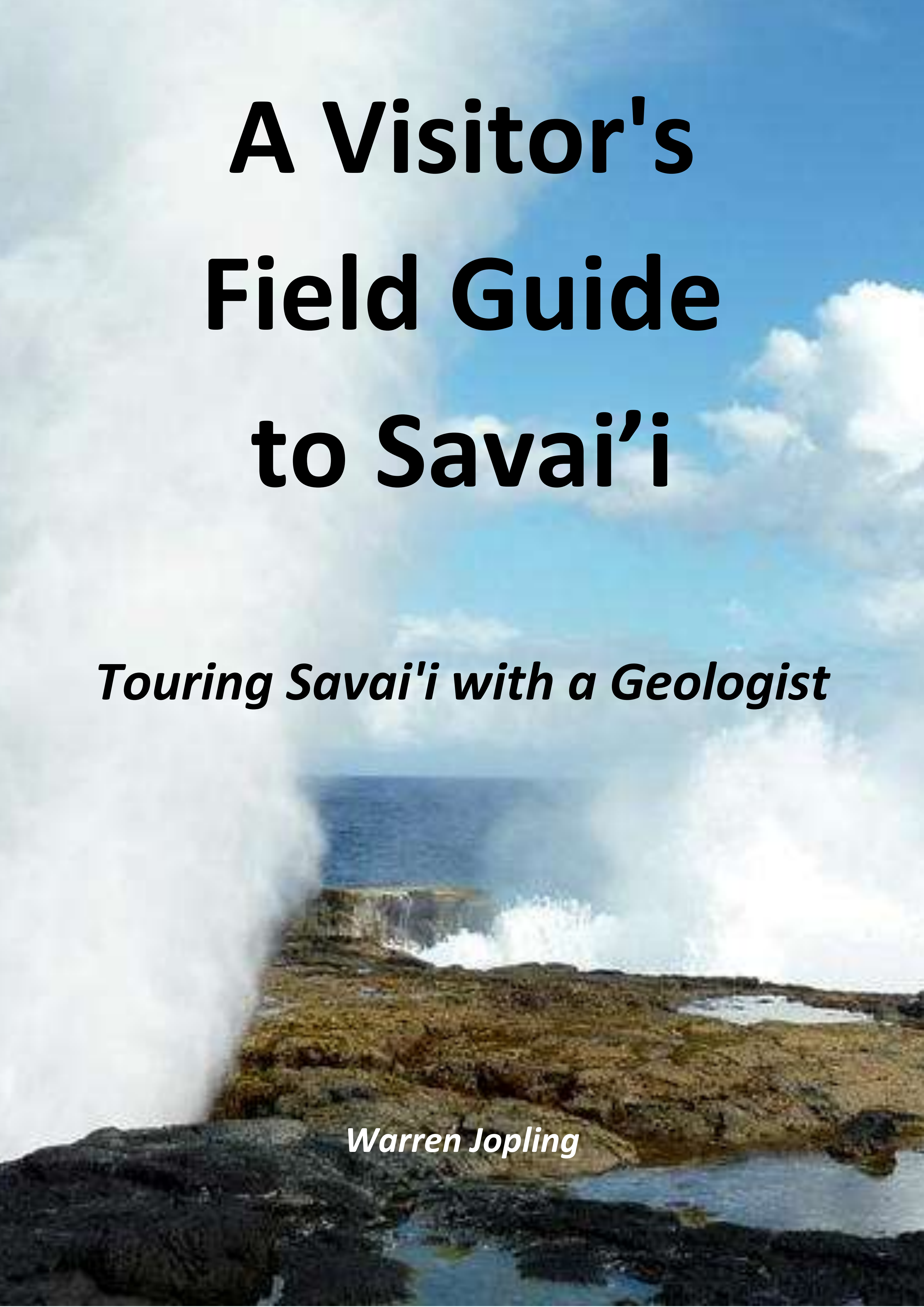
A Visitor's Field Guide to Savai'i

Touring Savai'i with a Geologist



Warren Jopling

ABOUT THE AUTHOR AND THIS ARTICLE

Tuapou Warren Jopling is an Australian geologist who retired to Savai'i to grow coffee after a career in oil exploration in Australia, Canada, Brazil and Indonesia. Travels through Central America, the Andes and Iceland followed by 17 years in Indonesia gave him a good understanding of volcanology, a boon to later educational tourism when explaining Savai'i to overseas visitors and student groups. His 2014 report on Samoa's Geological History was published in booklet form by the Samoa Tourism Authority as a Visitor's Guide - a guide summarising the main geological events that built the islands but with little coverage of individual natural attractions. This present article is an abridgement of the 2014 report and focuses on Savai'i. It is in three sections; an explanation of plate movement and hotspot activity for visitors unfamiliar with plate tectonics; a brief summary of Savai'i's geological history then an island tour with some geologic input when describing the main sites. It is for nature lovers who would appreciate some background to sightseeing.

The Pacific Plate, The Samoan Hotspot, The Samoan Archipelago

The Pacific Plate, the largest of the Earth's 16 major plates, is born along the East Pacific Rise.

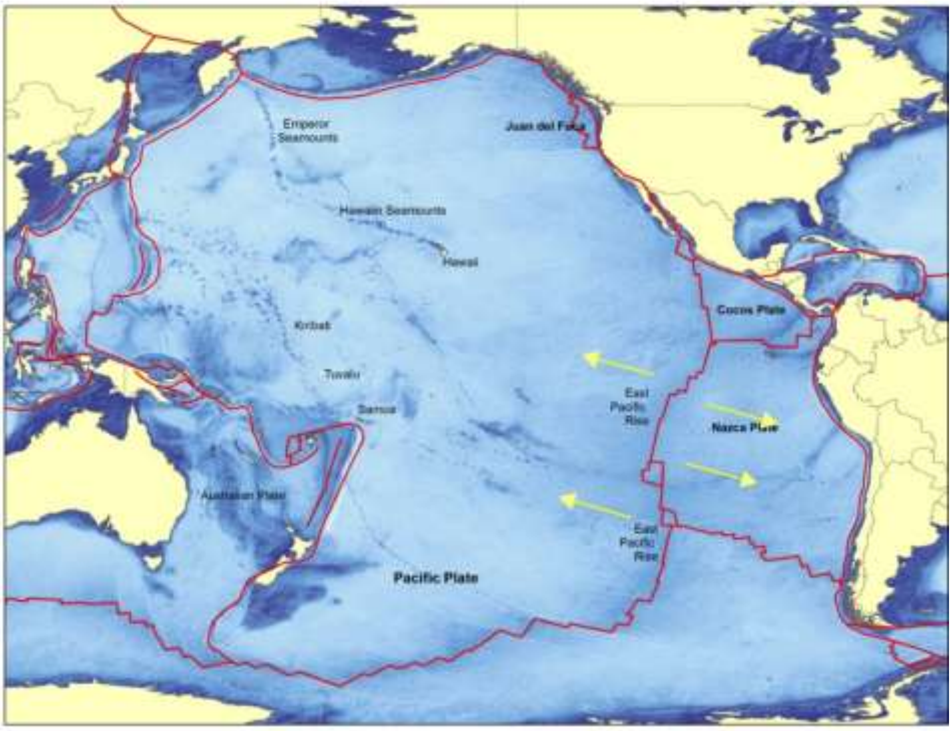


Figure 1. Pacific Ocean Plates

It is a 4 to 5 km thick plate of oceanic basalt moving at 7 cm yearly to the west-northwest across the Earth's mantle. In the area encompassing Samoa the plate is some 100 million years old but the islands it carries are much younger. Fig 2 shows the 400 km long Samoan Archipelago with Savai'i at the west and Mount Vailulu'u, an enormous submarine volcano at the east.

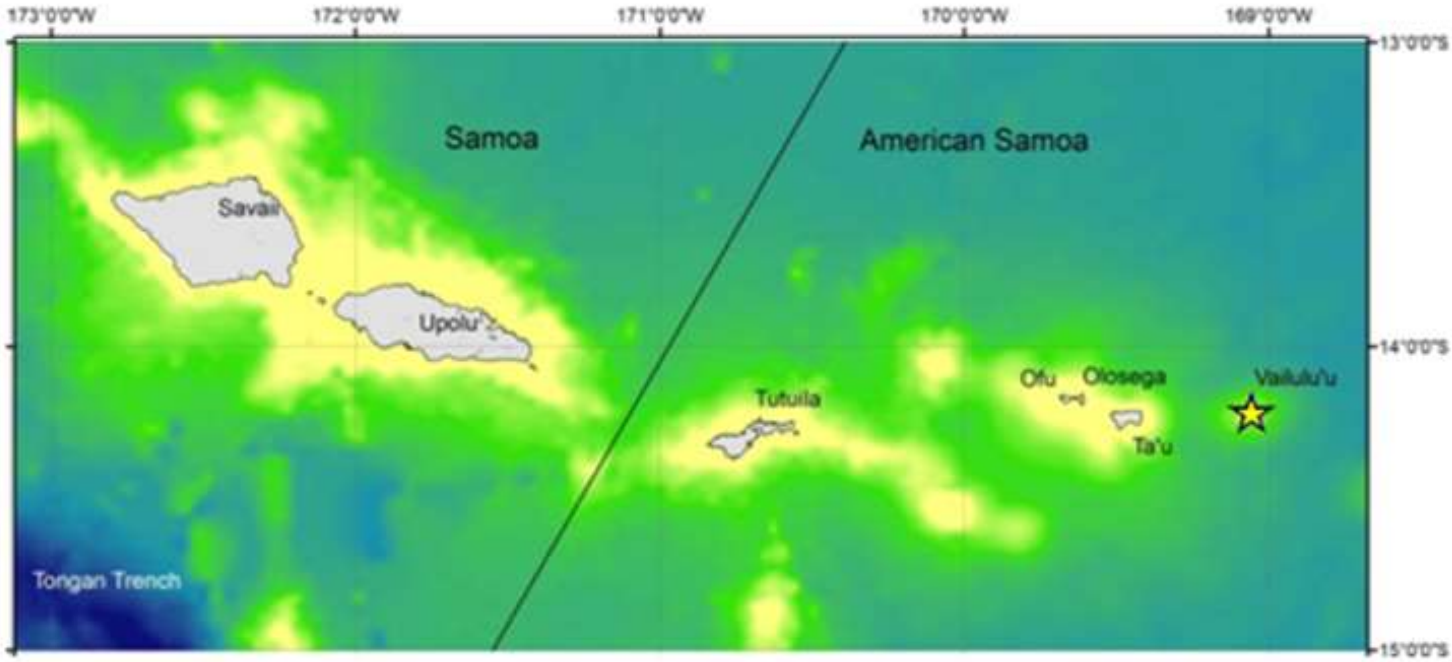


Figure 2. The Samoan Archipelago.

Mt Vailulu'u rises 4.5 km from the ocean floor, has a crater 400 m deep and 2 km wide, and is continously venting mineral - charged hot water. This is one of the Pacific Ocean's seven widely scattered hotspots - a hotspot being a stationary area deep within the mantle where heat escapes as a rising plume of molten magma; this burns through the slowly moving overlying plate to form a volcanic island or, if magma supply is deficient, an underwater seamount. These features are slowly carried away as new ones form. Mt Vailulu'u is presently 590 m below sea level but will possibly emerge in another 50,000 years or so to add another island to the eastern end of the archipelago. Savai'i, as shown by its oldest rock outcrops, formed over the hotspot 5 million years ago and Ta'u, the easternmost island of American Samoa, 500,000 years ago. The Samoan archipelago is the youngest and easternmost segment of a long volcanic trail of islands and seamounts that extends to the northwest of Samoa through the atolls of Tuvalu, Kiribati and the Marshall Islands (Fig 3)

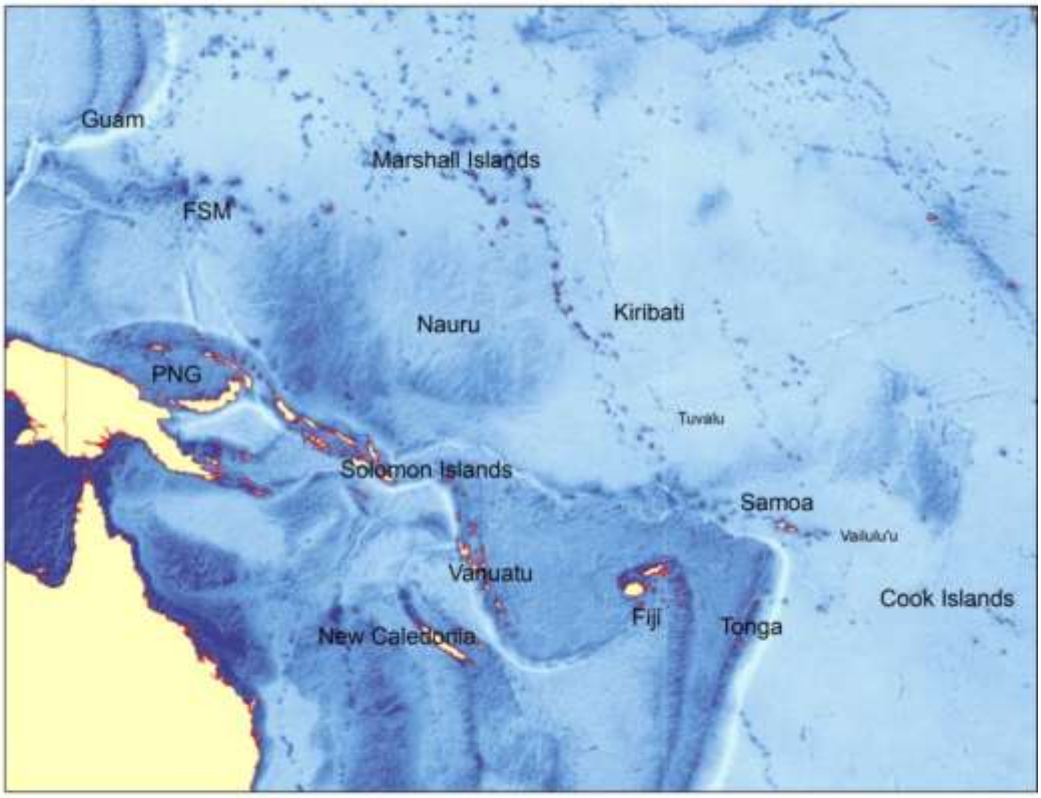


Figure 3. The Samoan Volcanic Trail.

Savai'i's Volcanic History

Savai'i built up over the hotspot 5.5 to 4.5 million years ago then was exposed to 4 million years of sub-aerial erosion before a second phase of volcanism commenced 390,000 years ago. Eruptions have continued periodically into historic time but are not related to the now-distant hotspot. Savai'i and Upolu are close to the northernmost extremity of the Tonga Trench where the heavy, westerly moving Pacific Plate subducts (pushes under) the lighter rocks of the Tonga Micro Plate, which is moving eastwards at 19cm yearly (Fig 4).

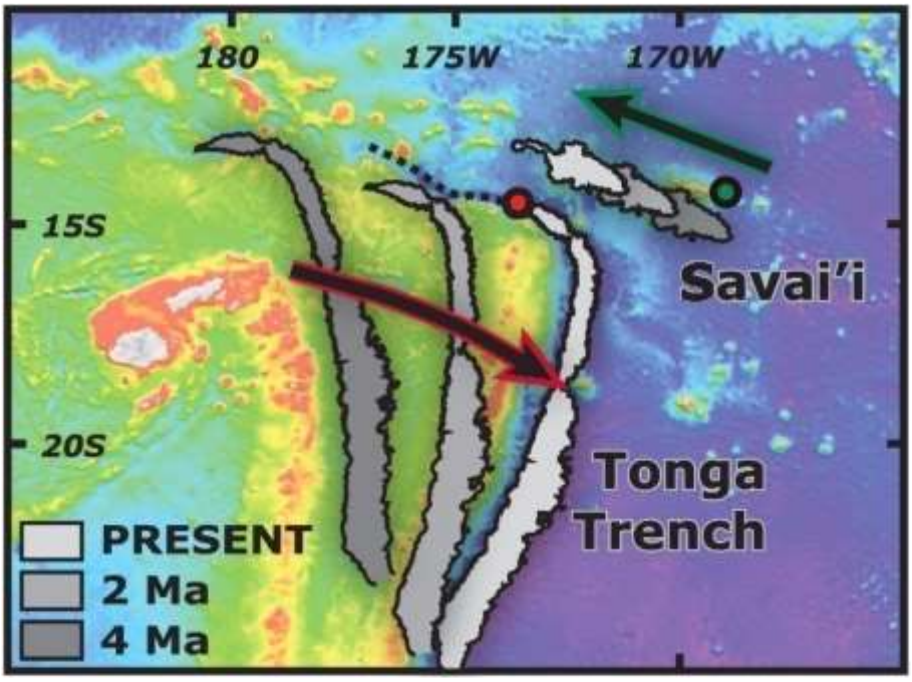


Figure 4. Tonga Trench Rollback.

The Pacific Plate encompassing Savai'i and Upolu is heavily deformed with molten magma from an underlying magma chamber rising along fractures to cover the old eroded rocks of hotspot origin (locally known as Fagaloa formation). Savai'i was completely covered by post-Fagaloa 4olcanic and Upolu partially covered but later stream erosion re-exposed several small Fagaloa outcrops in Savai'i (Fig 5). Potassium-Argon dating shows an age of 5 million years.

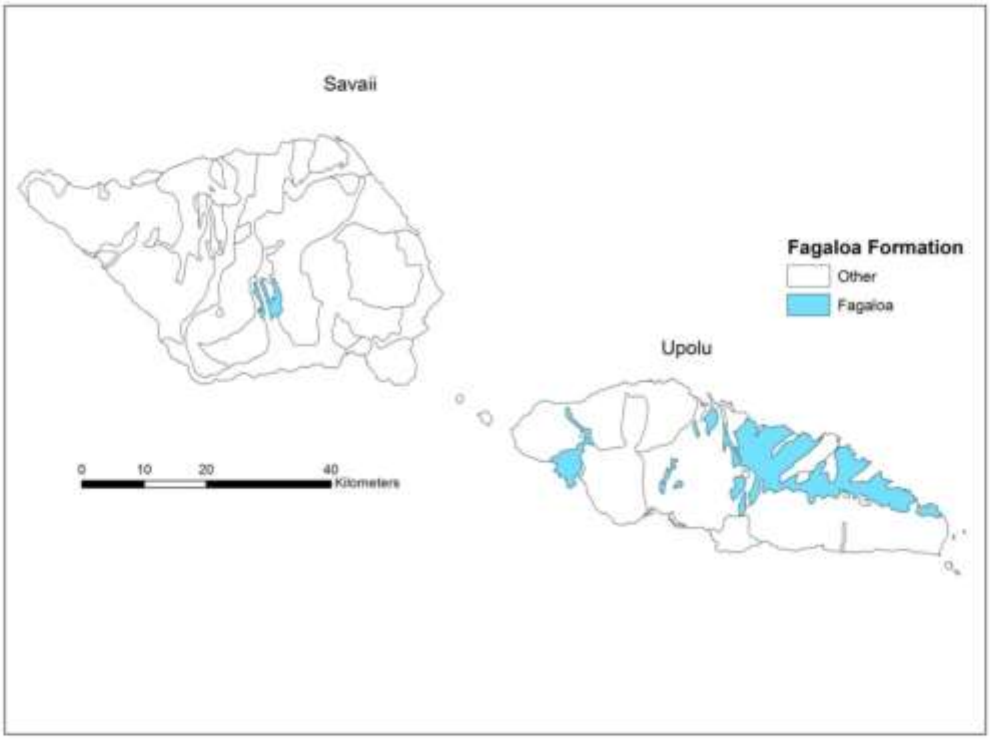


Figure 5. Fagaloa Formation.

Post- Fagaloa eruptions over Savai'i have built a stack of interbedded basalt lava flows and tephra (volcanic ejecta) to a height of 1863 m above sea level. Fig 6 shows the distribution of Samoa's rock units (formations). Areas coloured various shades of green are designated as the Salani, Mulifanua and Lefaga formations which range in age from 390,000 to 10,000 years ago; red, Puapua formation from 10,000 to 1722 when Samoa was first sighted by a Dutch navigator and yellow, Aopo formation, from 1722 onwards. (Fig 6) (Puapua and Aopo are very beautiful Savai'ian villages).

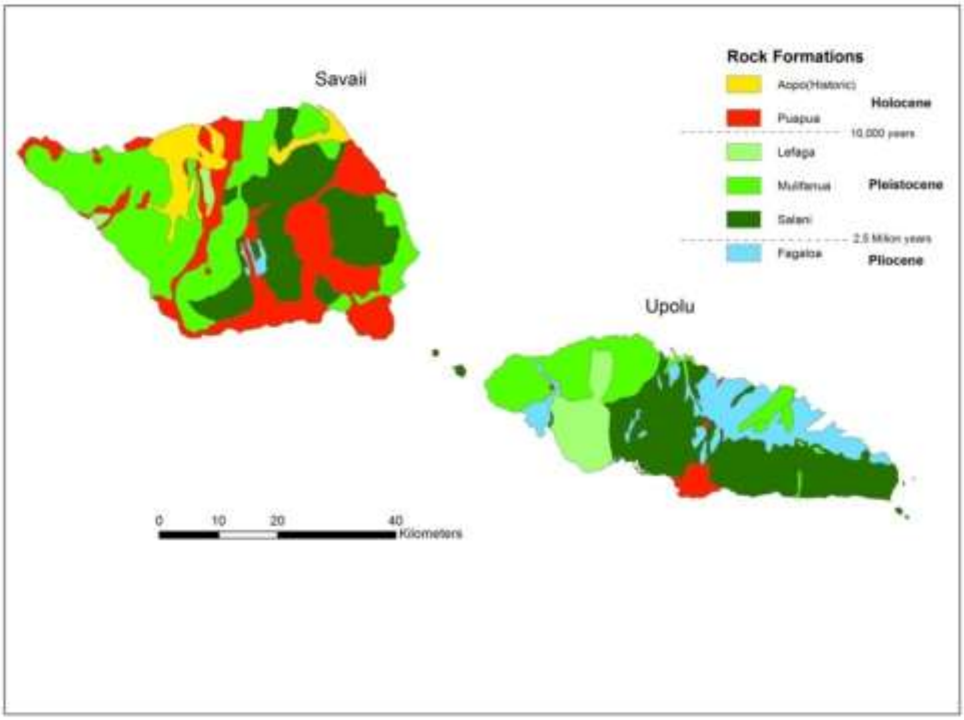


Figure 6. Samoan Rock Formations.

Green areas have soils suitable for farming, red areas (Puapua) have very thin topsoil unsuitable for ground crops but sustain tree growth when roots penetrate soil-filled joints between basalt blocks and yellow areas (Aopo) are either barren or covered by scrub. It is immediately obvious from Fig 7 that much of Savai'i's coastal area is covered by Holocene (Puapua and Aopo) rocks whereas Upolu has several Puapua cones and one small area of outcrop along the central south coast. Aopo volcanism has so far been restricted to Savai'i. This has impact on population distribution . Samoans mostly live by subsistence farming so Upolu, the smaller island, has a population of 145,000 as compared to Savai'i's 45,000.

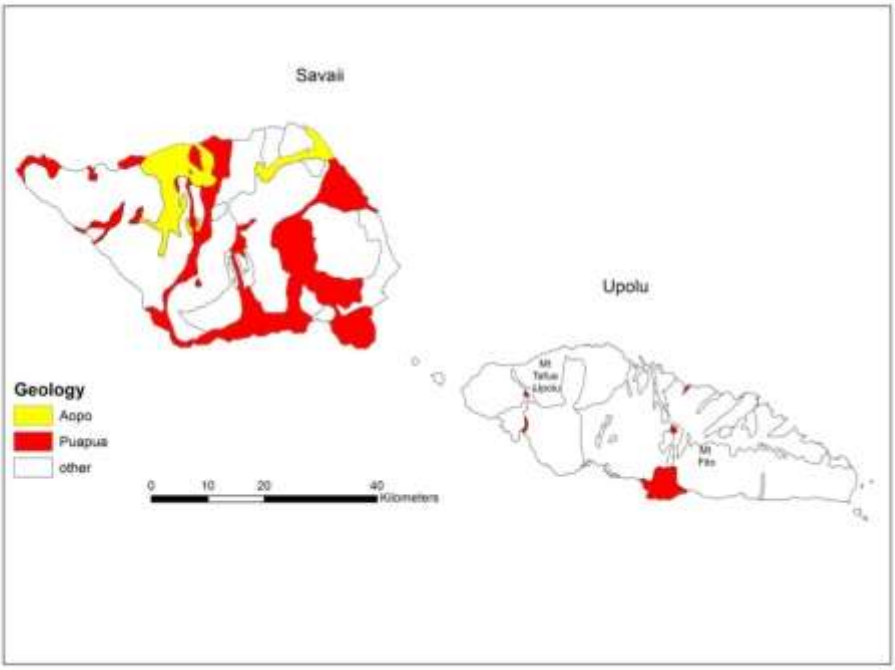
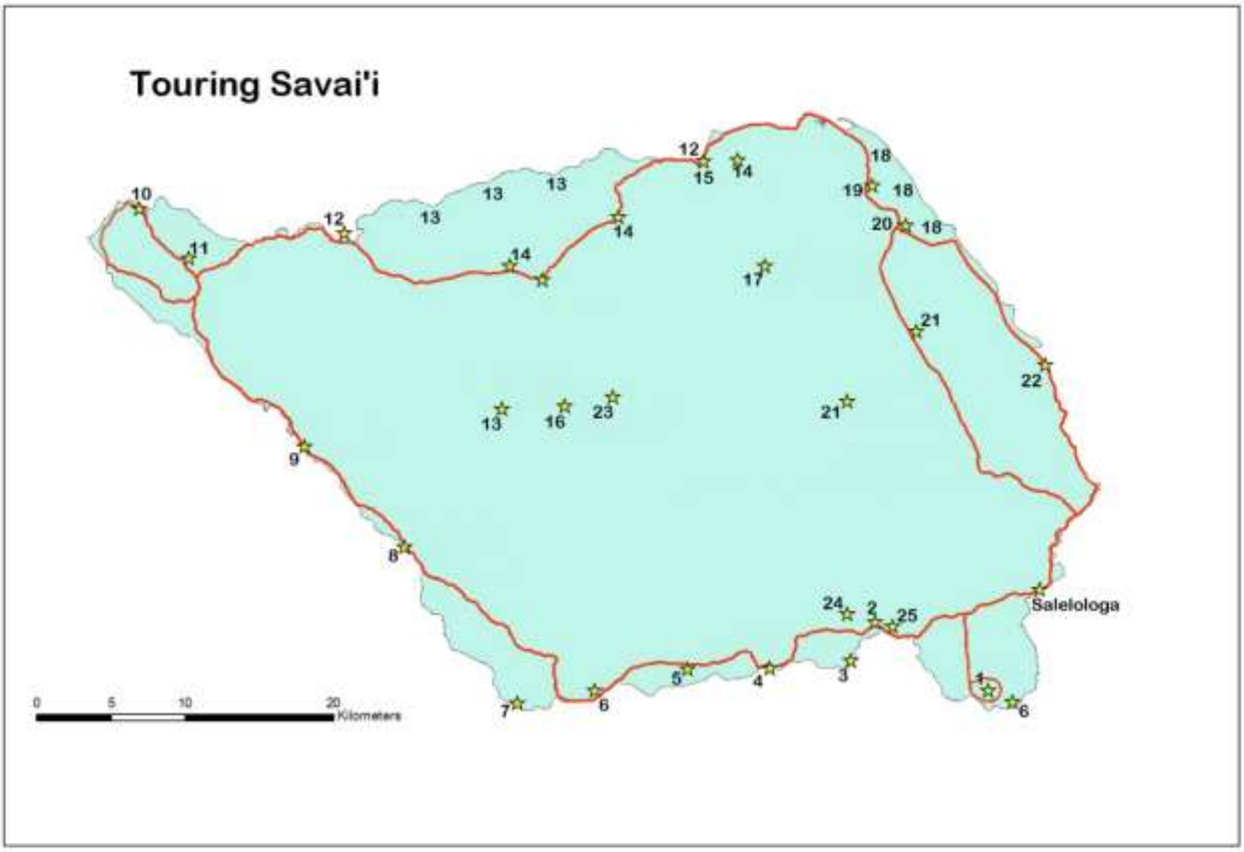


Figure 7. Aopo and Puapua Outcrops.

Touring Savai'i

Your tour starts at Salelologa, Savai'i's only commercial village and takes you clockwise visiting and discussing sites of interest.



1 The Tafua- Savai'i volcano. Tafua - Tai

2 The Afu A'au waterfall, Vailoa

3 A freshwater spring, Satupaitea

4 The Mu Pagoa waterfall and emerged shorelines, Puleia

5 An abandoned eucalypt forest, Gataivai

6 Sea arches and iron bound coastline, Taga

7 Alofa'aga Blowholes, Taga

8 Coral sand and beachrock, Satuiatua

9 Faulting, Fagafau

10 Moso's Footprint, Fagalele Bay

11 Canopy Walkway, Falealupo

12 The North Savai'i Fault, Sataua

13 The Mauga Afi eruption and Aopo Lava Field, Aopo

14 Lava tubes, Aopo, Letui, Paia

15 MataLeAlelo Spring, Mangroves, Safune

16 The Mauga Mu eruption - Discussion only

17 Mount Matavanu, Paia

18 Saleaula Lava Field, Saleaula

19 Mauga Crater

20 Samalaeulu

21 Mt To'iavea, Mt Tagotala

22 Puapua to Salelologa

23 Mt Silisili

24 Pulemelei Step Pyramid

25 Tapa

1. Tafua - Savai'i Volcano

Visitors nearing Savai'i by ferry will see on the port (left) side an irregularly shaped hill rising above the treeline. It is not a particularly impressive sight and most would be surprised to hear that this is the largest of Savai'i's 450 volcanic cones. It was also the source of an enormous eruption during early Polynesian times and is now a wonderful eco-tourism attraction.

Tafua-Savai'i started life less than 2000 years ago and is Savai'i's only volcano located on a shoreline. The cone is elongate in a WNW-ESE direction, and with a 130 m high central ridge separating two craters, east and west. A crater to most visitors means a deep, wide depression surrounded by vertical or sloping walls. The western crater fulfils this description but not the eastern where the entire northern wall has collapsed leaving a flat crater floor planted with village food crops.

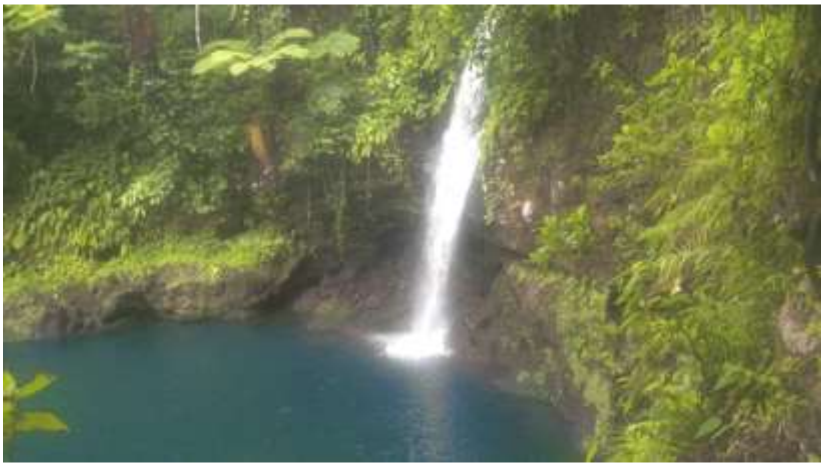
Before climbing to the western crater a word about Tafua-Savai'i's eruptive history will explain the two very different rocktypes you will see. Molten magma on reaching surface is called lava. This fragments explosively with the seawater contained in the underlying surface rocks to produce tuff, a brown unstratified, granular rocktype containing fragments and blocks of the underlying black basalt. This initial violent phase of hydro-volcanism built high tuff rings around the two vents (eruptive centres). Molten lava pooled over the vents and surging caused spill over their rims to consolidate as thin basalt beds, gassy at top, dense at the base. The western lake drained (by lava tube?) leaving a 150m wide and 50m deep vertically walled crater.

Marine tuff can be seen in quarries on either side of Tafua-Tai village and along the plantation road that encircles the volcano. It is compact in outcrop but crumbles into sand under pressure and can be mixed with cement to make concrete flooring. It provides good soil for garden crops. You see thin basalt strata in the crater's wall and you can't help walking on loose slabs that have been dislodged by tree roots.

Enough geology! The purpose of your Tafua visit is to see some of Samoa's wildlife in a beautiful natural setting. An easy 10 minute walk up the volcano's north flank takes you to a low point of the western crater. With patience you will see large, diurnal Samoan flying foxes (Pteropus samoensis) circling the rainforest below you or gliding on air thermals way above. And the crater's forest is a haven for birdlife with frequent sightings of the smaller birds and Pacific pigeons and occasional sightings of colourful fruit pigeons. It's all very worthwhile but if you are energetic and want a truly exhilarating experience climb the track around the crater's eastern rim to the summit for the magnificent panorama over cone-studded southeastern Savai'i. The large circular cone you see on the skyline to the northwest is the Mt Mafane ash cone, taller than the cone you are presently standing on but slightly smaller in area. You will see this from many points along the south coast road.

The return walk to the top of the western crater takes about an hour. But why hurry back? Just relax and enjoy nature.

2. Afu A'au Waterfall



The Afu A'au waterfall is in a narrow gorge cut into old Salani rocks by stream erosion. A two metre wide stream of water plunges over a rock ledge 12 m into a deep, wide pool of cool, clear water fringed by ferns and tropical vegetation. It's once idyllic beauty has been somewhat spoilt by local enterprise constructing a kilometre long access road to the very edge of the pool. If you drive, park about halfway and continue by foot to photograph the cataracts downstream from the pool.

During the dry season the waterfall seldom flows but the underlying pool is continuously flushed by a strong flow of cool water from an underground spring. Savai'i's hydrology will be discussed at the next stopping point, Satupa'itea.

3. Satupaitea Fresh Water Spring

You have not gone very far on your island tour but you just left a fast flowing stream, saw another from the Vailoa bridge and are now sitting by a walled - in spring by the shoreline. You must think there's water everywhere. In a sense you are right - but it's mostly underground. Next stop, you will see Savai'i 's largest river, which occasionally dries up, then you will travel right around the island back to the starting point at Salelologa with little likelihood of seeing running water except for two small usually sluggish streams east of Menase, North-Eastern Savai'i.

Rainfall is high, ranging from 4000 mm to 7000 mm annually in the high central plateau to 2000 mm to 3000 mm for coastal areas. Despite high rainfall there are only two permanently flowing streams, those you saw from the Vailoa bridge. Savai'i consists of a thick stack of poorly consolidated volcanic ejecta and heavily jointed lava flows. Rainfall sinks into these formations then, as groundwater, percolates down to enter a fresh-water aquifer at sea level. This Ghyben - Herzberg Lens is explained thus; rocks that are porous and permeable to rainwater are also porous and permeable to seawater. Saltwater underlies the island, saturating pore space between rock particles and the joints and fractures of lava flows. The seawater has mineral content and cradles the lighter fresh-water. A Ghyben-Herzberg Lens is thick in the central part of the island, tapers towards the coastline and is underlain by a zone of mixing, then of seawater. The lens is being added to constantly by groundwater and is under pressure from below by seawater trying to regain sea level, resulting in fresh-water being discharged continuously around the shoreline as seepages and springs.

Most coastal villages of Savai'i have walled-in springs, the water being fresh from low-tide to half-tide then brackish to high tide. Pool water is used for bathing and washing clothes but, without boiling, not for drinking. Savai'i's domestic water supply is heavily dependent on inland wells where the Ghyben-Herzberg Lens is thick and uncontaminated by village sewage.

4. Mu Pagoa Waterfall - Emerged Coastlines

The latter half of Savai'i's five million year history has been during the Pleistocene, the Ice Age when thick ice caps covered much of the northern hemisphere. The Ice Age was interspersed by 14 or 15 warmer inter-glacial periods with melting ice causing enormous fluctuations in sea level, the last meltdown starting 21,000 years ago (Fig 8).

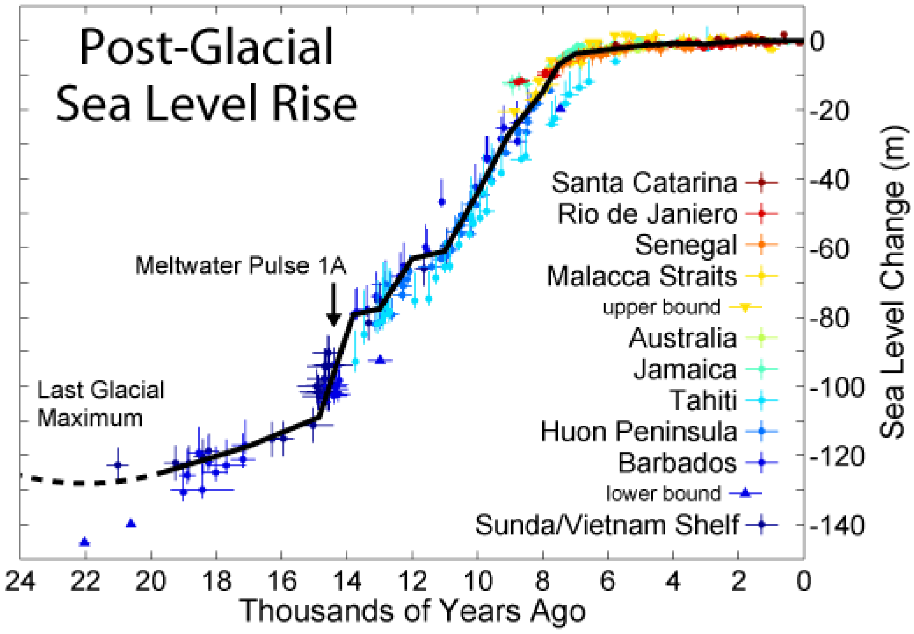


Figure 8. Sea Level Rise.

Sea level rose slowly at first, rapidly from 15,000 to 7,000 years ago followed by a 4m rise until today. This 120 m rise has had a profound effect on Samoa's coastal geology. Old coral growth was drowned out, re-starting about 6000 years ago and shorelines have risen because of hydroisostatic rebound. This needs explaining. It is a phenomenon common to every island located on thin plates of oceanic basalt. The weight of the 120 m sea level rise has depressed thin oceanic plates into the Earth's mantle with plastic mantle material collecting below the islands causing uplift (hydroisostatic rebound). Average uplift for most of Savai'i, Upolu, the Hawaiian and Tahitian islands was 1.5 m but 3 to 4 m along the Puleia coastline. Drive slowly when approaching Puleia to see an emerged coastline with wave cut caves, an inland sea arch now 100 m from the shoreline and stop at the Mu Pagoa waterfall where Savai'i's largest river drops into the ocean over a basalt ledge - a 3 to 4 m fall depending on tide.

It might be noted that uplift has raised strips of coral sand along the shorelines of both Savai'i and Upolu. This sand is less than 6000 years of age which means that uplift continued after the rapid sea level rise of 15000 to 7000 years ago. It is possible that uplift is continuing today, but is now but outpaced by rising sea. There are no figures for Savai'i but for Upolu sea level rise is three millimetres annually.

5. Gataivai, A Failed Forest Project

One km west of Gataivai village the road skirts a forest of Queensland gum trees (eucalypts) planted in 1988 but abandoned many years ago. Today, 28 years after planting, the trees are spindly. Why? Wherever the basalt surface is exposed you see unweathered flow patterns. It is too young, useless for ground crops and not much good for forestry. This section of Savai'i was lagoon before being filled with young lava flows.

6. Sea Arches And Iron-Bound Coastline

Many sea arches line the shoreline between Gataivai and Taga but only one is distantly visible from the road. To see them at close range stop at a 3 m wide gap in the bushes lining the road about 200 m east of the first houses of Taga village. If you pass it, turn around - this section of coastline should not be missed. A short walk to the cliff takes you to a well developed sea arch, a partly developed arch and gives you a great view along the rugged coastline to the blowholes.

Sea arches are cut into a 4 m high cliff of basalt made of stacked beds ranging in thickness from 0.5 m to 1.5 meters. The basalt layers are heavily jointed - (molten lava shrinks when consolidating leaving vertical joints between blocks.) Wave action against the cliff face undercuts and dislodges blocks at sea level, overlying blocks collapse and block by block attrition continues leaving a deeply indented shoreline of narrow closely spaced fingers (promontories) up to 30 m in length. If the lower layers of these fingers are dislodged you have a sea arch and, if the top layers collapse, a sea stack.

Visitors seldom see this section of coastline. It's wildly beautiful, dramatic and in stormy weather when great rollers crash against the cliff face, awesome. Tourism promotion rightfully focuses on lagoons and beaches, the popular leisure destinations. But lagoons occupy only one quarter of the coastline, the remainder being either faulted (described later) or 'iron-bound', iron-bound being an old mariner's term for an inhospitable shore of black cliffs offering no refuge in storms. Much of Savai'i's iron-bound coast is far from the road but several sections are easily reached. Adventure seekers would enjoy the cliff walk eastwards from Tafua-Tai village passing sea arches, two blowholes to arrive at the Paepae o le I'a, a rock platform with a good view of Apolima island. Several kilometres east of Falelima village you will see the Devil's Archway.

7. Taga - Alofaaga Blowholes

There are many blowholes around Savai'i's basalt shoreline but those at Taga are one of the Pacific's best tourist attractions. Local legend states that two drowned Tongan princes were washed ashore where their bodies rotted through a low-lying coastal shelf to from blowholes. A more scientific explanation is that wave-cut caves underlie the shelf, each with an overhead opening, that of the main blowhole being a 1.3m diameter fumarole. Waves surge into the cave, compress with air, and spray shoots skywards with a thunderous roar rising 30 metres (providing the trade wind is not blowing too strongly). A popular ploy is to toss coconut husks into the hole. With strong swell and split-second timing they rise 50 metres. Stand up-wind. The weaker blowhole blows spray seawards at a 45 degrees angle through disarranged surface blocks.

Pacific guide books state the best time to visit is high tide. This might help marginally if swell is weak but don't plan your day around a tide timetable. The blowholes are great at any time. And if you are visiting between August and mid-November keep an eye on the ocean. The blowholes attract humpback whales. They come close in to see if it's the big daddy of all whaledom.

8. Satuiatua, Coral Sand & Beachrock

Raised sections of compact coral sand outcrop along many sections of coastline protected by coral reef. Coral sand has already been mentioned when discussing hydro-isostatic rebound but this is your first sighting. Satuiatua, like many coastal villages of Savai'i and Upolu, is built on it, the name Tafagamanu sand coming from a village in Upolu. This is also your first sighting of beachrock.

Storm erosion of Tafagamanu Sand plus the addition of new sand by wave abrasion of the coral reef (and parrot fish grinding up live coral to extract the algae and protein) have built to-day's beaches but, quite often, access to the lagoon is obstructed by bands of dense, slippery rock deeply pitted at surface. This, previously called coquina, has been re-named beachrock. It occurs in the intra-tidal zone between a beach and lagoon.

Coral sand is composed of calcium carbonate and, like limestone, is slowly soluble in cool fresh water. Fresh water of a Ghyben-Herzberg Lens on seeping through Tafagamanu Sand will become charged with calcium carbonate which, on entering the tidal zone, will be precipitated by the chloride ion of the salt water thereby cementing unconsolidated sand grains into beachrock.

The width of the tidal zone and consequently that of the beachrock outcrop varies with the slope of the beach. When steep, 3 or 4 narrow, closely spaced bands of rock will be exposed with falling tide, each band being progressively higher towards the shoreline. You will see a fine example of this much later when driving by the beach at Faga. But what you are looking at now at Satuiatua is puzzling - two broad bands of beachrock with the seaward band slightly higher than the landward band. Evidence of ongoing uplift?

The walled-in pool at the western end of the beach contains freshwater from the Ghyben-Herzberg Lens.

9. Fagafau - Faulting

Look at your Savai'i map. The abrupt 45 degree change in coastline direction at Taga is caused by faulting - faulting that has not been dated but postulated to have been within the past 15,000 years. A large section of western Savai'i has collapsed into the ocean leaving a vertical fault scarp of black basalt (now partly lined with narrow strips of fringing reef).On leaving Satuiatua you soon pass Foailalo where the scarp is 30 m high them Faia'ai where it is higher. Stop at Fagafau (Lovers Leap) to look over the 65 m drop into the ocean and note the untidy heap of young basalt that has dropped over the scarp to pile up on a flat rock platform. While you're waiting to see a shark and a turtle read the placard relating the local legend of an old lady and child who jumped over the cliff.

Queensland's east coast is said to have been hit by a massive tsunami - Savai'i collapsing???

Drive on from Fagafau, stop at the Devil's Archway then circuit the Falealupo peninsula entering by the Tufutafoe road. You will pass a quarried cinder cone - cinders being volcanic ejecta with iron content oxidised red by gases - then drive around Savai'i's most westerly point on Tafagamanu sand. It is beautiful; coral sand beaches between black basalt outcrops, coconut palms everywhere but sparsely inhabited. Category 5 cyclones of 1990 and 1991 devastated the once thriving villages. You might visit the House of Rocks, a collapsed lava tube in Falealupo village before proceeding to Fagalele bay, home of Moso.

10. Moso's Footprint

There's a good story here but not much geology. Moso was a giant, a horrible child-eating giant, who made nightly one-step crossings to Fiji to visit his girlfriend. On returning one morning he left a footprint on the shore of Fagalele Bay. This 2m long depression is a bit small for a giant who must have been 1500 km tall but there's a natural explanation. The surface outcrop is a thin bed of heavily jointed basalt . A tree has spread roots over the surface with rootlets penetrating joints. When the tree toppled during a cyclone the roots dislodged surface blocks. There are other 'footprints' in Savai'i - and maybe some in Fiji.

11. Falealupo Canopy Walkway

The magnificent rainforest of 30 years ago has largely disappeared from the area surrounding the canopy walkway so climb it for a geological experience. There are four young Puapua cinder cones nearby, the small one across the road from the walkway being of interest. It has been quarried for road construction material leaving an open-cut face showing cinders top and bottom and an irregularly shaped lens of flow lava in between.

Now a word about eruptions in general. Magma, i.e lava while still in the ground, contains an enormous volume of water and dissolved gases under pressure. On nearing surface gases come out of solution, steam being the driving force of every eruption - either blowing or flowing. Eruptions will often start with magma being ejected by gas, particle size varying from fine ash to bombs, then later by flow. The cone across the road had a fluctuating steam drive.

12. Mauga Afi (Fire Mountain) Eruption & Aopo Lava Field

The Mauga Afi eruption was recorded by the French navigator Anton Bougainville when sailing by Savai'i's north coast in 1768. It has been ranked as one of the world's largest lava outflows but, as explained later, this needs re-defining.

The outbreak was from two cones spaced 3 km apart on Savai'i's high central plateau. Lava from these coalesced and flowed down the island's steep northern flank forming a wide lava fan over the coastal plain. There is no record of the start or end of this eruption but it covered a very large area to an unknown thickness. An old legend tells of 100 buried villages - probably an exaggeration but certainly indicating a high pre-eruptive population. Samoans, then as now, lived in villages by lagoons. The basalt cliff along the still smooth coastline probably built up over a coral reef, events that were replicated 150 years later during the Matavanu eruption.

The inland road from Asau to Aopo crosses the 2.5 km wide lava flow about 170 m above sea level. Vegetation changes abruptly to dense scrub. Rocktype also changes to loose angular basalt blocks called a'a lava - a Hawaiian term to distinguish it from the smooth ropey pahoehoe lava you will see later at the Saleaula lava field. Several openings in the vegetation along the road allow views over the lava fan - an endless uninhabited wasteland.

You might puzzle over the irregular outline of the Aopo lava field (coloured yellow in figures 6 and 7). Molten lava flows downhill, can spread laterally over flat surfaces but cannot flow uphill. You are now on the flow path between the two Mauga Afi cones and the lava fan but the areas to the east coloured yellow cannot be part of the same eruption. Their scrubby vegetation indicates a very young age, probably late Puapua.

13. The North Savai'i (Ologogo) Fault

Landslides make the news all too frequently. Never a month goes by without some disaster in China, Peru, Nepal, wherever. Most are local when part of a mountain collapses but what you are looking at from this steep hill overlooking Sataua was gigantic. A great slice of Savai'i dropped and slumped northwards towards the ocean. (Fig 9)

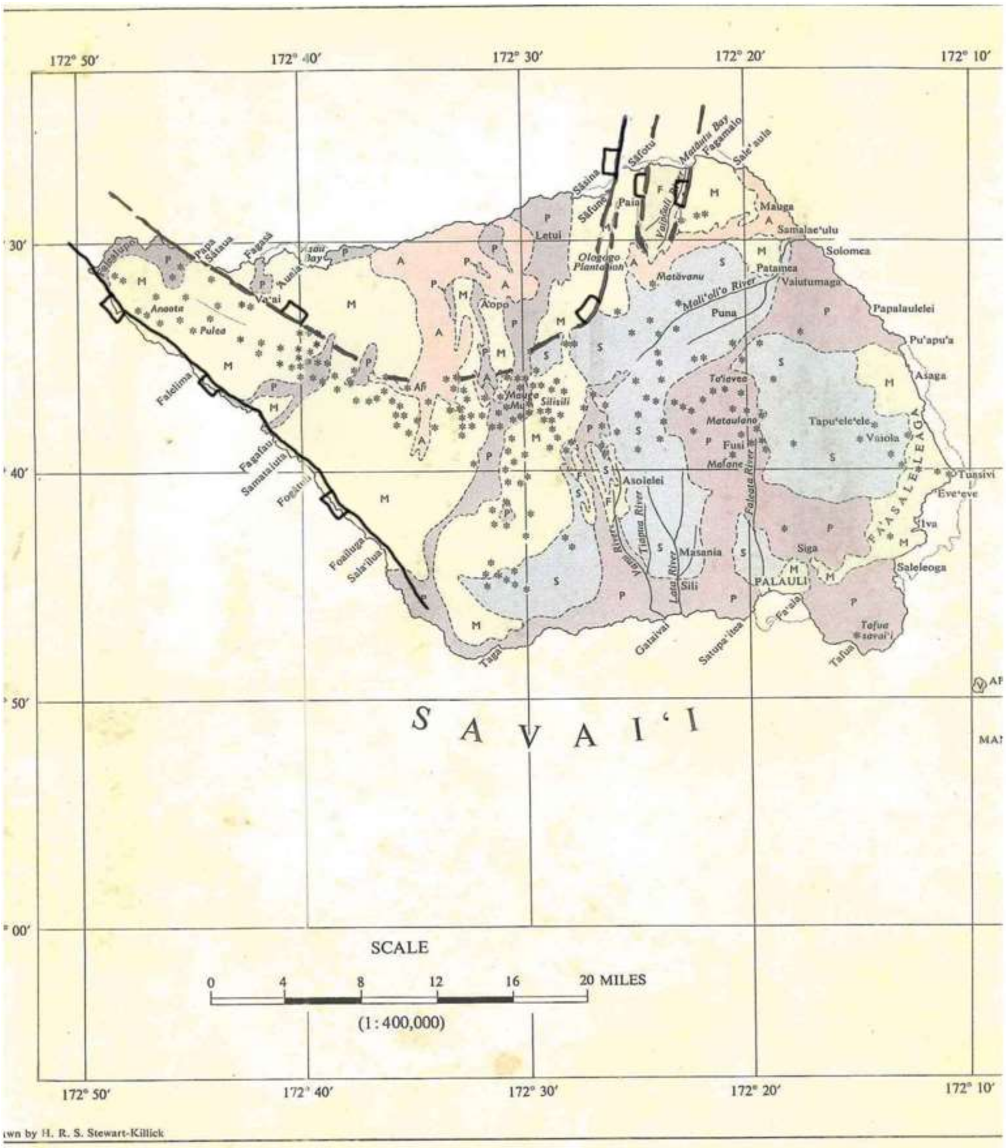


Figure 9. Savai'i Cone Distribution and Faulting.

Figure 9 is adapted from the original 1956 field mapping of New Zealand's Geological Survey. It shows a curved fault from Sataua to Safune and two step faults further east - a slump 42 km across and extending 13 km inland. The broad curvature of the main fault indicates the collapse of a thick stack of poorly consolidated volcanic ejecta and flow lavas, probably destabilized by rapidly changing sea level. The fault displaces Salani and Mulifanua beds and is partly covered by Puapua and Aopo flows. Consequently it is young, probably relating to rising sea of the last glacial meltdown. Cones of late-Mulifanua age and those of the 1760s and 1902 eruptions are on or close to the surface trace of this main fault. It has a vertical displacement of 150m south of Aopo and cuts the coastline at Safune in the east and Sataua in the west forming steep scarps into these villages. Visitors stop to photograph the magnificent coastal panoramas from the road above these villages without realizing the geological significance of these slopes.

Cones are concentrated on Savai'i's high central plateau with many lining the fault on both the upthrown and downthrown sides. Neither this faulting nor that of the south-western coastline has been dated but both are geologically young and possibly concurrent, one triggering the other.

Savai'i's coastline has changed considerably over the past 20,000 years by rising sea, faulting and volcanism. Coastal Savai'i was submerged by the 120 m post - glacial rise in sea level and faulting has displaced large coastal section into the ocean. Conversely, eruptions may have heightened parts of the interior but have certainly increased land area within the past 5,000 years by lava flows filling lagoons.

Savai'i has been extremely active volcanically and tectonically during the past 20,000 years. Such activity is predicted to continue until the island has moved to the northwest beyond the influence of the Tonga Trench.

14. Lava Tubes of Aopo, Letui and Paia

A lava tube (or tunnel) forms when molten lava is channelled into a topographic depression such as a dry stream bed. The surface cools and consolidates insulating the underlying flowing lava from the air. Flow continues with diminishing volume until the eruption peters out leaving a 4 m to 5 m diameter sloping tunnel with a flat floor.

Savai'i's 20 known lava tubes have been exposed by surface collapse but there are probably many more. Three tubes of this northern area are open to visitors; one a few kilometres west of Aopo (but not yet seen by this writer) is highly recommended by visitors; a 40 m long tube near Letui is alongside the road, convenient for a quick visit and the Dwarfs Cave 3 km from Paia is for adventure seekers. Enter via a steep slope into a large underground chamber then continue downwards by short steep drops, each separated by a shallow pool.

Lava tubes are exciting but don't enter without a local guide and adequate lighting. Take your own flashlight as a back-up. Polynesian white- rumped swiftlets nest in them. Dont panic if you're told they're bats.

15. Safune, Mangroves and Matalealelo Spring

After a long inland passage from Asau, you reached the coast at Sasina and are now at Safune about to climb a steep hill. This is the eastern scarp of the wide Sataua - Safune slump. The very abrupt 120^{0} change in coastline direction is a result of this faulting.

Note all the mangrove trees along the shore. They can grow in seawater but thrive in a brackish habitat. The many freshwater outlets of this area are fed by the Ghyben - Herzberg lens. The walled-in Matalealelo spring is a popular tourist stop with a legend about an eel who fell in love with princess Sina. It grew to enormous size as it followed her from pool to pool around Savai'i's, last stop being here. She fled to Upolu, the eel followed and was killed by village chiefs. Its dying request was to plant its head. This grew into the world's first coconut tree. If you don't believe this, ask a boy to husk a coconut then look at the three round rings on top.

16. The Mauga Mu Eruption

The Mauga Mu eruption is not an accessible tourist attraction but is discussed here for two reasons; it helps explain Savai'i's high concentration of small cones; and it was the beginning of an eruptive cycle that culminated with the massive Matavanu eruption.

The short-lived 1902 outbreak was on the high central plateau 4 km east of Mauga Afi, and was shielded from coastal view by the island's gentle curvature. It was not known if existing cones had erupted or new ones formed. Subsequent investigation showed two closely shaped clusters of spatter cones, together adding seven small cones to the hundreds already extant. This is monogenetic volcanism - new eruptions form new cones, possibly because old cones are underlain by solid basalt plugs. Savai'i's central plateau is heavily faulted with chains of closely spaced cones lining surface traces (Figures 9 and 10).

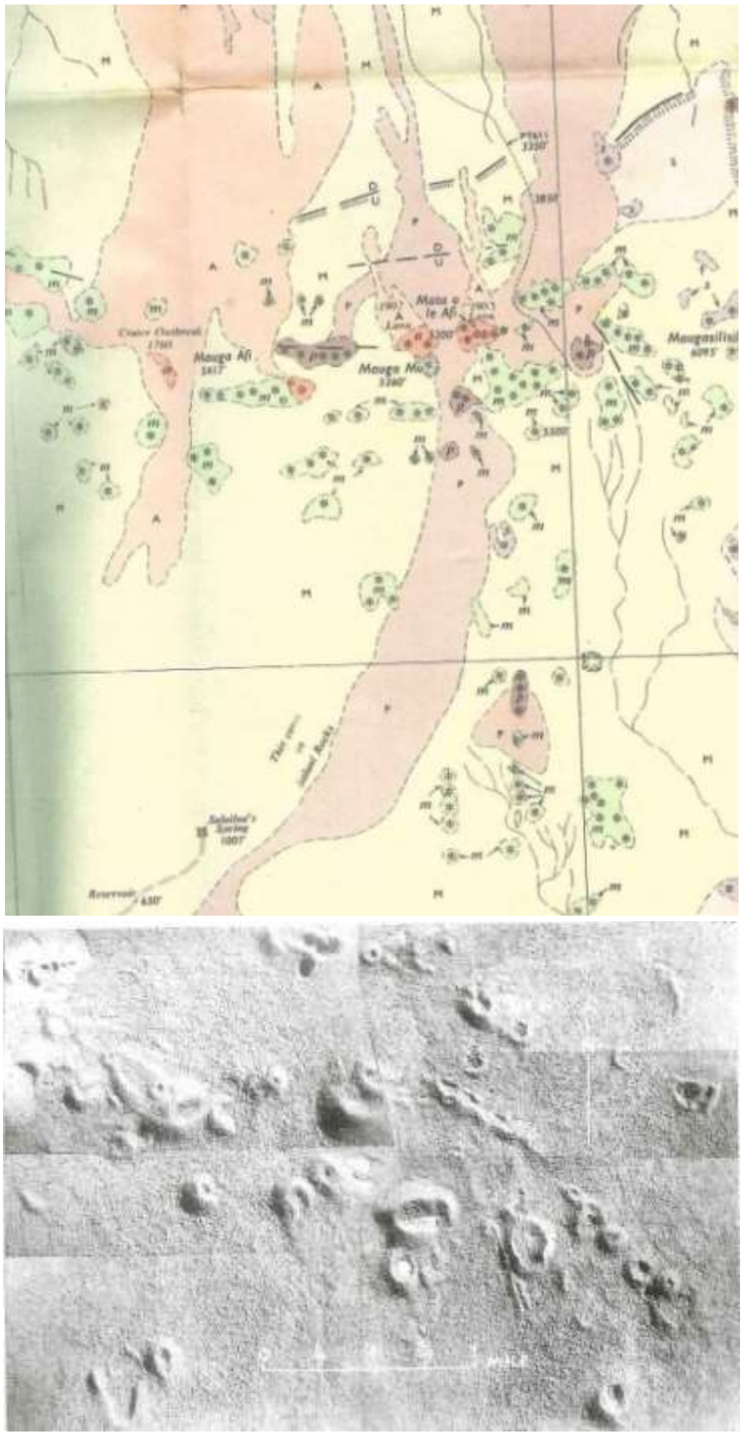


Figure 10. Central Savai'i

17. Mount Matavanu

Matavanu's birth in early August, 1905, was impressive. High lava fountains roared from the ground, quickly built a spatter cone and by early September great surges of incandescent lava were flowing down a river valley to flood the Saleaula coastal plain. This was the first of Savai'i's historic eruptions to be recorded in detail. Discussion of the Saleaula lava field follows this brief description of the Matavanu volcano.

Matavanu is visible 10 km away from an opening in vegetation along the East Coast road, one kilometre south of Mauga village. Visitors expecting a mighty volcano will be disappointed to see a gently sloping hill set way below the cone- studded skyline. The black band capping this lava cone is the uppermost part of the crater's western wall. The cone rises about 90 m above surrounding terrain, the summit being aproximately 700 m above sea level.

Matavanu has built over the step fault east of the Sataua - Safune fault block. The 8 km long plantation road from Safotu via Paia to Matavanu is along the downside of a steep 30 m high scarp to the base of the volcano where the scarp is buried under spatter*. Here the road climbs the northern flank and the lush tropical vegetation is replaced by thin scrub allowing great views over northeastern Savai'i. A 300 m track from the road ends at the 50m deep, vertically walled crater. Immature rainforest in and around the crater is attributed to high rainfall.

Discussion about faults providing conduits for rising magma needs clarification. Faults of 30 m or 150 m displacement create spectacular scenery but they are not major structural features and are far too small to have intersected an underlying magma chamber. Savai'i is the pinnacle of an enormous edifice of hotspot origin capped by younger volcanics. This edifice rises 6.8 km from the ocean floor with sub-aerial Savai'i accounting for 3 % of the total structure. The landslide and it's confining faults are a weak surface expression of considerable disturbance in submarine levels of this eoifice.

* The term spatter refers to falling blobs of molten lava that spread on impact.

18. Saleaula Lava Field and Ruins, Eruptions

Some 76 sq km of northeastern Savai'i's farmland and lagoon were overwhelmed by the Matavanu eruption, four villages were completely buried and Saleaula, the most northerly village, was partly buried. To-day, the long, wide coastal strip of black ropey (pahoehoe) basalt makes an awesome tourist attraction. Once past Saleaula village the next 2km of road follow the western boundary of the lava field. Walk a few hundred metres to one of the raised pressure ridges to overlook this great, desolate expanse of black basalt with the ocean to the east and the wide arch of Savai'i's skyline to the west. You will understand the term 'volcanic shield'. The surface is a combination of smooth pahoehoe lava showing intricate flow patterns and patches of jagged blocks broken by the pressure of either escaping steam or oncoming molten flow. You might also note that in many places a thin surface bed overlies increasingly thick underlying layers. This is common, the intense early eruptive stage diminishing with time.

Lava ceased spreading over land by late September, 1906 but continued by lava tube until late 1911. A local resident reported in August, 1908, "That the lava continued to run strongly into the sea." Lava dropping into seawater fragments into black sand. Much of this would have been dispersed by waves and currents but sufficient sand was washed back over the cliffs during the 1990 and 1991 cyclones to start a successful black-sand block industry. A less successful venture was a coconut plantation. A village family built a rough vehicle track across the lava field to the shoreline, planted hundreds of sprouting coconuts in straight lines but today, 18 years after the planting, many are still alive but only a little taller than the day of planting. Black sand is raw mineral not yet weathered into clay - a requirement for most plant life. You are recommended to walk to the shoreline, not to visit a failed coconut project but to see the jumble of enormous boulders lifted over the cliff by the 1990 and 1991 cyclones - some weigh 30 tons or more. Refer to the front page photograph.

Before visiting the Saleaula ruins a word about eruptions in general.

Eruptions – The Danger Factor

All magmas consist primarily of oxygen, silicon, aluminium, iron, magnesium and calcium in different proportions but it is silicon content which largely determines if an eruption will be mild or explosive. The basalts of the Pacific Plate and its intra-plate islands (Hawaii, Samoa) have low silicon content, all of which is combined with the metallic elements as minerals called silicates. There is no free quartz (silicon dioxide). These lavas have temperatures of about 1200^{o}C on emission and consequently are sufficiently fluid to allow dissolved gasses to come out of solution and escape at the volcano's vent. Gas pressure doesn't build up in the volcano causing it to explode. Steam is a gas and the main driving force in all eruptions.

Magmas with high silicon content can be very dangerous. Volcanoes over subduction zones (where a plate of oceanic basalt subducts under and melts an overlying continental plate of highly siliceous rocktypes) can explode violently. Temperature of a siliceous magma on emission can range from 800^{o}C to 1000^{o}C. This cooler magma can be too viscous to allow gasses to escape. Gas pressure will mount until the volcano explodes releasing a searing, rapidly expanding cloud of steam and toxic gasses charged with ash.

Some readers would know about the 1902 eruption of Mont Pelee, Martinique which completely destroyed the original capital St Pierre killing 28,000 residents; and many readers would remember the 1980 eruption of Mt St Helens, Washington State, which killed 57 old-timers who refused to evacuate. These are Pelean eruptions where a pyroclastic flow (or nuee ardente) blasts laterally and, together with Plinian eruptions where the blast is vertical, are the most dangerous. (Pliny the Elder died in the AD 79 eruption of Vesuvius). The Samoan eruptions are at the bottom of the danger list and are called Hawaiian - type or moderate eruptions. The Matavanu eruption ruined a large area of agricultural land, caused enormous material loss and disrupted life in Savai'i for many years but caused no loss of life.

Saleaula Ruins

Your final lava field stop is to see the old London Missionary Society Church then visit the Virgin's Grave. Saleaula is close to the northernmost point reached by the flow with pockets of land remaining uncovered. The cemetery behind the LMS church was spared but not the church. Lava flowed through the front entrance but was too viscous to reach the back wall. Of particular interest is the Virgin's grave. Local legend states that she died of tuberculosis at an early age while training to become a nun. She was buried some 150 m from the LMS church and was so pure that the lava parted and flowed around her grave leaving it untouched. There is a prosaic geological explanation about wet ground and the lifting power of steam but believe the Samoan story - it's charming.

19. Mauga Crater

Follow the road 3 km southeast of Saleaula to Mauga, a small village with fales and a large Catholic Church built around the rim of a gently dipping crater. This feature dates to 1906 when molten lava of the Matavanu eruption flowed into wetlands, fragmented explosively and mixed with limy sediments to build a 35 m high tuff cone. It has been called a pseudo - volcano - a cone without volcanic roots. Subsequent lava flows almost surrounded this cone with black, ropey basalt.

A dirt track encircles the rim but don't drive beyond the Catholic Church. This was consecrated in 1995 to commemorate both the 150th anniversary of the arrival of Catholicism in Samoa and the destruction of Samoa's first Catholic Church when lava overwhelmed the nearby village of Sataputu.

20. Samalaeulu

When crossing Savai'i's second largest stream, the Mali'oli'o river at Samalaeulu, don't be surprised if there's no water. It is a typical alia - a dry stream bed which flows only during or following heavy, prolonged rain.

NOTE : Don't try crossing the un-bridged alias at Sasina, Samalaeulu, Lano or Sapapali'i when the current is strong or at night. Watch out for floating logs.

21. Mt To'iavea and Mt Tagotala

To'iavea and Tagotala are visible from any high pressure ridge of the Saleaula lava field. Both are Pu'apu'a cinder cones and both stand well above the skyline, To'iavea being Savai'i's tallest cone. Its summit (1073 m above sea level) is approximately 200 m above surrounding ground level. Tagotala rises about 100 m above ground level but is much closer to the coast than To'iavea. They rank as Savai'i's third and fourth largest cones in area.

For an extraodinary view of these cones stop at a narrow roadside clearing 7 km from the Samalaeulu-Patamea road junction. To'iavea, 13 km inland, has near-vertical slopes due to collapse (landslides) of its south-western and north-eastern flanks. It looms over Tagotala like a gigantic black headstone. From other viewpoints along the coast road its profile is less impressive.

22. Pu'apu'a to Salelologa

When driving through this sparsely settled stretch of vine-covered forest north of Pu'apu'a you will see introduced Asian teak trees, rainbow gums from PNG and Pacific mahogany from the western Pacific. These were part of a large forest project abandoned because of cyclones and slow growth. The Pu'apu'a basalts of this area are less than 2000 years in age.

Landscape changes abruptly on entering Pu'apu'a village to a wide lagoon and fales built on Tafagamanu sand surrounded by coconut palms and breadfruit trees. The next 19 km to Salelologa will be on Tafagamanu sand and weathered Mulifanua basalts, both supportive of garden crops. This is the Savai'i of tourist brochures. It is also the product of geology but there are few specific sites of interest. You might stop at Saipipi to photograph the four most easterly cones of the Tuasivi Ridge (a chain of cones aligned with Pacific Plate movement) and slow down where the road skirts Mt Asi at Fogapoa. This, the easternmost of Savai'i's 450 cones, is 8 m high and would easily fit into a standard sized football field.

This island tour ends with descriptions of two seldom visited remote sites then a final note about tapa making, an early Polynesian handicraft needing no geological commentary.

23. Mount Silisili

Mount Silisili is a small cinder cone on Savai'i's high central plateau. Its crest at 1863 m is slightly higher than the dozens of cones that surround it. As such, it is the highest point of the Samoan Archipelago. Access is from the sawmill 5 km west of Aopo by a recently constructed dirt road to within 6 km of the cone, but firstly enquire about the road condition. If walking from Aopo the uphill trek takes 7 hours then overnight camping. All hikers are accompanied by local guides.

24. The Pulemelei Step Pyramid

Polynesia's largest ancient rock structure is located in the abandoned Letolo coconut plantation 3 km from Vailoa village. It is 65 m in length, 60 m wide and 13 m high. Archaeological investigations between 2002 and 2005 determined two stages of construction, firstly between 900 - 1000 AD (the time of Tongan occupation) then the upper steps between 1400 - 1600 AD.

Thin surface beds of old Salani basalt have weathered into fertile soil leaving an abundance of loose, tabular blocks suitable for building. One of Savai'i's few permanent streams flows through the area, an ideal place for early settlement. A large village was periodically occupied from 2000 years ago until abandonment in the late 1600s.

Nothing has come down in legend about the function of Pulemelei. It probably had administrative or religious usage, but is unlikely to have been a burial site. A geo-radar survey indicated stacked rock layers but no inner or underlying chamber. It was built on a gentle slope overlooking Palauli bay so, apart from its main purpose, it would have been an excellent watch tower.

Pulemelei is one of the Pacific's most important archaeological monuments and has been considered for World Heritage status. It deserves recognition as one of Samoa's prime visitor's destinations but it is presently abandoned, vine - covered and impossible to find without a guide.

25. Tapa Making

Tapa making using the inner bark of the paper mulberry tree was an early Polynesian introduction for making clothing. It is still worn at some formal functions, in decorating churches , in burials and as souvenirs in the tourist trade. Visitors can watch an hour - long demonstration of this entire fascinating process from the cutting down of a paper mulberry tree to the finished product. When driving through Vailoa village look for the road sign 'Siapo Demonstration', Siapo being Samoan for tapa.

Travel Tips

Before leaving Salelologa (or wherever you are staying) make sure you have a Savai'i road map in addition to the location map of this article.

Road distance around Savai'i (including the loop road around the Falealupo Peninsula) is 202 km. The 40 km/hour speed limit should never be exceeded when driving through villages or on the narrow, roller - coaster north road between Asau and Sasina.

Visitors wanting a satisfactory overview of the island should allow a minimum of two days sightseeing but preferably much longer.

And wherever you go and whoever you meet you will be reminded that Savai'i is one of the most beautiful, most interesting and most friendly islands of the world.

Acknowledgements

This Savai'i Guide is a supplement to a 2014 article "Samoa: A Geological History", which was compiled from the 1957 field mapping of New Zealand's Geological Survey and from more recent scientific reports supplied by Dr Shaun Williams of NIWA (National Institute Water Atmospheric Research) and Paul Anderson of SPREP (Secretariat of the Pacific Regional Environmental Program).

Special thanks go to Marie Tiatia, Scholar of Savai'i's LDS Vaiola College, for transcribing my hand-written text to her laptop; To Jo McKenzie, New Zealand Horticulturalist for her Savai'i photographs and to Kevin Hartin, Australian expat and Savai'i resident for compiling text, diagrams and photographs into this printed report.

References

Geology.com
The deadly Samoa-Tonga Earthquakes was Three Large Quakes

Hart S. R
Genesis of the Western Samoa Seamounts Province; age, geochemical fingerprint and tectonics.

Jackson M. G.
Samoan hot spot track on a "hot spot highway"; Implications for mantel plumes and a deep Samoan mantel source.

Kear D. and Wood B. L.
The geology and hydrology of Western Samoa. New Zealand geological survey, bulletin 63.

Koppers A. A.
Samoa Reinstated as a primary hotspot trail

Natland J. H.
The Samoan Chain: A shallow lithospheric fracture system.

Nemeth K Cronin S. J.
Volcanic structures and oral traditions of volcanism of Western Samoa (S.W. Pacific) and their implications for hazard education.

Scarth A.
Savage earth: the dramatic story of volcanoes and Earthquakes

My sincere thanks to the Savaii Samoa Tourism Association for their assistance in making this document available.