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Coastal Geological Map of Samoa (Savai'i Island)

- Map Sheet Explanation -

2008. 12

S.W. Chang[*], S.-P. Kim[*], J.H. Chang[*],
L. Talia[†], S. Taape[†],
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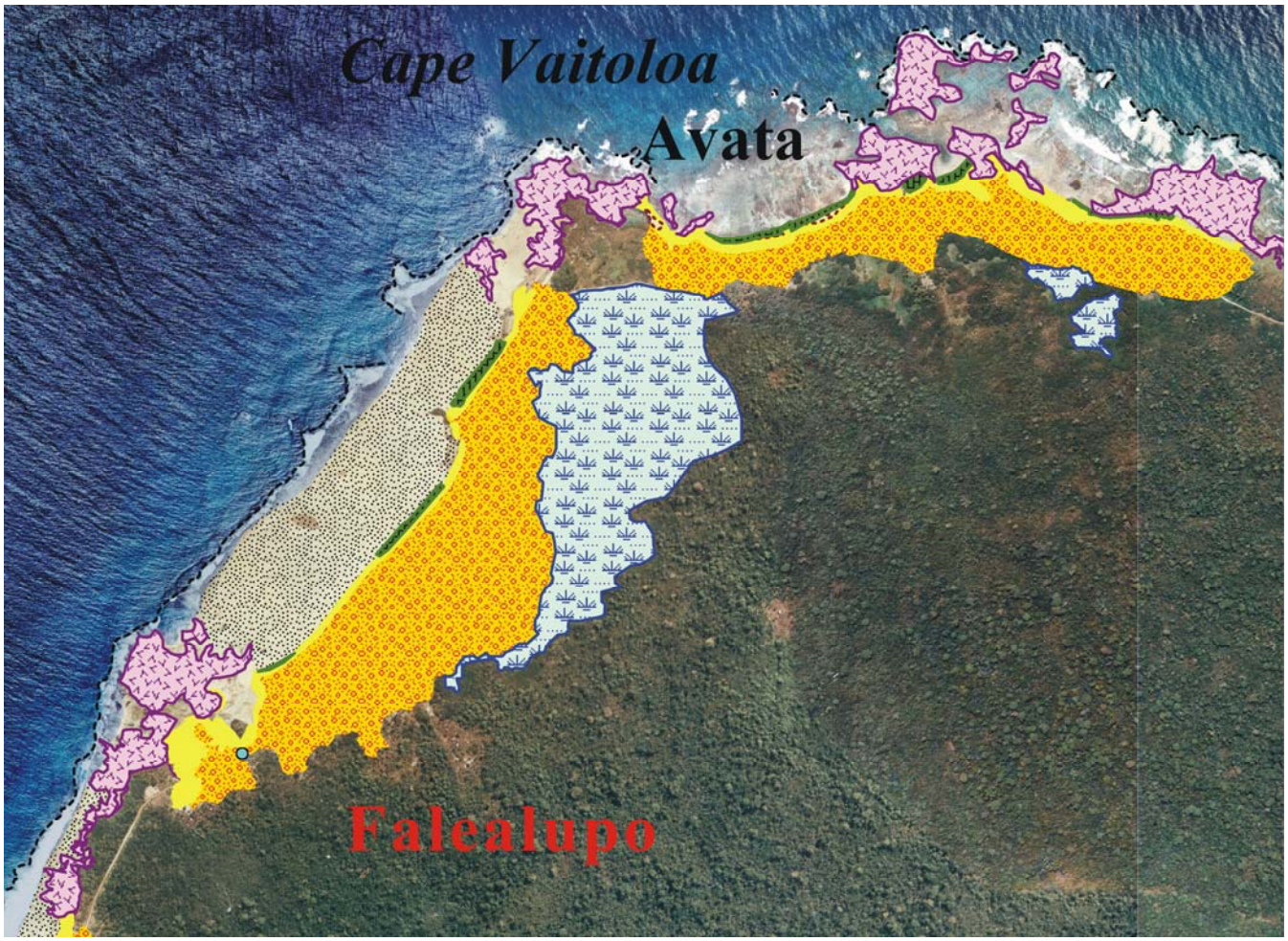

The image in the cover page shows a part of the Sheet I of the Coastal Geological Map of Samoa, in which the coastal features around the Cape Vaitoloa between Avata and Falealupo villages. A carbonate sand beach draped with wind-blown sand landward decorates the coastal area which resides on the Pu'apu'a volcanic formation (Middle to late Holocene). In the backshore area swamps are developed presumably due to coastal inundation during storm or cyclone periods.

[텍스트 입력]

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Introduction

Since 2005 Korea Institute of Geoscience and Mineral Resources (KIGAM) has conducted a three-year project of the United Nations Development Programme (UNDP Project Number: 00044540 (ROK/05/003)). The project is aimed at capacity-building of the Samoan government for establishing their management strategy and relevant faculties against coastal geohazards. The main objects of the project are; (1) to produce coastal geological map of the Savai'i Island, (2) to support staff training of the Samoa Meteorology Division, (3) to give advices on geohazard mitigation planning, and (4) to improve public awareness on coastal geohazard indicators.

The coastal geological map sheets and this explanation document were produced as a partial result of this UNDP project and include basic information on major geologic and geomorphologic units featuring coastal area of the Savai'i Island.

The UNDP project conducted by KIGAM toward Samoa has its original root in the 1998 request by the South Pacific Applied Geoscience Commission (SOPAC) toward Samoa, the main object of which was coastal geomorphological mapping of the eastern coast of the Savai'i Island (Salelologa to Pu'apu'a).[1] Before the KIGAM's activities, Richmond (1992) has made field trips and published a complete set of geomorphological maps of the Upolu Island, where the capital city is located.[2]

Samoa consists of several volcanic islands (Upolu, Savai'i, Manono, Apolima, Nuutele, etc.) which are located in the South Pacific region (13° 35' S, 172° 20' W), approximately half way between Hawaii and New Zealand. The total land area is 2,944 km^2 and the length of coastline is ca. 403 km. The estimated population is 217,083 (July 2008 est.) being mostly concentrated in the low-elevation coastal area.[3] The Upolu is the main island where the capital city is located and mostly populated. The Savai'i is the largest and relatively well-preserved attracting many overseas tourists. The others are much smaller in their size and population than the first two. All the islands are aligned in east-to-west direction forming a part of the long South Pacific island chains close to the northern end of the Tonga-Kermadec trench. They are residing on the Pacific Ocean plate moving westward over a hot spot erupting magma.

Geological Backgrounds

Stratigraphy and Tectonic Setting

The basement of the islands is composed of several volcanic deposits, of which the first was formed in Pliocene (Fig. 1). The stratigraphy and the ages of volcanic layers are shown in Table 1. Regarding to recent tectonic history three controversial theories; (1) northern emergence and southern submergence, (2) general uplift (at least locally), and (3) subsidence due to cooling, have been suggested.[4]

Holocene sea level change

The sea level in Samoa during the Holocene age has been reported to fall resulting in old sand beach deposits and rocky features after the maximum level about 2,000 yr BP. The rising rate is ca. 1 m/1,000 years and the falling rate ca. 2 m/1,000 years.[5]

Coastal geohazard indicators in Savai'i Island

The most significant indicator of recent coastal geohazards would be storm surge deposits around the islands. Typical examples are resulted from the cyclones Ofa (1990), Val (1991) and Heta (2006) and their remains are still recognizable as light-colored onshore coral sands in the aerial photographs, megaclasts in the lava field and sand dunes mixed with marine sands. Other indicators would be beach erosion, shoreline retreat, cliff collapse, fresh water spring, etc.

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[1] Kim, S.P. and Lee, S.-R., 1999. Mapping the coastal morphology from Salelologa to Pu'apu'a on the island of Savai'I, Samoa. SOPAC Miscellaneous Report 281.

[2] Richmond, B.M., 1992. Coastal Morphology of Western Samoa – West Upolu. 1:25,000 SOPAC Coastal Series Map 1A – 1D. SOPAC Miscellaneous Report 111.

[3] CIA World Factbook. https://www.cia.gov/library/publications/the-world-factbook/geos/ws.html

[4] Nunn, P.D., 1998. Pacific Island Landscapes. Institute of Pacific Studies, The University of the South Pacific, 318p.

[5] *Ibid.*

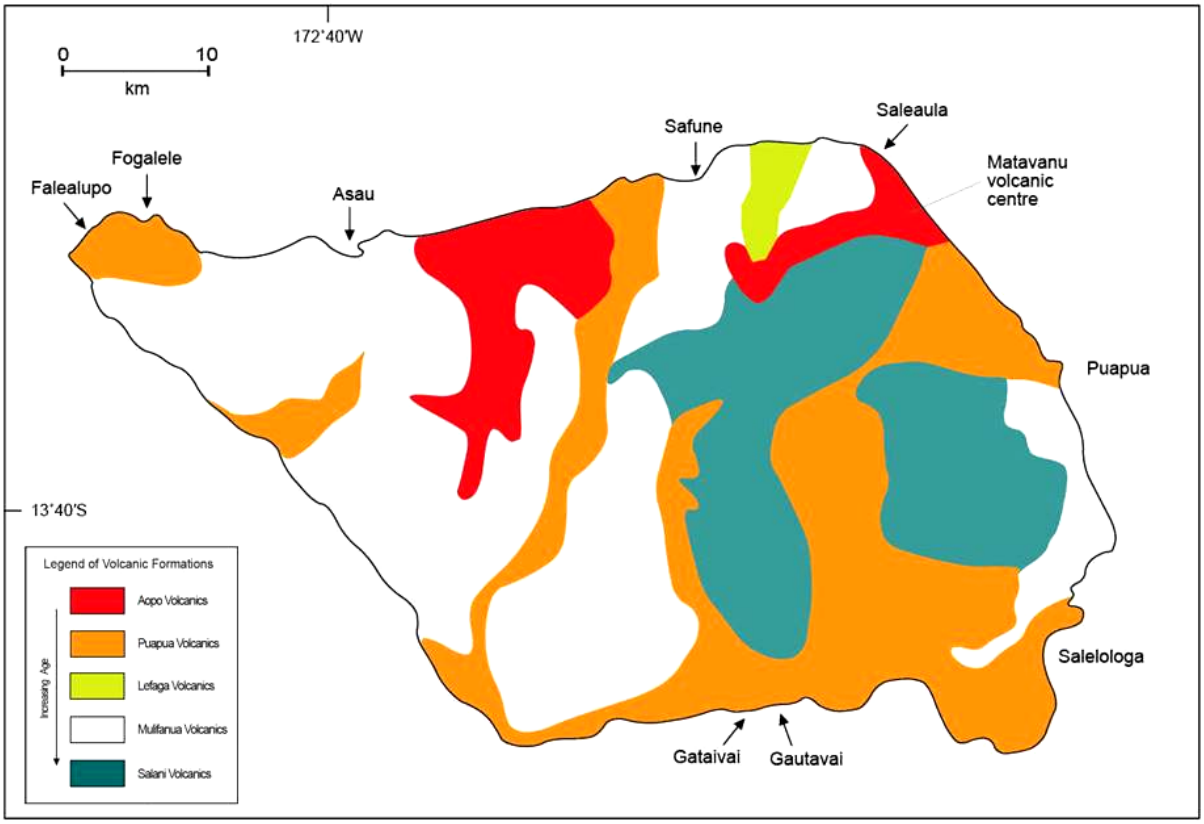

Fig. 1. Simplified geologic map of the Savai'i Island (modified from Nunn, 1998).[6]

Table 1. Stratigraphy and ages of the volcanic layers of the Savai'i Island.[7]

Volcanic Layers	Age of Eruption	Remarks
Aopo Volcanics	AD 1760, 1902, 1905, 1911	Only in Savai'i
Puapua Volcanics	Middle to late Holocene	1,850~750 C^{14}-year BP
Lefaga Volcanics	Early to middle Holocene	
Mulifanua Volcanics	70,000~10,000 BP	
Salani Volcanics	~125,000 BP	Shallow water and intertidal deposits containing mollusks and coral fragments 9 m above sea level
Vini Tuff		
Fagaloa/Vanu Volcanics	2.69 to 1.54 Ma	Older in Savai'i than in Upolu

Materials and Methods

Aerial photographs taken in 1999 were mainly used for overall mapping. Satellite (Ikonos) images, 1:100,000-scale geology map and 1:50,000-scale topography maps were also used as supplementary data. In order to check image interpretation, *in situ* surveys were conducted along the whole coastal area of the Savai'i island. Visual check and description, photographs or video recording, beach profiling, bathymetry survey and sampling were performed. In the laboratory, re-interpretation of images was performed based on the results of surveys and laboratory analysis. The final data were compiled using GIS software (MapInfo™) and produced into 1:12,500- to 1:50,000-scale map sheets.

[6] *Ibid.*

[7] *Ibid.*

Types of Coasts in Savai'i Island

The coast of the Savai'i Island shows approximately 260-km length and could be divided into three types; barrier-reef coast (82 km, 32%), fringing-reef coast (19 km, 19%) and lava-cliffed coast (130 km, 50%). Although the division of coast types is mainly based on visual description of reef development and geomorphology, basement geology and hydrology presumably show close relationship with their origins and characters (Fig. 2).

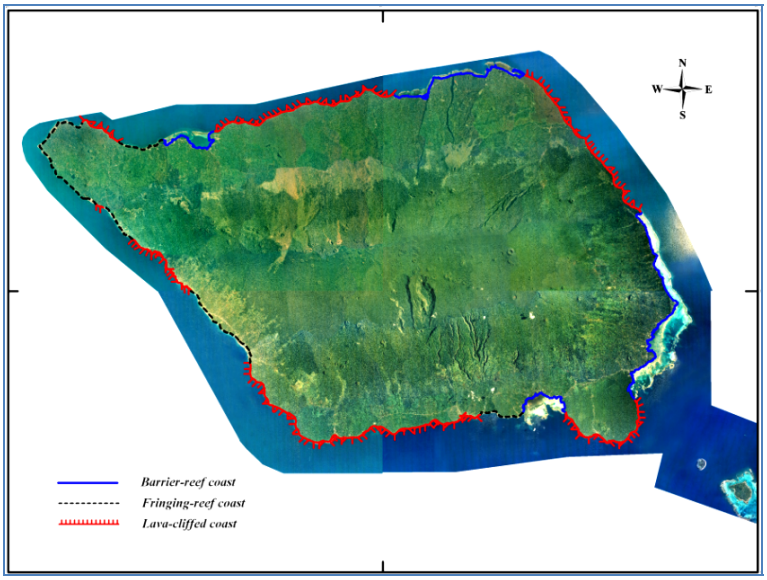

Fig. 2. Mosaic image of aerial photographs of the Savai'i Island. Note the distribution pattern of each type of coasts. Barrier-reef, fringing-reef coast and lava-cliffed coasts are blue, black(dots), and red, respectively.

Barrier-reef coast

The barrier-reef coast could be characterized with shallow lagoons bounded by long continuous barrier reefs seaward and low elevation irregular-shaped coast landward (Fig. 3). The land-side coast is generally decorated with well-developed mangrove or coconut vegetation.

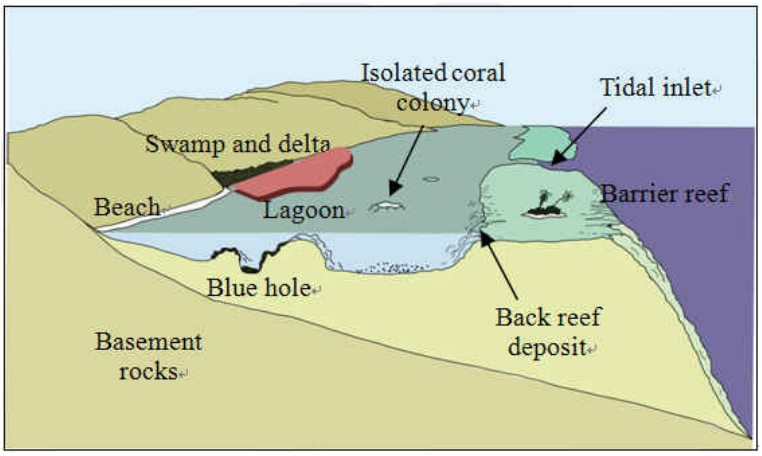

Fig. 3. Major features and their names in a barrier reef environment (modified from Spalding et al., 2001).[8]

Small rivers or creeks are well-developed and mostly connected to fresh (or brackish) water swamps, marshes, river mouth bars, spits, and delta (Fig. 4). Fresh water springs are frequently recognizable and utilized for swimming pools and washing at some places. At some places weathered volcanic rock cliff being retreated could be recognized (Fig. 5).

[8] Spalding, M.D., C. Ravilious, and E.P. Green, 2001. World Atlas of Coral Reefs. University of California Press, p.25.

Fig. 4. Fresh water swamp connected to a small river between Lano and Asaga villages.

Fig. 5. Retreating sea cliff of weathered volcanic rock draped with a pocket sand beach and rubbles (Cape Tuasivi during low tide)

In the intertidal zone gravel or sand beaches, beach rocks, rubble-topped mud flats occur (Fig. 6). The most prominent feature of the lagoon would be the blue (sink) holes (Fig. 7). They are supposedly originated from dissolved paleo-reef platform. Isolated coral colonies on coral-algae pavement also occur frequently on the sea floor.

The barrier reefs are the outermost feature which could be recognized in the aerial photographs. Clast-supported debris of reef-building materials cover the reef flat, where storm- or cyclone-driven debris mounds are occasionally found. Behind the reefs, back reef deposits are formed by wave run-off over the reef top. Tidal inlets or reef breaks commonly dissect the barrier reef.

Population density is generally higher than in the other types of coast so that artificial activities along the coastline such as harbor management, sea wall construction and reclamation are prevailing.

Barrier-reef coasts are developed in the eastern part of the island from Salelologa to Pu'apu'a, the southeastern part around Palauli, and the northern parts in Asau, Sasina and Manase villages.

Fig. 6. Beach rock in coral sand beach during low tide in Faga

Fig. 7. An aerial view of blue (sink) holes and back reef deposits along the barrier reefs in the Salelologa village

Fringing-reef coast

The fringing-reef coast is characterized by shore-attached reef of narrow width. The coastline is generally straight and made of old volcanic layers. Pocket sand or gravel (rubble) beaches occur frequently (Figs. 8, 9). The bathymetry shows rather flat sea floor on the reef whereas it changes rapidly into deep shelf area. Raised reef terraces possibly originated from relative sea level fall could be recognized in some places. The fringing-reef coasts mainly develop in the western and southwestern parts of the island (Falealupo to Tufutafoe, Satuiatua, Papa).

Fig. 8. A pocket beach near Falealupo composed mainly of white coral sand.

Fig. 9. A gravel beach in fringing-reef coast near Taga.

Lava-cliffed coast

The lava-cliffed coast is characterized by steep vertical cliffs formed by relatively young plunging lava flow deposits or rocky shore originated from older lava deposit. The lava flow deposits usually show fresh blocky outcrops made by persistent wave action. Reef development is very weak or none so. Water depth increases very

rapidly from the foot of the cliff to several hundreds of meters only within several tens of meters. Besides of the cliff itself the shoreline is generally decorated with sea stacks, notches, arches, wave cuts (Fig. 10). Gravel or black sand beaches are frequently recognizable. Transported volcanic rocks (megaclasts) could also be found on top of the cliff (Fig. 11). The lava-cliffed coast is most dominant coast type and could be found in the northeastern (Pu'apu'a to Sale'aula), southeastern (Aganoa), southern (Taga to Gataivai) and northwestern (Sataua to Cape Puava, Neiafu, Falelima) parts of the island, the first (the northeastern part) of which is related to the most recently erupted volcanic lava.

Fig. 10. A sea arch near Nuu in the southern coast. Note recent collapse of lava deposit in the left.

Fig. 11. Vertical lava cliff (>20 m in height) in the Mauga village. Note the boulder on the cliff (ca. 1 m^3).

Map sheet information

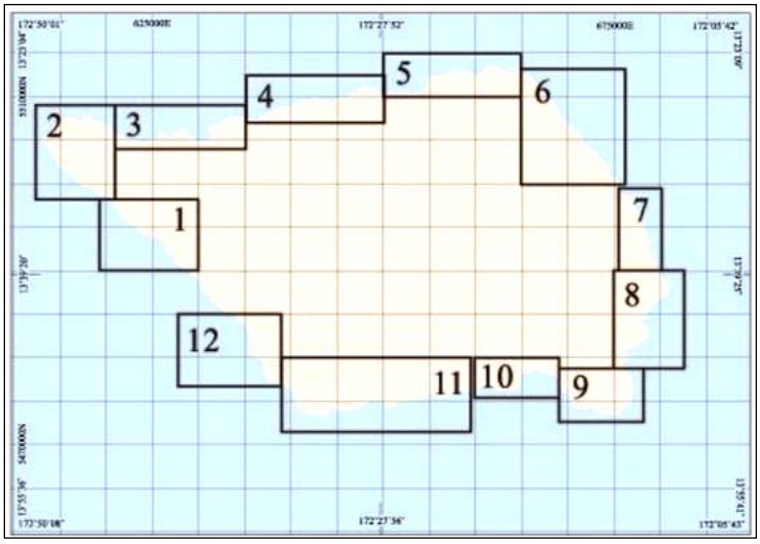

Fig. 12. Index map showing the map sheets and their numbers. A part of the southwestern coast was omitted intentionally for map arrangement as prominent features are almost similar as in the sheets 1 and 12.

1. Cartographic parameters
   World Geodetic System 72 and Samoa Integrated Grid were adopted as datum and projection for the map sheets, which are the official cartographic parameters of the Department of Lands, Survey and Environment of the Samoan government for the topographic maps of Samoa. The scale of each map was decided among 1:12,500, 1:25,000 and 1:50,000 considering the physical dimension of major features and map arrangement.

2. Map sheet arrangement
   The whole area of the Savai'i Island was divided into four sheets of zones and named after the directional quarter of the region. Each sheet includes two to four subdivided regions as follow;

SHEET I: COASTAL GEOLOGICAL MAP OF SAMOA
(NORTHWEST SAVAI'I)
1. FALEALUPO (1:50,000)
2. FALELIMA (1:12,500)
3. ASAU (1:25,000)
SHEET II: COASTAL GEOLOGICAL MAP OF SAMOA
(NORTHEAST SAVAI'I)
4. ALUPE (1:50,000)
5. SAFOTU (1:25,000)
6. SOLOMEA (1:25,000)
SHEET III: COASTAL GEOLOGICAL MAP OF SAMOA
(SOUTHEAST SAVAI'I)
7. PU'APU'A (1:25,000)
8. SALELOLOGA (1:25,000)
9. TAFUA (1:50,000)
10. PALAULI (1:25,000)
SHEET IV: COASTAL GEOLOGICAL MAP OF SAMOA
(SOUTHWEST SAVAI'I)
11. TAGA (1:50,000)
12. SATUIATUA (1:25,000)

3. Legend
   The coastal geology was described and coded with a symbolic legend, which is divided into three groups based on the relative location in the coast; onshore, shoreline and back reef. Each group has several feature units classified and arranged mainly with respect to grain size, composition, assumed origin and stratigraphic relationship of the component materials. Several prominent morphological features and man-made structures were also classified and their assumed distribution was delineated on the basis of aerial photographs and ground-check result. The shoreline definition and the road and river (or stream) data were adopted from the MapInfo™ tables from the coastal hazard zone study. [9] The following is brief explanation of each items in the symbolic legend and their representative pictures.

Fig. 13. Shore dune near Tufutafoe village, mostly composed of washover sand and modified by aeolian process.

– Onshore Geology
  Cyclone or storm gravel: Gravels presumed to be moved far into or deposited in the onshore area by strong swash or surges originated by cyclones or storms. Mostly the gravels are carbonate in origin

[9] Lameko, T., per. com.

but, in the extreme case, volcanic blocks of a meter in diameter could be discovered on the more than twenty-meter high sea cliff (Fig. 11).

Washover Sand: Mostly carbonate sand-sized deposits of similar origin of the cyclone or storm gravel. The northwestern coast of the island near the Falealupo village shows good examples of this unit made by the cyclone *Heta* in 2003 (Fig. 13).

Swamp: Low energy coastal environment filled with fresh or brackish water usually connected to the sea through a small river. Mangroves are the dominant biota covering muddy bottom (Fig. 4). In some places the entrance to the swamp is blocked by growing spits or mouth bars.

– Shoreline Geology

Rubbles: Grayish or leucocratic, poorly-sorted boulders scattered in the intertidal zone. Mostly very angular and made of carbonate materials possibly originated from the reef building corals or coral mounds by strong wave action (seaward side of the beach in the Fig. 5).

Volcanic Boulders: Black, relatively poorly- to well-rounded volcanic materials mostly of boulder size. Presumably they are originated from adjacent volcanic rock deposit by land slide or cliff collapse (Fig. 14).

Fig. 14. Volcanic boulder deposit in front of a lava cliff, northeastern coast of the Savai'i Island.

Gravels: Black, well-rounded volcanic materials mostly of gravel size. Presumably they are originated from adjacent volcanic rock deposit by strong wave action (Fig. 9).

Volcanic Beach Sand / Carbonate Beach Sand: Beach sand composed either of volcanic material or of carbonate material. The former is easily seen in the pocket beach in or nearby the cliffed coast (Fig. 5) and the latter in the barrier-reef coast (Fig. 6).

Beach Rock: Beach rocks are consolidated or semi-consolidated old beach deposit stranded in the present beach. Usually they show lower elevation than the high tide level and run parallel to the shoreline. The surface is mostly rugged and undulatory due to differential dissolution by rain or ground water (Fig. 6).

Mud with Mangrove Vegetation: Mud-sized deposit in the low energy intertidal area. The composition is mostly carbonate in origin except those in the areas nearby small rivers where silt-sized volcanic material are locally dominant. Usually the surface is covered by dense mangrove vegetation and bioturbated by abundant benthic animals (Fig. 15).

Rocky Bottom: Relatively old basement exposure of low elevation along the shoreline (the middle part of the Fig. 5)

Rocky Shore: Relatively fresh volcanic basement exposed along the shoreline, usually in a cliff form (Fig. 10 and 11)

– Back Reef Geology

Volcanic Sand / Carbonate Sand: Sand covering the lagoon area, usually overlying the coral-algal pavement. Depending on the proximity to the river mouth and lava deposit the composition of the sand is either volcanic or carbonate. In some cases, volcanic sands form subaqueous delta being transformed into carbonate sand toward offshore. Bedforms (sand waves, current ripples, etc.) and isolated coral mounds (colony) could be observed in both features (Fig. 16).

Fig. 15. Mud-filled mangrove vegetation area with abundant crab holes.

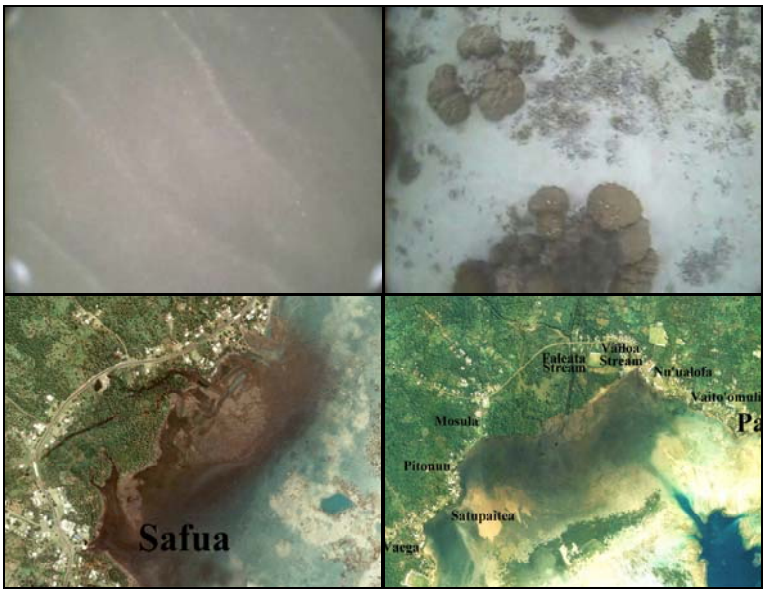

Fig. 16. Volcanic sand with straight-crest sand waves (upper left); Isolated coral colony in carbonate sand (upper right); Aerial photographs showing river-driven volcanic sand deposits (deltas) entering into the lagoon area near the Safua and Palauli villages (lower two pictures).

Back-barrier Washover: Relatively bright zones behind of barrier reefs in the aerial photographs. They are usually covered with coral debris which is presumed to be transported landward from the reef face or edge by overwash or surging waves (back reef deposit in the Fig. 7).

Coral-algal pavement: Most dominant feature of the lagoon sediments composed of coral and/or algal colonies. They usually overlie old reef-building structure and show relatively flat surface (Fig. 17). In the southeastern and southern lagoons of the Savai'i Island the underlying reef-building structures show collapsed seafloor called blue holes (sink holes) possibly formed by ground water dissolution (Fig. 7). Bleached corals are also visible at some locations which indicate environmental change possibly due to negative physicochemical condition.

– Morphologic Features

Sea Cliff: Steeply standing rock walls, mostly volcanic in origin, being eroded by incoming waves and decorated with sea arches, wave cuts, sea stacks, blow holes, pocket beaches, etc. (Figs. 10, 11, 18).

Volcanic Rock Terrace: Inferrably raised old coastal plains or cliff tops composed of volcanic rock. They are easily seen in the southern coast from Puleia to Gataivai villages (Fig. 19).

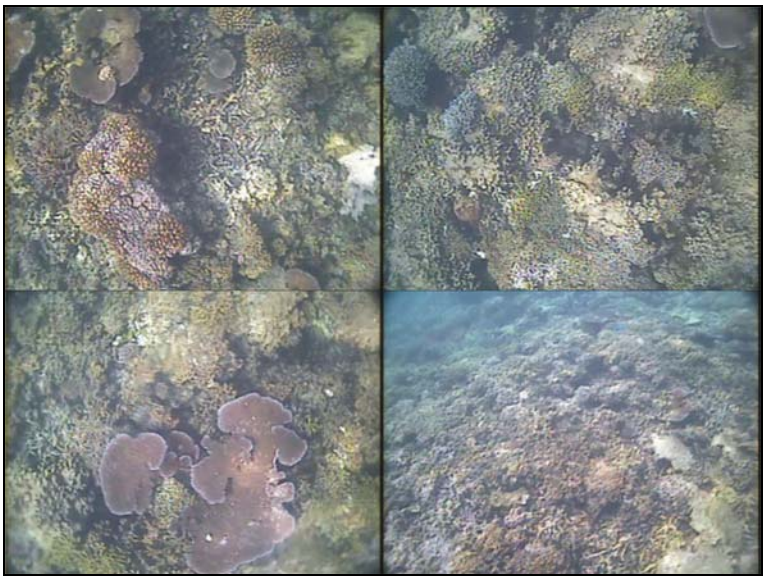

Fig. 17. Underwater photographs showing well-developed coral-algal colony.

Fig. 18. Alofaaga blow holes in the Cape Asuisui of Taga.

Fig. 19. Volcanic rock terrace in the southern coast possibly being raised by tectonic uplift.

Blue Hole: Vertical or steep-angle collapsed holes of the coral-algal zones in the lagoon possibly eroded by ground water intrusion (Fig. 7). The depth change reaches up to approximately 20 m from the sea floor (Fig. 20).

Lineation: Linear strips visible in the aerial photographs in the back reef deposits behind the barrier reef. They are presumed to be the remained structures of reef erosion formed by waves overwashing the barrier reefs (Fig. 21).

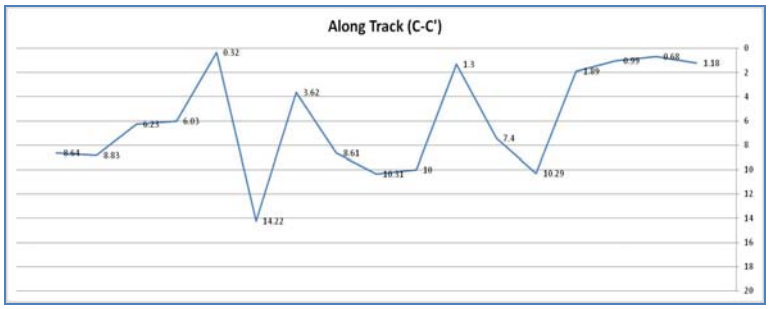

Fig. 20. An example of along-shore track of echo-sounding profiles showing depth change of ca. 14 m acquired in the blue hole area of the Salelologa village.

Reef Edge: Inferred seaward limit of growing barrier reef delineated with subtle color change in the aerial photographs (Fig. 21).


Fig. 21. An aerial photograph showing beach lineation near the Pu'apu'a village.
Note the lighter color of the sea water out of the barrier reef indicating the reef edge.

– Man-made Structures

Pool: Artificial water reservoir for swimming, washing, and bathing, etc. Usually they are made using fresh water springs with concrete and gravels (Fig. 22).


Fig. 22. Picture showing pool construction in a resort

Wharf or Ferry: Artificial structures for berthing cargo, passenger or small fishing boats. Normally they are built perpendicular to the shoreline so that disturb local current and sediment transport system (Fig. 23).

Seawall: Mostly revetment or riprap along shoreline against land erosion or inundation induced by wave, surge or tsunami. Depending on the financial condition of the builder, location and level of importance, they are constructed in various ways using gravels, concretes, tetrapods, etc. (Figs. 23 and 24).

Reclaimed Area: Artificially filled underwater area in order to increase land use (Fig. 25).

Fig. 23. The seawall at the Salelologa wharf in 1998 (upper); the newly-built Salelologa wharf (lower left) at which a big car ferry, the lady Samoa II (lower right), could berth. Note the well-constructed concrete wall beside a small boat. Lower pictures were taken in 2005.

Fig. 24. A seawall made of gravels and boulders without cementation.

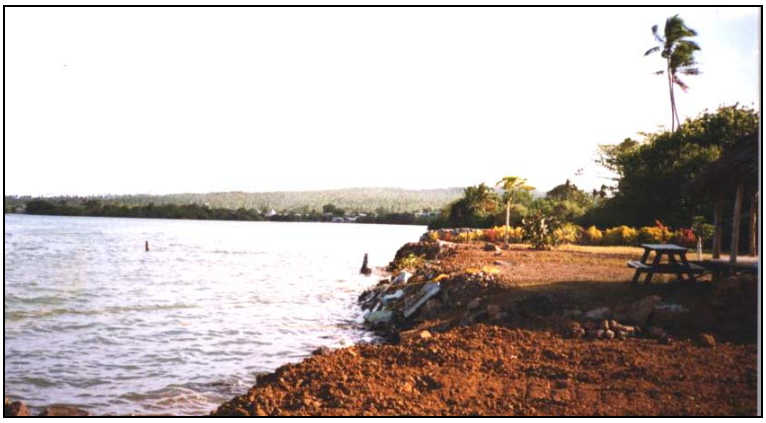

Fig. 25. An example of reclaimed area in a hotel being constructed in 1998.

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Coastal Geological Map of Samoa (Savai'i Island)

- Map Sheet Explanation –

Teuila, The national flower of Samoa

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Ministry of Education, Science and Technology (MEST)
United Nations Development Programme (UNDP)