. Knowing how the islands formed is vital to understanding the current landscape and to predicting potential future geologic events.

In the late Paleozoic, all continental landmasses joined to form one large supercontinent called Pangaea (fig. 13). During this time, mountain ranges formed by active continental collision. A huge water body, the Panthallassic Ocean, surrounded Pangaea. This water body had persisted in some form since the late Proterozoic Era (about 570 Ma), when it appeared after a previous supercontinent, Rodinia, broke apart (Fossil Museum 2002).

The supercontinent Pangaea began to break apart early in the Triassic Period. Pangaea split into a northern continent called Laurasia and a southern continent called Gondwana. Further rifting divided Laurasia into the North American and Eurasian continents, whereas Gondwana eventually separated into the continents of South America, Africa, Australia, and Antarctica (Condie and Sloan 1998). Continental rifting opened new oceans such as the Atlantic Basin between the Americas and Europe and Africa. The Indian Ocean Basin formed between Africa, Antarctica, and Australia. Rifting continued throughout the Mesozoic (Fossil Museum 2002). The oceanic crust of the Panthallassic Ocean Basin was also changing during this time.

Approximately 125 Ma (early to middle Cretaceous), evidence suggests that a massive increase in volcanic activity in the western Pacific Ocean Basin produced large volcanic plateaus above several large mantle plumes. This activity was concurrent with a rapid increase in sea- floor- spreading rates. Rates increased by 50% to 100% and remained high until the late Cretaceous (Condie and Sloan 1998). This event correlates with rising sea level, global climate change (warming), and several extinction events in the middle Cretaceous.

The present Pacific plate fills most of the North Pacific Ocean Basin, but this relation was not always so. The Pacific plate, on which the Samoa Archipelago is located, is relatively young in geologic terms. In the Cretaceous, several plates existed within the basin, likely derived from the partitioning of the Panthalassic Ocean upon the breakup of Pangaea.

The Pacific plate started as a small central plate surrounded by the Aluk plate to the south, the Farallon plate to the east, and the Kula plate to the north (fig. 14) (Condie and Sloan 1998; University of California Santa Barbara 2006). Separated by mid- ocean ridges, the plates surrounding the Pacific plate began moving away from it. During the middle Tertiary, the surrounding plates were mostly assimilated into the earth's crust by subduction. Oceanic crust is denser than continental crust, so in a collision between the two, the oceanic crust tends to sink (subduct) beneath the continental crust. This subduction generates heat as the plate sinks into the upper mantle. The oceanic crust melts and rises to the surface often forming a volcanic arc above the melting plate, in effect recycling the oceanic crust material.

The Kula plate plunged beneath the northeast Asian subduction zone, possibly coincident with the opening of the Sea of Japan. A remnant of this plate remains as an inactive area of the Bering Sea. The Farallon plate subducted beneath North and South America resulting in the Sevier- Laramide orogenic event and the eventual formation of the San Andreas boundary. Remnants of this plate include the Juan de Fuca plate off the coast of the Cascade volcanic chain in Oregon and Washington, the Cocos plate in the eastern Pacific off the coast of central America, and the Nazca plate subducting beneath South America (Condie and Sloan 1998). During this time, the Pacific plate enlarged by seafloor spreading to nearly fill the north Pacific Basin. It now is moving slowly northward and westward—away from the East Pacific Rise spreading center and towards the subduction zones bordering the Australian- Indian plate, the Philippine plate, the Eurasian plate and the Aleutian Islands of the North American plate (fig. 15)(University of California Santa Barbara 2006).

The Pacific plate covers a considerable portion of the earth's crust, and is the largest tectonic plate on the planet today. Throughout the Pacific Basin are linear chains of volcanic islands and seamounts (submerged volcanoes). Many of these chains progress in age from one end to the other (fig. 7). As does The linear trend of the Samoa Islands records the movement of the Pacific plate over a stationary hotspot in the upper mantle. Other such spots across the basin are: the Hawaiian-Emperor seamount chain, the Caroline, Marquesas, Society, Pitcairn, Austral, and Easter hotspots (fig.16) (Condie and Sloan 1998). Several of these hotspots are part of a feature referred to as the South Pacific isotopic and thermal mantle anomaly. This anomaly, an area of possible mantle upwelling, supports at least eight major hotspots. The western terminus of the anomaly is just west of Samoa and the eastern edge is near the Easter Island hotspot (Koppers et al. 1998). Other criteria limit classic hotspots to those active areas displaying extensive oceanic basaltic plateaus and long- lived volcanic activity. These criteria exclude the Samoan hotspot as well as limit the number of spots considered to be deep- mantle plumes in the Pacific to three (Clouard and Bonneville 2001).

Hotspots form in response to rising plumes of very high temperature material from the lower mantle, just above the core- mantle interface. These plumes are thought to form as a result of localized thermal disturbances in the molten core of the earth. A portion of the core cools, causing the overlying mantle to heat up and rise owing to its decreased density. Once the plumes reach the upper levels of the mantle (~200 km (125 mi) deep), the lower pressure causes the material to melt. If this molten material (magma) finds a way to the outer crust, it may erupt and produce a series of volcanoes that decrease in age toward the plume (hotspot) (Condie and Sloan 1998).

The Samoa Islands are part of a volcanic archipelago that is located along the crest of the Samoa Ridge overlying the Samoa hotspot. This ridge extends more than 485 km (300 mi) from the Rose Atoll, westward towards Savai'i and beyond (fig. 1) (Wingert and Pereira 1981; Hart et al. 2004). The volcanic- lineament model at Samoa is not necessarily consistent with a strictly plume- driven hotspot model. On the westernmost and oldest (~5 million years old) Samoan island of Savai'i, voluminous young volcanic rock has sparked debate over the validity of the plume- driven hotspot model to the Samoan Archipelago (Hart et al. 2004). Upolu, the second oldest island, is dated at 2.8–1.7 Ma with little to no rejuvenated volcanic activity (McDougall 1985).

Isotopic dating of dredge basalts from four seamounts and submarine banks from along the entire trend of the Samoan lineament (some 1,300 km (800 mi) west of the island of Savai'i) indicates that Samoan volcanism is older to the west (fig. 17). The oldest rocks are more than 23 Ma at Alexa Bank, some 1,690 km (1,050 mi) west of Vailulu'u, the current hotspot location (Hart et al. 2004).

The next- oldest date is 11.1 Ma at Combe seamount (some 940 km (584 mi) west of Vailulu'u). These and other age dates are in keeping with the velocity of the Pacific plate movement listed below (Hart et al. 2004). Rejuvenated volcanism on Savai'i and other areas, such as Lalla Rookh, may be explained by the unique tectonic setting of the Samoan archipelago (Hart et al. 2004).

Samoa is close to the junction of the Pacific plate and the Australian- Indian plate. Currently at Samoa, the plate is moving N. 63° W. at 71 mm/year (2.8 in./year). The Australian plate, New Caledonia, and the Fiji platform are converging in an approximate N. 30° E. direction (Hart et al. 2004). At this point, the Pacific plate is tearing laterally in a pattern propagating eastward at the northern end of the Tonga arc (fig. 18) (Hart et al. 2004). Convergence of lithospheric plates produces a suite of geologic features such as volcanic arcs, fore- arc basins, deep- sea trenches, high relief (>600 m [>1,900 ft]) associated normal and reverse faults, and outer trench swells (also called oceanic rises) (Coulbourn et al. 1989; Hill and Tiffin 1993).

The nature of this boundary produces earthquakes associated with two structural features: (1) the partial subduction of the Pacific plate along the Tonga trench (figs. 17, 18) some 160 km (100 mi) south of Samoa and (2) the transform fault boundary between the northern edge of the Australian- Indian plate and the Pacific plate (bounding the Tonga trench (figs. 17, 19)) (Hart et al. 2004; Craig 2006). The crustal tearing at this junction may also be responsible for some renewed volcanic activity in the area, including that on Savai'i, and the formation of the Vitiaz lineament (figs. 17, 19). The lineament is a tectonically inactive structure composed of a series of west- northwest to east- southeast and east- northeast to west- southwest trending segments and a belt of seamounts and ridges in front of large volcanic massifs (Pelletier and Auzende 1995; Hart et al. 2004).

Renewed volcanism may relate to crustal interactions between the Pacific plate and the eastward migration of the Tonga trench corner (fig. 19) (Keating 1992). That trench corner migrates by >190 mm/year (7.4 in./year). Hart et al. (2004) suggest that the Vitiaz lineament is the trace of the eastward motion of this tear. Tearing may facilitate volcanic rejuvenation unrelated to the Samoan hotspot. If this is so, resource management at National Park of American Samoa can assume future volcanism may occur in areas distant from the present hotspot location.

Volcanic activity on the oldest island of National Park of American Samoa, Tutuila, lasted a relatively short time, some 0.6 million years (my), during the early Pleistocene (fig. 13). The major shield volcano of Pago was built between 1.54 and 1.28 Ma (Walker and Eyre 1995). Lavas forming that volcano erupted at the same time as Alofau and Olomoana volcanic rocks. The collapse of Pago's caldera occurred approximately 1.27 Ma. Minor caldera filling and emplacement of trachyte lava bodies ended about 1.03 Ma (McDougall 1985; Walker and Eyre 1995). Tutuila's long axis is oriented east- northeast, in contrast with the west- northwest orientation of rift zones and island elongation elsewhere in Samoa (including the islands of Manu'a). Feeder dikes present on Tutuila also show this east- northeast orientation. This difference is enigmatic and may suggest that the crustal offset associated with concealed faults (related to Samoa's location north of the Tonga trench and the Vitiaz lineament) has shifted volcanism during the formation of Tutuila (Walker and Eyre 1995).

The Manu'a Islands lie approximately 115 km (71 mi) east of Tutuila. These islands were formed by later volcanism associated with the migration of the Cretaceous- age crust of the Pacific plate over the stationary Samoa hotspot. Some dates report volcanism on Ofu and Olesega at less than 0.3 Ma and less than 0.1 Ma for the island of Ta'u. From these dates the average historic rate of migration of the volcanic center from Tutuila to Manu'a is about 100 mm/year (4 in./year) (McDougall 1985).

Ta'u is the easternmost Samoan island; however, volcanic activity associated with the stationary hotspot beneath the mobile Pacific plate has not stopped along the Samoan chain. A 3,444 - meter (11,300 ft) high submerged, active volcano is located 43 km (27 mi) east of Ta'u. This feature (named Vailulu'u) still lies some 610 m (2,000 ft) below the ocean's surface. It is isolated from Ta'u and has an enclosed crater. If volcanism persists at Vailulu'u, the volcano may rise above the surface of the ocean in the next 1,000 years (Lippsett 2001).

Volcanic activity is still a very real possibility at National Park of American Samoa. Tutuila Island was formed during a rapid series of eruptions only 1.5 Ma. In the Manu'a islands, subaqueous eruptions and earthquakes spewed clouds of pumice, volcanic ash, and steam for several months from September to November in 1866 (Keating 1992; Craig 2006).

The currently active submarine volcano, Vailulu'u, is building layers of basaltic lava and venting hydrothermal, mineral- laden water towards the ocean's surface and may in the future become the next Samoan island (Hart et al. 2004; Staudigel et al. 2004). As recently as 1905, lava flows from several large eruptions destroyed villages in Savai'i, Samoa (Craig 2006).

During periods of volcanic quiescence, the basalts, tuffs, breccias, cinder cones, and ash deposits are exposed to intense weathering and erosion in the wet Samoan climate. Landforms thus produced on the islands include amphitheatre valleys, steep- sided stream valleys, dissected volcanic plateaus, alternating valley and ridge topography, small- scale gullies, isolated plateau remnants, talus slope deposits, levee deposits, sea cliffs and benches (Ollier 1988). Ocean waves continuously pound the shorelines, carrying away sands and gravels eroded by the islands' rivers. Coral reefs rim the islands and contribute carbonate sediments to the islands' beaches.

A volcano's own mass causes it to sink and subside into the oceanic crust of the Pacific plate (fig. 8) (Ollier 1988; Craig 2006). Samoan volcanoes are subsiding at various rates (average at Tutuila is ~0.03 mm/year [0.001 inches/year]) (Dickinson 2001). Submarine mass wasting, landslides, and debris flows carry material from the shoreline, down the slopes of the islands to spread onto the deep sea floor. These mass movements are an important influence on the lowering of the Samoan Islands (fig. 8) and the development of the overall ocean island volcanic complex (Keating et al. 2000).

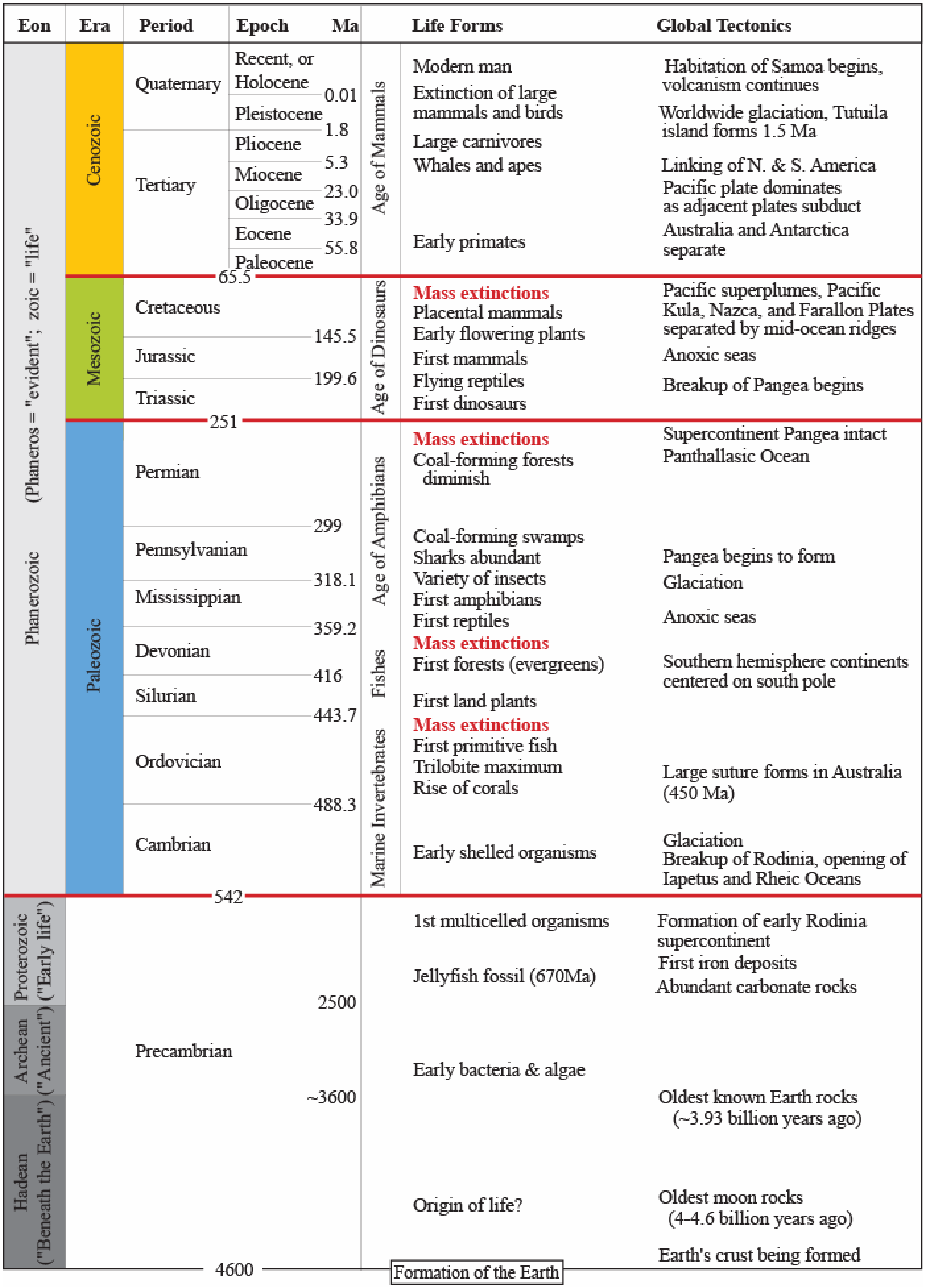


**Figure 13. Geologic time scale; adapted from U.S. Geological Survey (http://www.usgs.gov) and Condie and Sloan (1998). Red lines indicate major unconformities between eras. Included are major events in life history and global tectonic events that affected the South Pacific region. Absolute ages in millions of years.**

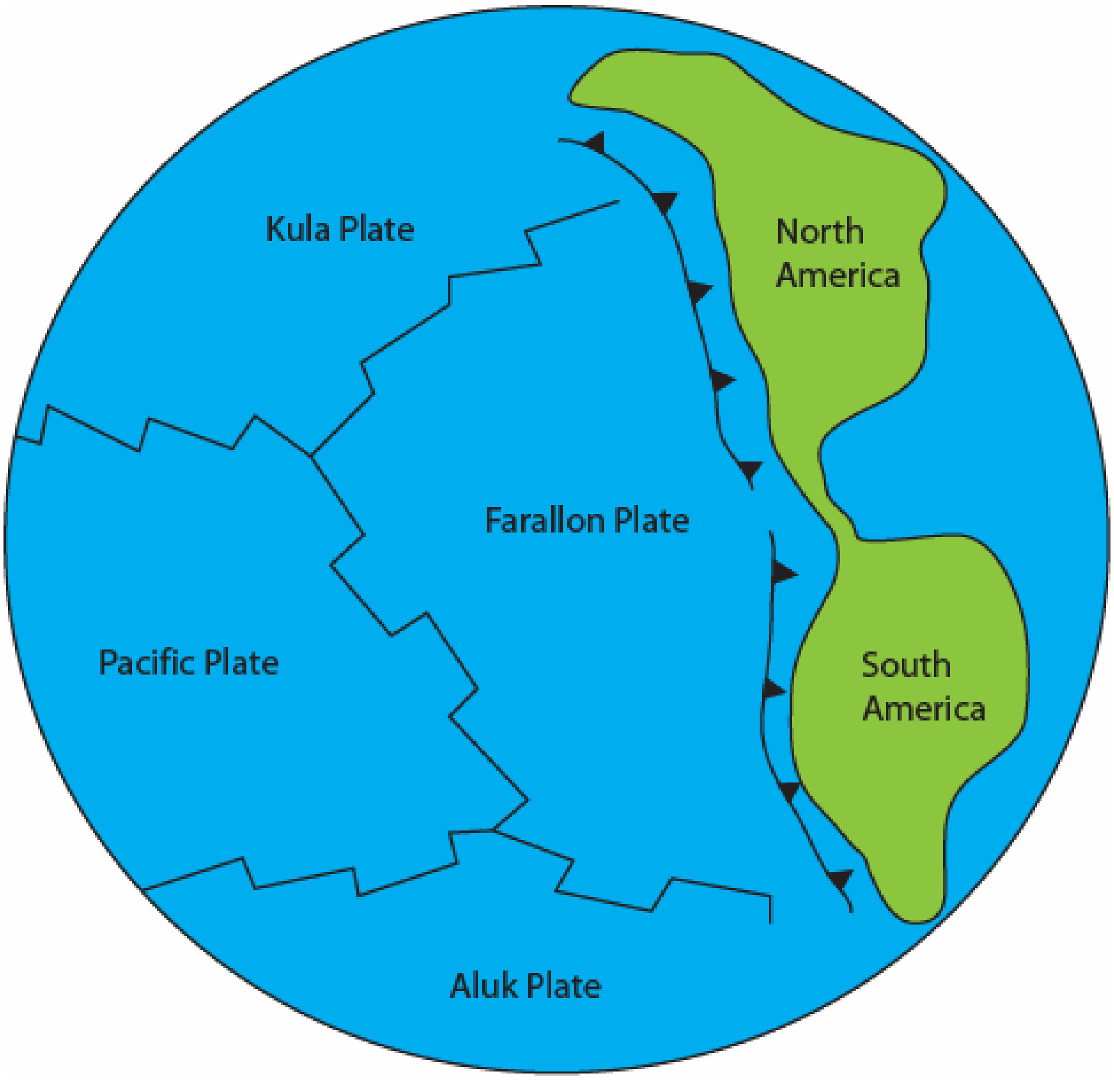


**Figure 14. Generalized location of plates in the Pacific basin during the middle Cretaceous. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University).**

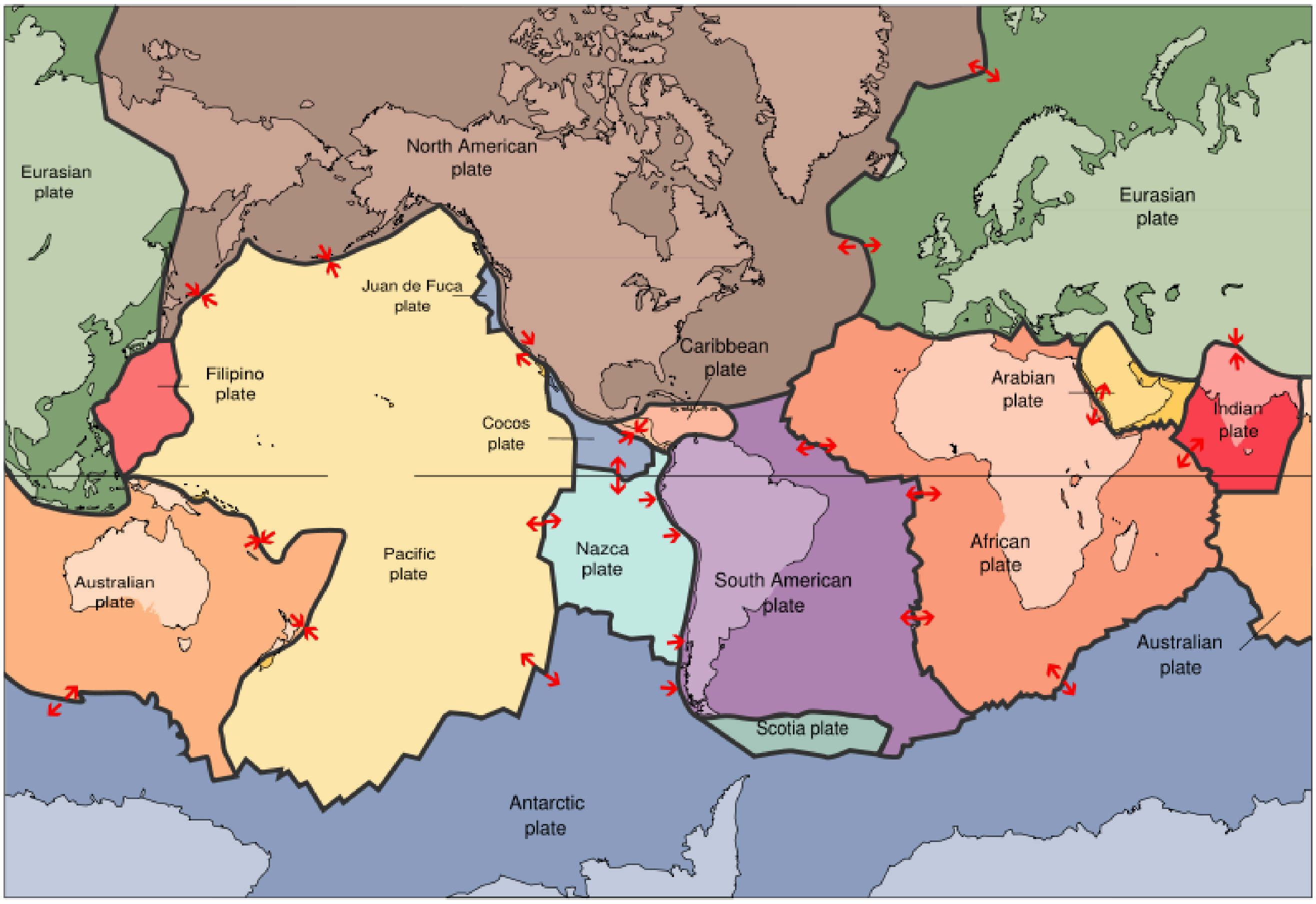


**Figure 15. Geographic map of the current tectonic plates. Graphic is from www.wikipedia.org (accessed August 20, 2007).**


**Figure 16. Location of hotspots across the South Pacific. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) adapted from figure 2 in Clouard and Bonneville (2001).**

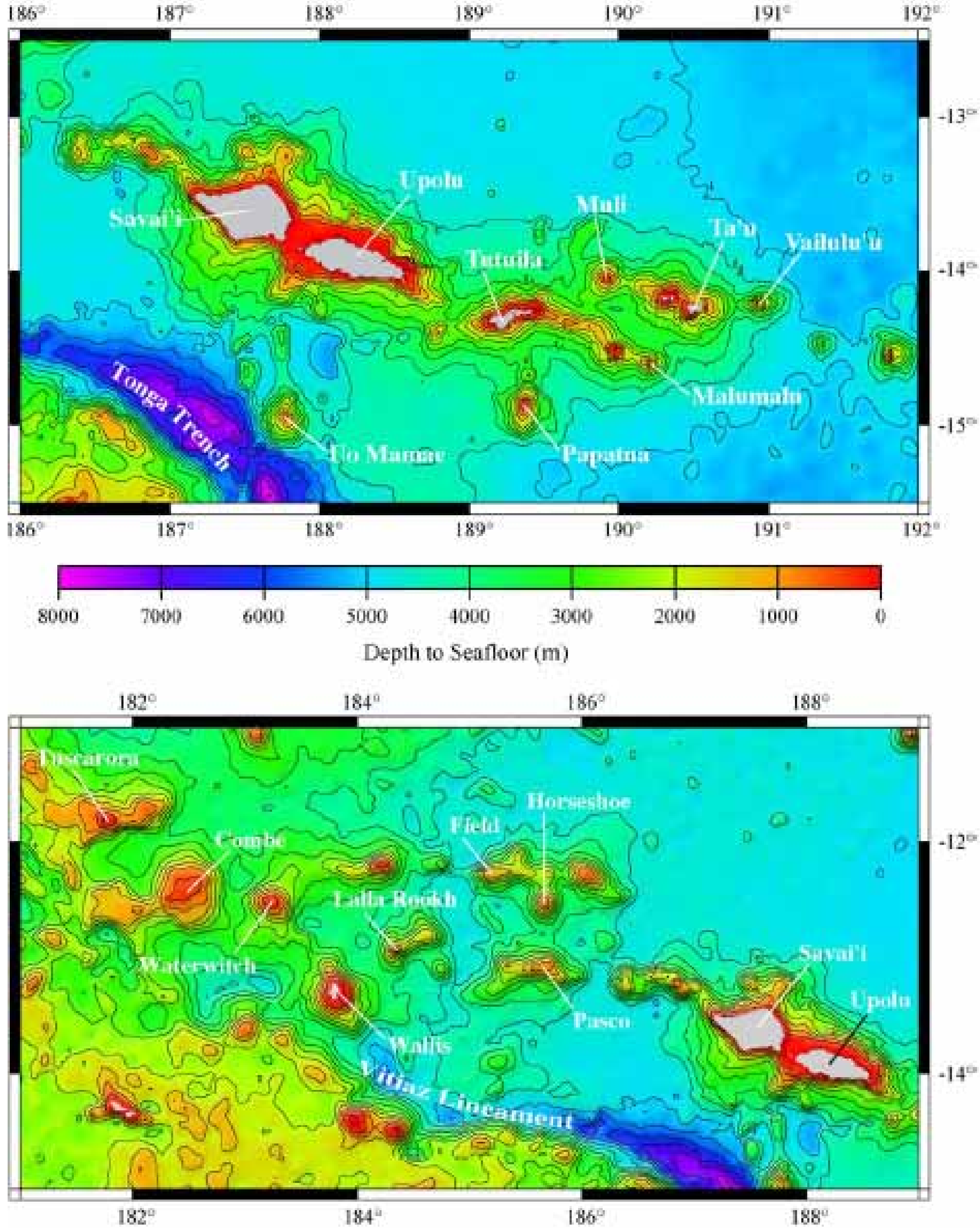


**Figure 17. Bathymetry of the Samoan seamounts (some named) relative to the subaerial islands including Ta'u, Tutuila, and Upolu. Note the location of the Tonga trench, Vailulu'u, Lalla Rookh, and the Vitiaz lineament, a tectonic structure mentioned in the Geologic History section of this report. Graphic is from Hart et al. (2004).**

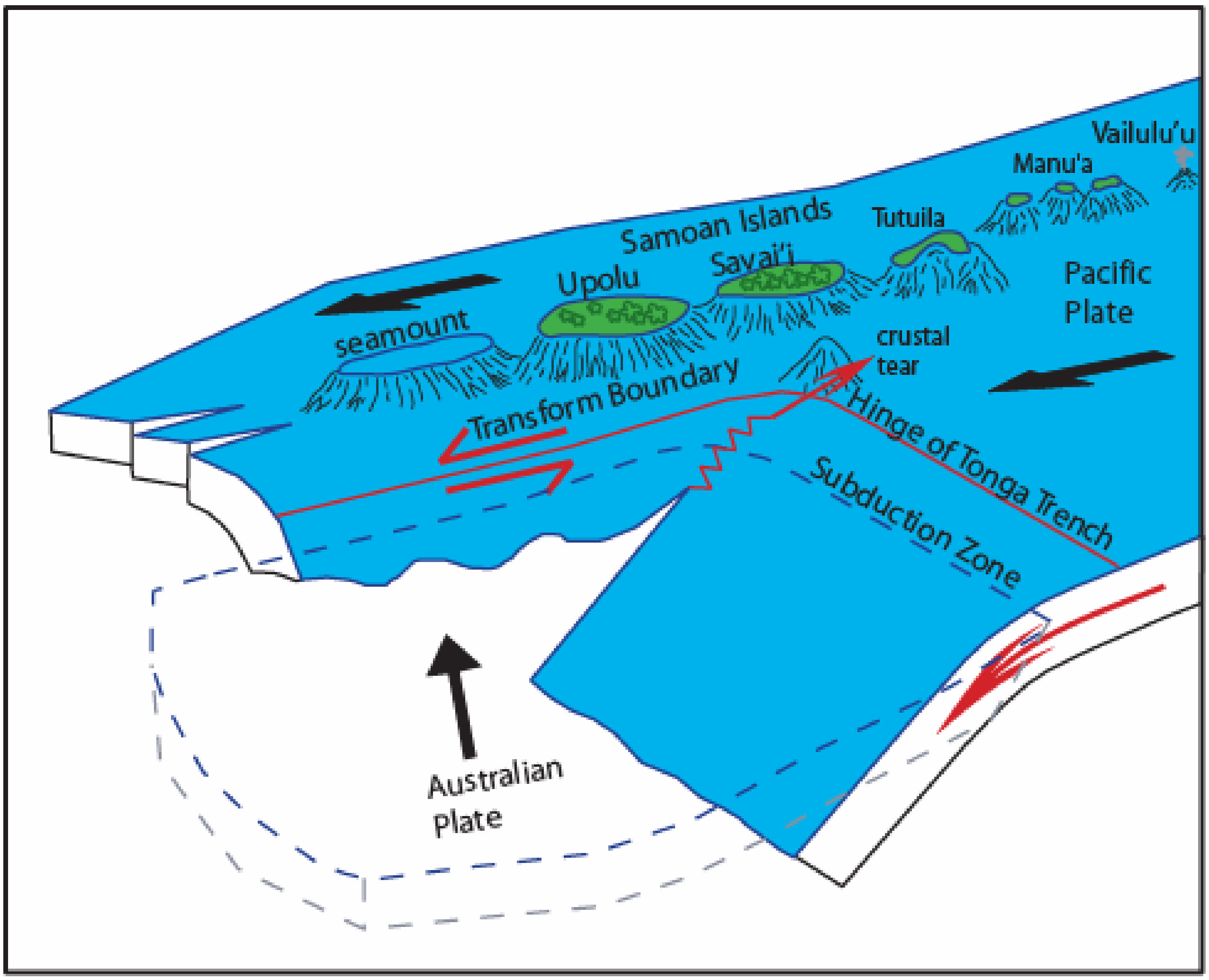


**Figure 18. Samoa Islands atop the Pacific plate in the vicinity of the Tonga trench. Note the location of the crustal tear just south of the Samoan Islands. Not to scale. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) adapted from figure 3 in Hawkins (1987).**

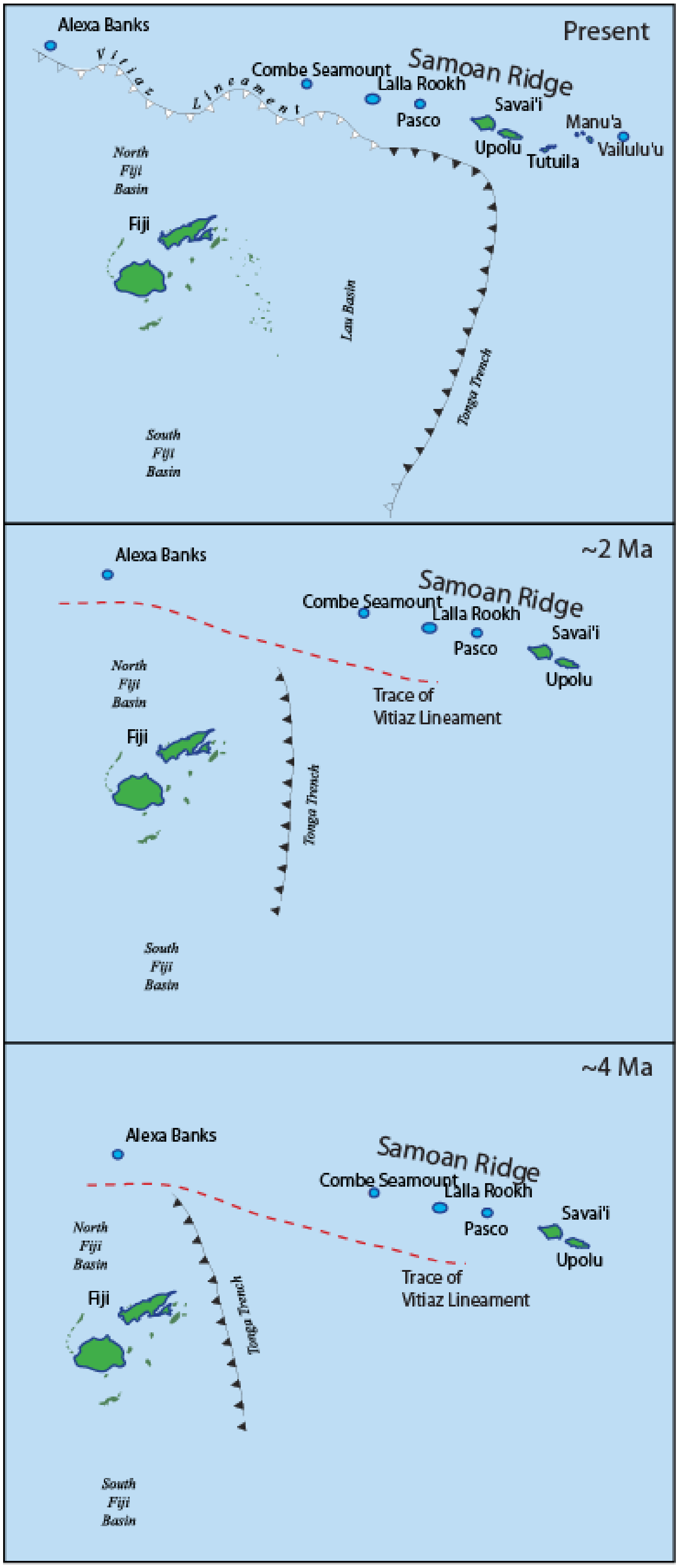


**Figure 19. Evolution of the positions of the Tonga trench, seamounts, and Vitiaz lineament relative to Fiji and the Samoan Island archipelago from ~4 Ma to present. Diagram is only roughly to scale. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University), based on information from Hart et al. (2004), figure 9.**

# Glossary

*This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit http://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html.*

**alluvium.** Stream- deposited sediment that is generally rounded, sorted, and stratified.

**aquifer.** Rock or sediment that are sufficiently porous, permeable, and saturated to be useful as a source of water.

**ash (volcanic).** Fine pyroclastic material ejected from a volcano (also see tuff).

**basin (structural).** A doubly- plunging syncline in which rocks dip inward from all sides (also see dome).

**basin (sedimentary).** Any depression, from continental to local scales, into which sediments are deposited.

**beach.** A gently sloping shoreline covered with sediment, often formed by action of waves and tides.

**bedrock geology.** The geology of underlying solid rock as it would appear with the sediment, soil, and vegetative cover stripped away.

**breccia (volcanic).** A coarse- grained, generally unsorted volcanic rock consisting of partially welded angular fragments of ejecta such as tuff or ash.

**calcareous.** A rock or sediment containing calcium carbonate.

**caldera.** A large bowl- or cone- shaped summit depression in a volcano formed by explosion or collapse

**clastic.** Rock or sediment made of fragments or pre-existing rocks.

**conglomerate.** A coarse- grained sedimentary rock with clasts larger than 2 mm in a fine- grained matrix.

**continental crust.** The type of crustal rocks underlying the continents and continental shelves; having a thickness of 25- 60 km (16- 37 mi) and a density of approximately 2.7 grams per cubic centimeter.

**continental drift.** The concept that continents have shifted in position over Earth (see and use 'plate tectonics').

**convergent margin.** A plate boundary where two tectonic plates are moving together (such a boundary will be a zone of subduction or obduction).

**cross section.** A graphical interpretation of geology, structure, and/or stratigraphy in the third (vertical) dimension based on mapped and measured geological extents and attitudes depicted in an oriented vertical plane.

**crust.** The outermost compositional shell of Earth, 10- 40 km (6- 25 mi) thick, consisting predominantly of relatively low- density silicate minerals (also see oceanic crust and continental crust).

**debris flow**. A rapid and often sudden flow or slide of rock and soil material involving a wide range of types and sizes.

**deformation**. A general term for the process of faulting, folding, shearing, extension, or compression of rocks as a result of various Earth forces.

**dike.** A tabular, discordant igneous intrusion.

**divergent boundary.** A tectonic plate boundary where the plates are moving apart (such a boundary will form a spreading ridge or continental rift zone).

**fault.** A subplanar break in rock along which relative movement occurs between the two sides.

**fracture.** Irregular surface of breakage in a mineral; also any break in a rock, such as a crack, joint, or fault

**hawaiite.** A type of volcanic rock with a potash:soda value of less than 1:2, a moderate to high color index, and a modal composition that includes essential andesine and accessory olivine.

**hot spot.** A volcanic center, 100 to 200 km across and persistent for at least a few tens of millions of years, that is thought to be the surface expression of a rising plume of hot mantle material.

**igneous.** Refers to a rock or mineral that originated from molten material; one of the three main classes or rocks: igneous, metamorphic, and sedimentary.

**intrusion.** A body of igneous rock that invades older rock. The invading rock may be a plastic solid or magma that pushes its way into the older rock.

**island arc.** A line or arc of volcanic islands formed over and parallel to a subduction zone.

**landslide.** Any process or landform resulting from rapid mass movement under relatively dry conditions.

**lapilli.** Pyroclastics in the general size range of 2 to 64 mm.

**lava.** Magma that has been extruded out onto Earth's surface, both molten and solidified.

**lineament.** Any relatively straight surface feature that can be identified via observation, mapping, or remote sensing, often representing tectonic features.

**lithology.** The description of a rock or rock unit, especially the texture, composition, and structure of sedimentary rocks.

**lithosphere.** The relatively rigid outmost shell of Earth's structure, 50 to 100 km (31 to 62 mi) thick, that encompasses the crust and uppermost mantle.

**magma.** Molten rock generated within Earth that is the parent of igneous rocks.

**mantle.** The zone of Earth's interior between crust and core.

**normal fault.** A dip- slip fault in which the hanging wall moves down relative to the footwall.

**oceanic crust.** Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6- 7 km (3- 4 mi) thick and generally of basaltic composition.

**outer trench swell.** A subtle ridge on the seafloor near an oceanic trench formed where a subducting plate begins to flex and fault into the trench.

**Pangaea.** A theoretical, single supercontinent that existed during the Permian and Triassic Periods (also see Laurasia and Gondwana).

**permeability.** A measure of the ease or rate that fluids move through rocks or sediments.

**picrite.** Olivine rich basalt.

**plate tectonics.** The theory that the lithosphere is broken up into a series of rigid plates that move over Earth's surface above a more fluid aesthenosphere.

**plume.** A persistent pipelike body of hot material moving upward from the earth's mantle into the crust.

**pluton.** A body of intrusive igneous rock.

**plutonic.** Describes igneous rock intruded and crystallized at some depth in Earth.

**porphyritic.** An igneous rock characteristic wherein the rock contains conspicuously large crystals in a fine-grained groundmass.

**pyroclastic.** Pertaining to clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent; also pertaining to rock texture of explosive origin.

**recharge.** Infiltration processes that replenish groundwater.

**reverse fault.** A contractional, high angle (>45°), dip- slip fault in which the hanging wall moves up relative to the footwall (also see thrust fault).

**slump.** A generally large, coherent mass movement with a concave- up failure surface and subsequent backward rotation relative to the slope.

**spring.** A site where water flows out at the surface due to the water table intersecting the ground surface.

**strike.** The compass direction of the line of intersection that an inclined surface makes with a horizontal plane.

**strike-slip fault.** A fault with measurable offset where the relative movement is parallel to the strike of the fault.

**subduction zone.** A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

**subsidence.** The gradual sinking or depression of part of Earth's surface.

**talus.** Rock fragments, usually coarse and angular, lying at the base of a cliff or steep slope from which they have been derived.

**tectonics.** The geological study of the broad structural architecture and deformational processes of the lithosphere and aesthenosphere (also see structural geology).

**thrust fault.** A contractional, dip- slip fault with a shallowly dipping fault surface (<45°) where the hanging wall moves up and over relative to the footwall.

**tombolo.** A bar or barrier that connects an island with the mainland or with another island.

**topography.** The general morphology of Earth's surface including relief and location of natural and anthropogenic features.

**trace.** The exposed intersection of a fault or lineation with Earth's surface.

**trachyte.** A group of fine- grained, generally porphyritic, extrusive rocks having alkali feldspar and minor mafic minerals.

**transgression.** Landward migration of the sea due to a relative rise in sea level.

**trend.** The direction or azimuth of elongation or a linear geological feature.

**tuff.** Generally fine- grained, igneous rock formed of consolidated volcanic ash.

**vent.** An opening at the surface of Earth where volcanic materials emerge.

**volcanic.** Related to volcanoes; describes igneous rock crystallized at or near Earth's surface, such as a lava.

**water table.** The upper surface of the saturated (phreatic) zone.

**weathering.** The set of physical, chemical, and biological processes by which rock is broken down in place.

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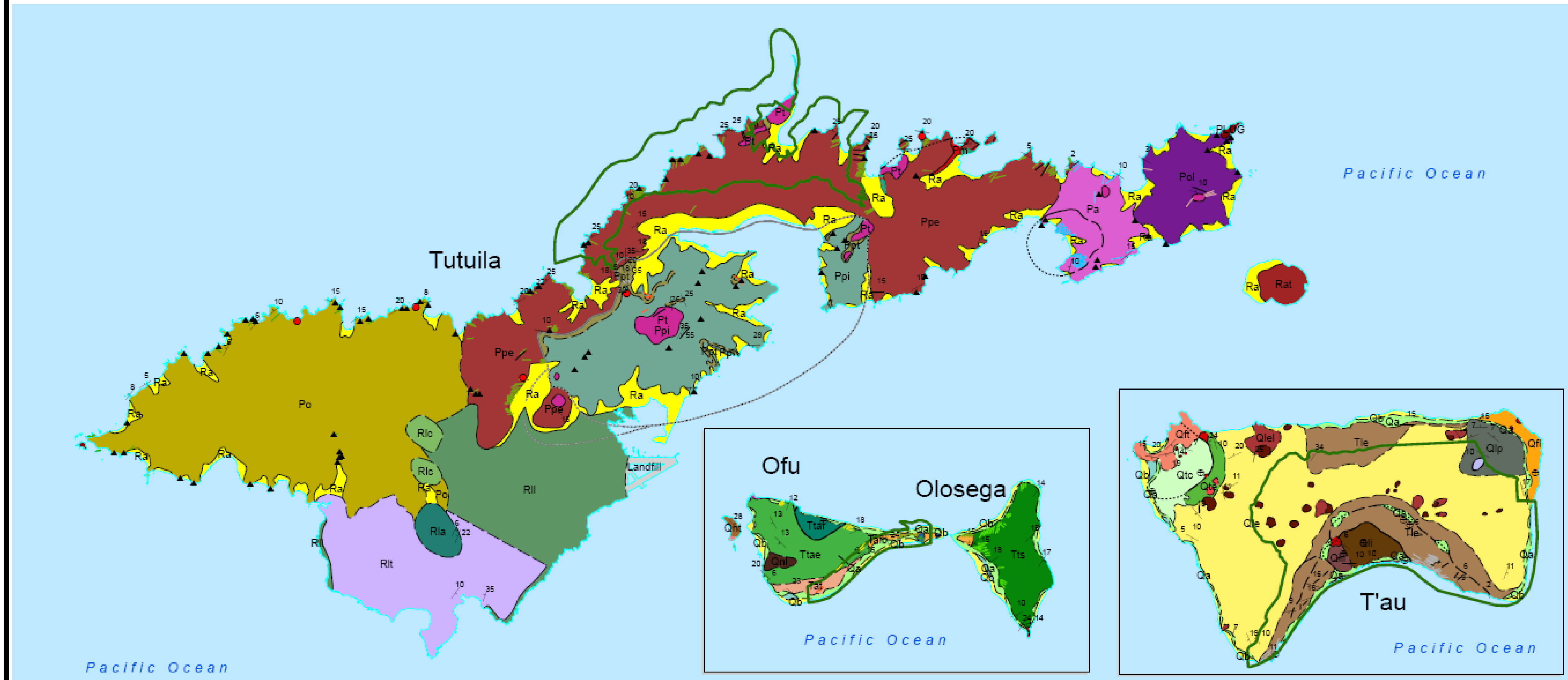
# Appendix A: Geologic Map Graphic

*The following page is a preview or snapshot of the geologic map for National Park of American Samoa. For a poster- size PDF of this map or for digital geologic map data, please see the included CD or visit the Geologic Resource Evaluation publications Web page (http://www2.nature.nps.gov/geology/inventory/gre_publications).*

# Geologic Map of National Park of American Samoa



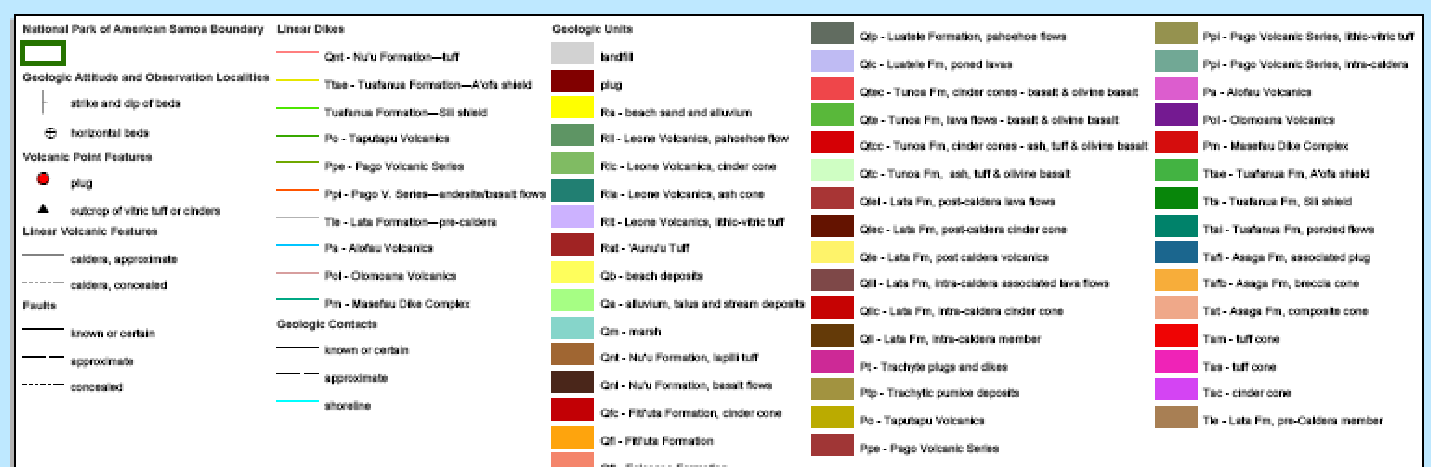

This map graphically presents digital geologic data prepared as part of the NPS Geologic Resources Division's Geologic Resource Evaluation Program. The source map used in creation of the digital geologic data product was:

Geology of Tutuila island - Harold T. Stearns, 1994, Geology of the Samoan Islands: Geological Society of America, Vol. 55, pp. 1279-1332. Scale approximately 1:63,000.

Geology of Tau island - Gary D. Stice and Floyd W. McCoy, Jr. 1968, Geology of the Manu'a Islands, Samoa: Pacific Science, Vol. XXII. Scale approximately 1:56,000.

Geology of Ofu and Olosega islands - Gary D. Stice and Floyd W. McCoy, Jr. 1968, Geology of the Manu'a Islands, Samoa: Pacific Science, Vol. XXII. Scale approximately 1:56,000.

Digital geologic data and cross sections for National Park of American Samoa, and all other digital geologic data prepared as part of the Geologic Resource Evaluation Program, are available online at the NPS Data Store: http://science.nature.nps.gov/nrdata/




Produced by Geologic Resources Division

January 2008

# National Park of American Samoa

*Geologic Resource Evaluation Report*

Natural Resource Report NPS/NRPC/GRD/NRR—2008/025
NPS D-21, February 2008

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## Natural Resource Stewardship and Science

*Acting Associate Director* • Mary Foley, Chief Scientist of the Northeast Region

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