EU EDF 8 – SOPAC Project Report 77
Reducing Vulnerability of Pacific ACP States

SAMOA COUNTRY MISSION AND TECHNICAL ADVISORY REPORT
AGGREGATE ASSESSMENT IN SELECTED PARTS OF SAVAI'I AND UPOLU ISLANDS

1st – 15th October 2005

Sand dredging and haulage at Mulifanua, northwestern Upolu.

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March 2007

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INTRODUCTION

The Samoa Group is geologically young with the Pliocene-Early Pleistocene Fagaloa Volcanics being the oldest volcanic rock formation that occurs predominantly in eastern Upolu. The youngest volcanic formation is the Aopo Volcanics that erupted from a number of volcanic centres on Savai'i and were active between 250 and 100 years ago. The volcanic rocks on these two major islands are the traditional sources of sand and gravel in Samoa that have been extracted from on-land quarries, rivers and along the coastal zones. Recently, due to the increasing demand for sand, private aggregate extraction companies have ventured into marine sediment dredging.

In addition to the reconnaissance aggregate survey that was conducted in February 2004, the SOPAC-EU EDF8 Project undertook further assessments at selected sites in Samoa. Due to the forecasted increasing demand for aggregate supply, the Project has been requested to assist in identifying good sand and gravel resources, in terms of quality and quantity, on both Upolu and Savai'i islands (Figure 1). As requested by stakeholders, the site visits and assessments concentrated on on-land and lagoon aggregate sources on and around these two islands. This task addresses identified aggregate activities outlined in the Samoa Work Plan (Task Nos. WS 1.2.2 to 1.2.5).

The Samoa aggregate survey was conducted over a period of two weeks in October 2005.

Objectives

The principal objectives of this mission are listed below.

- Investigate the potential of on-land aggregate sources closer to Apia, apart from the existing quarries.
- Prospect for other potential sand and gravel sources on other parts of Upolu Island.
- Liaise with the Meteorology Office on the additional survey for sand and gravel sources on the eastern flank of Savai'i.
- Investigate other hard rock sources on Savai'i as potential sources of aggregate.
- Carry out aggregate assessment in selected areas in Upolu and Savai'i.
- Collect rock and sand samples for scientific analysis.
- Discuss with key aggregate stakeholders, especially developers in Apia, extraction-related issues such as demand and supply; production; cost of operation; aggregate resource ownership; and monitoring of extraction sites.
- Hold a debriefing meeting with stakeholders in Apia to present results of dredged sand sample analysis and hard rock tests, collected during the February 2004 Samoa Mission.

An order of events is in Appendix 1.

List of People Consulted

Ausetalia Titimaea (Assistant CEO, Meteorology Division (MD)), Ministry of Agriculture (MOA))
Lameko Talia (Principal Scientific Officer, MD)
Samuelu Taape (Assistant Scientific Officer, MD)
Sina Lui (Samoa Country Intern)
Arthur Meredith (Manager – Finance, Samoa Ports Authority (SPA))
Tiumalu Tiumalu (Operations Manager, Apia Concrete Products (ACP))
Lealiiee Ott (Operation Manager, Ott Transport)
Johnny Ahkau (Scientific Officer, MD)
Stuart Tuifoi (Accountant, Mana Industries Limited (MIL))

Peter Ott (Ott Transport)
Korea Strickland (MIL)
Alofa Faaofo (Strickland Brothers)
Henry Westerland (Bluebird Transport)
Tuaiaufai Tuimauga (Samoa Port Authority (SPA))

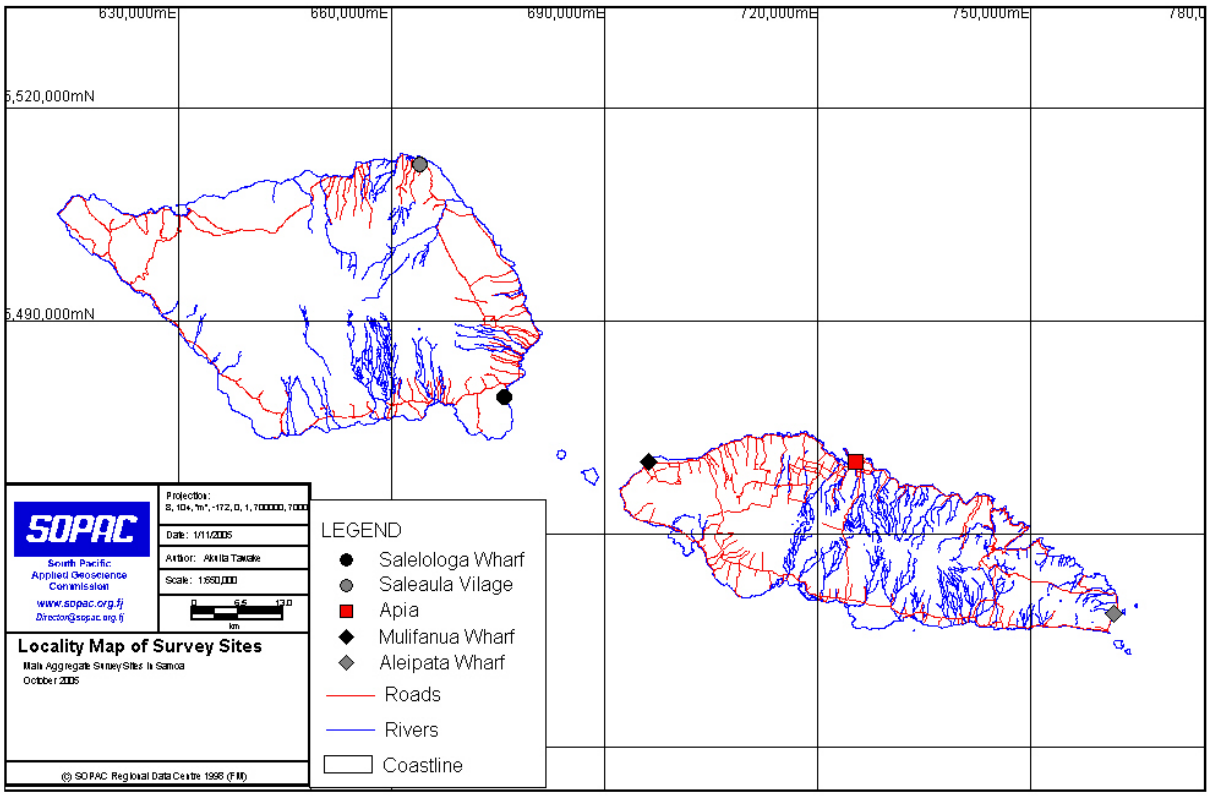

Figure 1. *Locality map of the main survey sites in Samoa.*

EXECUTIVE SUMMARY

The aggregate survey in Samoa was discussed and clarified at two separate meetings with relevant stakeholders in the last week of September 2005 – during the week of the SOPAC Annual Session in Apia, prior to the commencement of survey in the first week of October. The first meeting was held with Arthur in the Samoa Port Authority office where their dredging interests in Salelologa and Mulifanua for the purpose of deepening these two harbours and at the same time selling dredged sand to customers, were discussed. At the second meeting with Meteorology Division officials (Ausetalia, Lameko and Samuelu) at the Kitano Hotel, the work plan for the following two weeks was discussed and finalised.

It was agreed during the second meeting that due to the huge Project intervention area in Samoa, aggregate assessment would only concentrate on high-priority sites. The sites that were identified for investigations included lagoon sand deposits in Salelologa; Savai'i; Mulifanua and Aleipata in Upolu (Figure 1); and potential on-land aggregate sources on both islands. Sand sampling exercises were carried out in Salelologa, Mulifanua and Aleipata harbours, and at the mouth of Vaisigano River that drains into Apia Harbour. In addition, on-land hard rock sources on both islands were visited, inspected and where possible strength tests were carried out.

Sand sampling was first carried out in the immediate vicinity of the Salelologa Wharf. Nine hand-dug sand samples were collected with the assistance of a local diver. In addition, on-land hard rock sources around Savai'i were also investigated. With the aid of the Schmidt Rock Hammer, random tests were conducted on outcrops/boulders at every site to gauge the strength of the rock. Interestingly, the Saleaula Lava Field was also visited and assessed as a potential aggregate source. Small-scale domestic rock extraction has been ongoing at this site. See Appendix 2 for a preliminary report on the Savai'i assessment.

Sand samples were also collected around the wharves in Mulifanua, which is located in the northwest of Upolu, and in Aleipata, in the east of the island. Six hand-dug samples were collected in Mulifanua, and in Aleipata seven additional samples were collected. All the samples were sent to Fiji for scientific analysis. As carried out in Savai'i, active and potential on-land aggregate sources were also inspected and tested using the Schmidt Hammer. See Appendix 3 for a preliminary report on the Upolu assessment.

Some private aggregate extraction companies were visited in an endeavour to acquire production and selling price figures.

The mission was concluded with a meeting with stakeholders to present the results of the analyses/testings that were conducted on samples collected in 2004; and to debrief on the outcome of this survey.

GENERAL

Tabulated below are the Samoa Work Plan Tasks that were addressed during this visit, with subsequent follow up action:

Work Plan ID	Activities	Follow-Up Action
WS 1.2.1	Previous aggregate assessment data and reports in Samoa reviewed.	No further action.
WS 1.2.3	Carried out site assessment and sand sampling at an active dredge sites and three other potential extraction sites. These include the Mulifanua dredge site, the Salelologa, and Aleipata Harbours and the mouth of the Vaisigano River.	Sand analysis to be carried out and technical report to be completed.
WS 1.2.4	Testing of rock exposures using the Schmidt Hammer was concentrated on bigger outcrops that can potentially be developed as aggregate sources for both Savai'i and Upolu.	Results will be presented in the Technical Report. Preliminary assessment reports are in appendices 2 and 3 of this report.
WS 1.2.5	Capacity building for identified locals through on-the-job training. Additional training is planned for 2006.	The identified candidate attended the SOPAC aggregate workshop in early 2006. Sand sample analysis training followed.
WS 1.2.6	After consultation with Fiji Industries Limited (FIL), the idea of manufacturing clinker from carbonate and silica sands was deemed uneconomical. Stakeholders have been advised to buy clinker from overseas if they want to make cement locally.	No further action required for this task.

APPENDIX 1

Order of Events

Order of events during the time spent in Samoa:

- *Sunday (25/09/05):* Depart Nadi for Samoa.
- Saturday (24/09/05): Arrive in Samoa. Attend the opening and beginning of STAR.
- *Sunday (25/09/05):* SOPAC 35th Session Picnic.
- *Monday (26/09/05*): Resumption of STAR.
- *Tuesday (27/09/05*): Completion of STAR.
- *Wednesday (28/09/05) – Friday (30/10/05):* Attended Annual Session, visited the Geology Lab and Ministry of Works Lab. Finalised work plan with relevant stakeholders.
- *Saturday (01/10/05) – Sunday (02/10/05):* Started working on my power point presentation to stakeholders in Apia.
- *Monday* (03/10/05): Departed for Savai'i. Arranged for sand sampling in Salelologa Harbour.
- *Tuesday (4/10/05):* Sand sampling in Salelologa Harbour was postponed due to unavailability of boat. Commenced on-land aggregate assessment in Savai'i.
- *Wednesday (5/10/05):* Sand sampling in Salelologa Harbour was carried out.
- *Thursday* (6/10/05): Continued prospecting for on-land aggregate sources.
- *Friday (7/10/05):* Completed aggregate assessment in Savai'i.
- *Saturday (8/10/05):* Returned to Apia
- *Sunday (9/10/05):* Rest Day
- *Monday (10/10/05):* On-land aggregate source assessment in Upolu.
- *Tuesday (11/10/06):* Sand sampling around Mulifanua Harbour.
- *Wednesday (12/10/05):* Sand sampling around Aleipata Wharf.
- *Thursday (13/10/05):* Visit aggregate extraction companies on their production and price. Collected sand samples from the mouth of Vaisigano River. Site visits to Laulii and Aggie Grey Beach Resort.
- *Friday (14/10/05):* Held a debriefing meeting for stakeholders, where the analysis results of the samples collected in February 2004 were presented together with the initial findings of this survey.
- *Saturday (15/10/05):* Returned to Fiji.

APPENDIX 2

Savai'i Aggregate Assessment

INTRODUCTION

The aggregate assessment in Savai'i by the New Zealand Oceanographic Institute (NZOI) in late 1988 has indicated that there is a need to shift additional assessment to priority areas, where aggregate extraction is active; or is most likely to happen in the future. In consultation with representatives from the Samoa Port Authority (SPA) and the Meteorology Division, the Salelologa Harbour and accessible on-land aggregate sources were investigated as potential sources of sand and gravel in Savai'i.

The Salelologa Harbour was identified by SPA for dredging in the not-too-distant future in order to deepen the boat channel to allow bigger cargo boats to berth at the wharf. As in the case of Mulifanua, SPA is planning to sell the dredged sand to local customers. The EDF Project was requested to assess the suitability of the sand and gravel that occur in the lagoon as construction materials. This survey should also consider the environmental implications of such an operation.

A technical report will eventually be produced highlighting the details of aggregate assessment, sample analyses and results, along with recommendations.

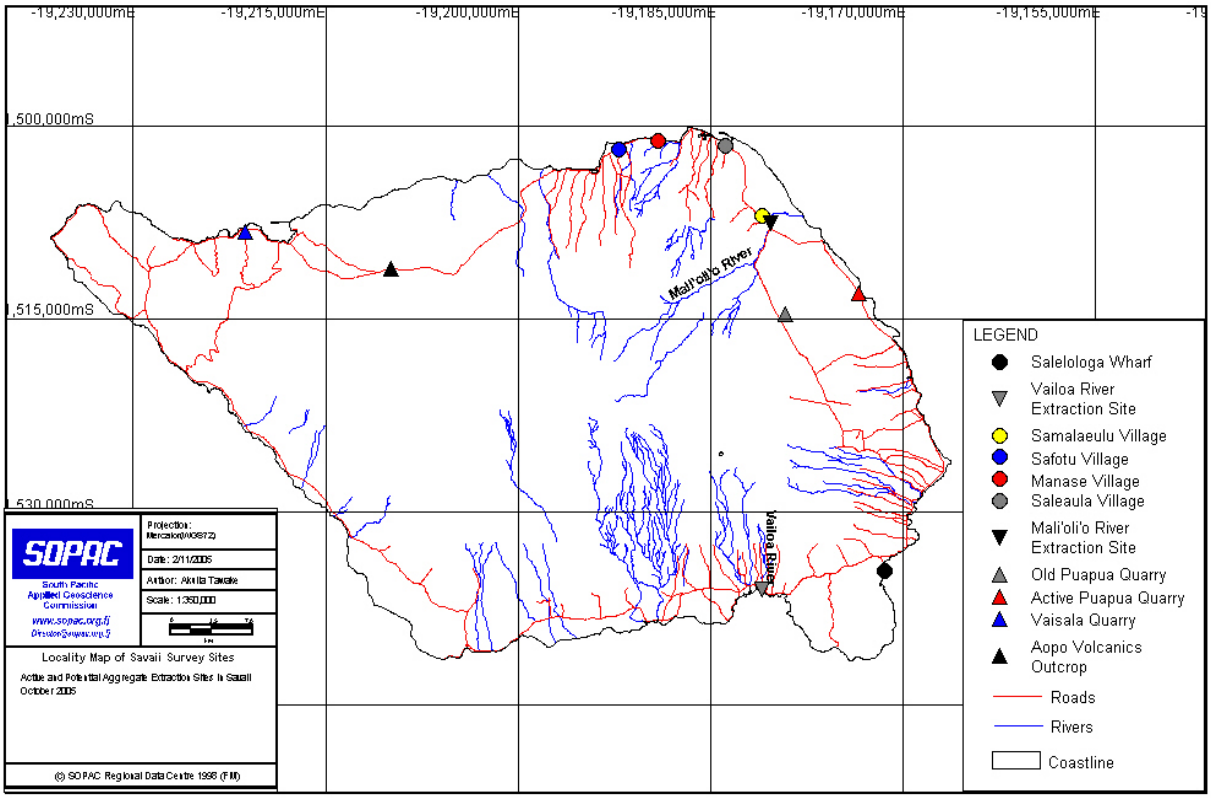

Figure 2. *Map of aggregate survey sites on Savai'i Island.*

SALELOLOGA HARBOUR

The Salelologa Harbour is located on the southeastern coast of Savai'i Island (Figure 2). It is surrounded by fringing reefs with a deeper channel linking the open ocean and the wharf and is used daily by the two passenger / cargo boats that operate between Upolu and Savai'i. The harbour is too small and shallow for bigger cargo / container ships to use.

Sand samples were collected from the offshore areas around the wharf, mainly on the edge of the reef flats. Sand sampling was hampered by the absence of a grabber, which could have made collecting samples in relatively deeper areas much more efficient. Seabed sand samples were obtained by hand digging and the samples collected at each location were subsequently stored in a plastic sample bags.

The proposed dredging operation in Salelologa Harbour is part of the SPA plan for improving operational efficiency and service to Savai'i. However, there is a need for someone to assess the economic, social and environmental impacts of such an operation. The primary purpose of the dredging operation being carried out in Mulifanua, is to deepen the boat channel in order to enable bigger ships to berth at the wharf. The proposed dredge site is relatively deep and is bound by coral reefs to the north, east and south of the wharf. Due to this restriction, there are only limited sand resources within the harbour. There are vast sand deposits to the north part of the lagoon, right up to Puapua Village but it is too shallow for the dredge boat to access.

After the inspection of the site during the sand sampling exercise, it was found that the lagoon environment appeared to be in a near pristine condition. Many of the coral reefs appear to be rejuvenated although parts are dead probably killed in the 2000 bleaching event (Webb and Tawake, 2004). Coral heads are in a healthy state and have been inhabited by a number of fish species. The nearshore and shallow parts of the harbour are colonised by seagrass and populated by benthic organisms. Sediments that were collected at this location are softer with slightly higher mud content.

The presence of muddy sand in the harbour indicates the potential danger of fine sediment particles in suspension in the water column that could eventually be deposited on the coral reefs. The fringing reefs and associated reef flats surrounding Salelologa Harbour are only separated by a boat channel approximately 50 by 100 m wide and relatively deep. This reef environment can be affected if significant amounts of sand are being continuously deposited on them.

To ensure minimal environmental impacts, relevant authorities should make a concerted effort at putting in place certain guidelines that will preserve the relatively pristine environment condition at Salelologa. The current prevailing conditions at the Mulifanua dredge site must be avoided at all costs. With all the environmental considerations that have been discussed above, it is proposed that dredging should await the outcome of the sand sample analysis that is to be undertaken after the survey.

ON-LAND AGGREGATE SOURCES

Selected on-land aggregate sources on Savai'i were inspected and tested using the Schmidt Hammer. This includes the following sites: Puapua Quarry, Old Puapua Quarry, Saleaula Lava Field, Manase-Safotu outcrop, Vaisala Quarry and Aopo Volcanics outcrop.

Active Puapua Quarry

The Puapua Quarry is located to the northwest of Puapua Village (Figure 2), adjacent to the main highway. The Ministry of Works in Savai'i has used the aggregate extracted from this site for road upgrading and maintenance, on a when-required basis. Due to the small scale of this operation,

the extraction process has an insignificant environmental effect. The fresh near-surface rock face at the quarry is about 10 by 2.5 m in area and is overlying a highly weathered breccia zone.

The visible fresh rock exposures around the quarry are limited and have variable degrees of weathering (Figure 3a). The exposed material consists of about 40 % fresh rocks and 60 % moderately to highly weathered materials. Reconnaissance survey of the surrounding areas confirmed that there is no indication of massive rock outcrops that can support a larger-scale quarry operation.

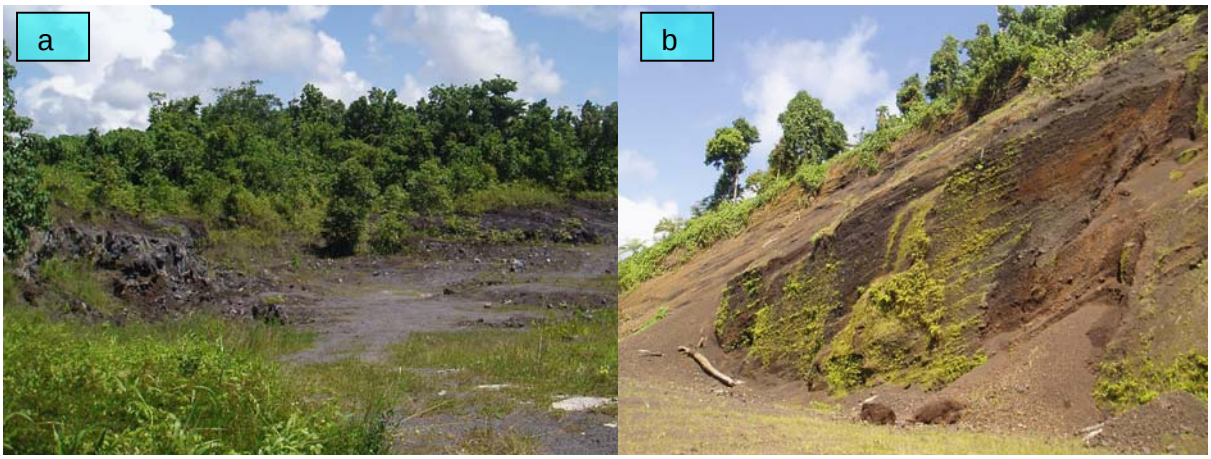

Figure 3. Puapua Quarries, Eastern Savai'i. a) The Active Puapua Quarry revealing the limited existing resource; b) the Old Puapua Quarry exhibiting bedded unconsolidated volcanic material.

Old Puapua Quarry

The old Puapua Quarry was also inspected during this trip. It is located further inland to the west of the active Puapua Quarry (Figure 2) and can only be accessed from an inland gravel road that runs along the Mali'oli'o River. The quarry site is essentially a hill of poorly consolidated scoriaceous volcanic rock fragments. This loose material is bedded and shallowly dipping to the north (Figure 3b). The hand specimen can be generally described as slightly to moderately weathered, highly porous and light in weight.

Saleaula Lava Field

The 1905 – 1911 effusive volcanic eruption that occurred to the north of Savai'i had generated enormous pahoehoe lava flows that were deposited along a portion of the northeastern coast of the island. Massive lava flows, locally referred to as the Saleaula Lava Field, can be seen between the coastal villages of Samalaeulu and Saleaula (Figure 2).

This younger rock unit is part of the Aopo Volcanics, the most recent volcanic formation in the Samoa Group. The lava flow is generally fresh to moderately weathered, highly vesicular (Figure 4a) and comparably light in weight. Weathering seems to be relatively strong at the surface of the lava flow, due to prolonged exposure to wind and rain in the last century. The ropey surface lavas (Figure 4a) that occur in some places within the Lava Field tend to exhibit a less brittle behaviour that could be attributed to high percentage of porosity and a moderate weathering pattern.

The Lava Field was assessed as a potential source of sand and gravel. One whole day was spent on inspecting and assessing the different lava forms that occur between Samalaeulu and Saleaula villages. Piles of lava boulders and gravel were seen near Mauga and Saleaula villages

that indicates the local people are extracting lava material from areas closer to the main highway for domestic use.

Figure 4. The Saleaula Lava Field. a) A closer look at the ropey, highly-vesicular pahoehoe lava. b) Rock strength test using the Schmidt Hammer. c) Remnant outcrop of the older Mulifanua Volcanics in the lava field. d) Better quality lava flows that occur between Samalaeulu and Mauga villages.

The Schmidt Hammer (Figure 4b) was again used to test different areas within the Lava Field. The locations of the area tested had been carefully chosen to ensure that they are spread out and representative of the different lava types (columnar, glassy, degrees of porosity and weathering). Three readings were taken at any test site by applying the Hammer, held in a vertical position, on to the horizontal rock face (Figure 4b).

Remnant outcrops of an older rock formation can also be found within the lava field (Figure 4c). These older rocks occur as poorly-developed columnar joints that have disintegrated over time. The in-situ lava and the loose rock fragments on the side of the outcrop are still fresh and stronger than the surrounding younger Saleaula lava flows.

Generally, the Saleaula lava flow strength test results indicate low to medium rock strength. This is largely due to the weathered and vesicular nature of the material. Therefore, the surface materials are not suitable for high-stress applications such as the construction of high-rise buildings, and sealing of roads and runways. However, huge and fresh lava flow blocks with lower pore density (Figure 4d) could be found on the seaward side of the main road between Samalaeulu and Mauga villages. This could potentially be a better source of sand and gravel for the surrounding villages and bigger infrastructure developments on Savai'i.

The test results, discussions and recommendations will be included in the technical report.

Fagaloa Volcanics

The Fagaloa Volcanics represents the oldest volcanic rocks in the Samoa Group. The geology map of Savai'i (Kear and Wood, 1959) indicates that there are only patches of this formation in Savai'i and the only accessible portion occurs to the north of the island between the coastal villages of Manase and Safotu (Figure 2).

This Fagaloa Formation outcrop that occurs between Manase and Safotu villages was also assessed during this survey. This massive outcrop is about 110 m long with an average height of about 20 m (Figure 5a). It occurs along the main highway and adjacent to the coast. Coastal defences around this area must have been constructed during the 2001 road-upgrading project where the rock boulders from this site were used. Smaller outcrops of the same rock appear on the landward side of the road, towards Safotu Village.

Due to the proximity of this rock to the main highway, it may be a futile exercise to try to develop this resource. It may be equally difficult and expensive to re-align the road in order to set up a quarry operation at the site. The small demand for aggregate in this part of the island, coupled with its long distance from the sub-urban Salelologa Township, supports the notion that it may not be feasible to develop this site.

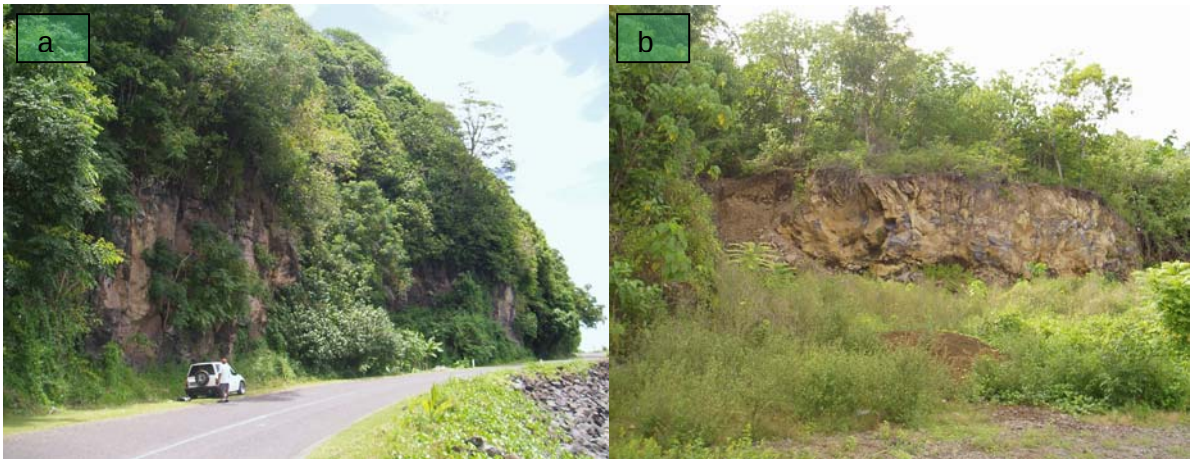

Figure 5. Potential aggregate sources in northwestern Savai'i. a) Massive outcrop of the Fagaloa Volcanics between Manase and Safotu villages. b) Vaisala Quarry, where rock boulders are extracted to construct coastal defences.

Vaisala Quarry

The Vaisala Quarry is located near the village of Vaisala in northwestern Savai'i (Figure 2). The quarried outcrop is part of the Mulifanua Volcanics that occurs extensively on the western part of the island. Fresh hand specimen at this site resembles the appearance of source rocks at Saleimoa Quarry on Upolu Island.

The rock face, as it appears at the quarry, is a slightly- to highly-weathered layer of lava flow (Figure 5b). However, the inner, fresh lava flow is porphyritic and compact with relatively low vesicle density. As frequently witnessed in other parts of Samoa (e.g. the Fagaloa Formation in eastern Upolu), the lava is overlying a layer of highly weathered volcanic breccia. This could potentially reaffirm the scenario that the breccia unit had been incorporated in between layers of lava flow.

Rock boulders from this site have been used for coastal defences along Vaisala and Sataua villages. This rock can be an excellent source of sand and gravel provided the appropriate crushing facility is in place. Further aggregate source investigations should be focused on

identifying similar size or bigger outcrops of the Mulifanua Volcanics in the surrounding areas that can further support a quarry operation in this part of Savai'i.

If a rock crushing facility will be required in the future to develop this resource, a mobile crusher will be the best, as it is relatively easy to operate and to shift from place to place. This can further boost the supply of sand and gravel in this part of Savai'i in order to meet local demand. The mobile crusher can be used anywhere in Savai'i and can possibly solve the problems of sand and gravel supply on the island.

River Aggregate Extraction

River sand and gravel extractions, as witnessed during the trip, are active at two localities in Savai'I: at (1) Mali'oli'o; and (2) Vailoa rivers.

Mali'oli'o River

The Mali'oli'o River runs on the eastern side of Samalaeulu Village (Figure 2). The rock boulders, cobbles and pebbles that occur in the river are predominantly volcanic in origin. The river catchment geology is dominated by the Salani Vocanics, where the rock fragments that occur in the lower part of the river derive from. During the inspection of the river catchment, boulders dominate the upper part, while sand and gravel tend to occur closer to the coast on either side of the Mali'oli'o River Bridge. The sand and gravel extraction operation was conducted in the river channel, on the landward side of the bridge (Figure 2).

A closer look at the black sand in the river revealed that it is largely made up of volcanic rock fragments with minor components of volcanic glass, and felsic and mafic minerals. The sand and gravel at this site is generally used for domestic construction in Samalaeulu and neighbouring villages. While the sand and gravel at this site can be used for construction, the limited resource volume is the major constraint to a larger extraction operation.

Vailoa River

The Vailoa River is situated to the west of Salelologa, and just to the west of Vailoa Village (Figure 2). The geology of the river catchment is predominantly made up of the Salani and Mulifanua Volcanic formations. Therefore, it is presumed that the composition of sand and gravel in the river channel and in the immediate vicinity of the river mouth is dominated by volcanic rock fragments.

Sand stockpiles were seen at the junction of the river and the main highway. It was reported that Vailoa villagers have been extracting sand on the eastern side of the Vailoa River mouth (Figure 2) and transporting material by truck to the current stockpile site and point of sale. Another landowner is also proposing to carry out a small-scale sand extraction on the western side of the river mouth for the purpose of making concrete blocks to sell to the local people.

APPENDIX 3

Upolu Aggregate Assessment

INTRODUCTION

The demand for aggregate in Upolu is higher and more constant compared with that in Savai'i. Apart from the Ministry of Works (MOW), there are a number of private companies that engage in sand and gravel extraction and processing. The high demand for sand in Apia and in hotel development sites has resulted in increasing beach sand mining in the recent past that has consequently placed the coastal zone under a lot of stress.

Aggregate extraction operations in Upolu are quite intensive compared to Savai'i. During the recent assessment, it was found that there are abundant on-land aggregate sources available, particularly on the eastern half of the island. The inability of quarry operators to meet the demand for sand in Upolu has resulted in the sourcing of sand from the coastal and lagoonal areas.

During the time of the visit, four offshore dredging operations were active in northern and northwestern Upolu (Figure 6). As noted in the site visit and observation, there are operational issues pertaining to the development and management of offshore aggregate that need immediate action and improvement. Most of these extraction problems are associated with the lack of scientific assessment of the site prior to the extraction of the resource. In order to address these problems, there is an urgent need to establish and institutionalise a framework for sustainable aggregate resource development in Samoa.

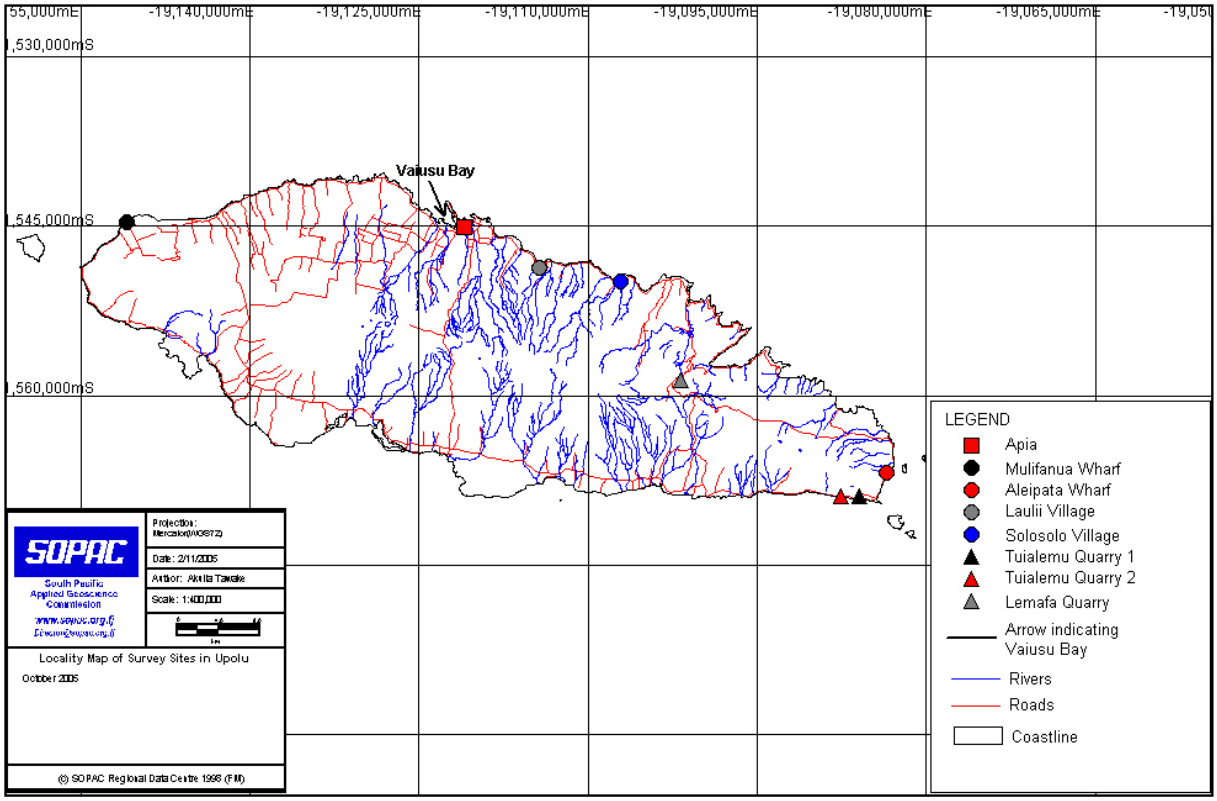

Figure 6. Map of aggregate survey sites on Upolu Island.

Mulifanua Dredge Site

The Mulifanua dredge site is a natural lagoon environment bounded by fringing reefs and shorelines. A wharf has been built at this site to facilitate boat services between Upolu and Savai'i and is used as a landing point for people travelling between these two islands. There are no naturally deeper boat channels or harbours in this part of Upolu. The lagoon at Mulifanua is relatively shallow and it is therefore necessary to keep the boat channel deeper and accessible by bigger boats. There are abundant sand resources in the lagoon, which is also host to coral and living marine organisms such as seagrass, foraminifera, halimeda, benthos and fish.

Lagoon sediment dredging started in Mulifanua in early 2004 (Tawake, 2004) primarily for the deepening of both the boat channel and the immediate vicinity of the wharf in order to allow passenger/cargo boats to berth at the wharf (Figure 7). The dredge operation, as witnessed in February 2004, was initially carried out around the wharf (Figure 8a) and the sediment was subsequently pumped directly to a settling pond onshore (Figure 7). The sediment was allowed to settle in the pond and the clear water was drained back into the sea. This earlier stage set up was efficient and environmentally friendly, although, the water around the wharf was slightly turbid.

However, it was seen during this recent visit that the whole set up had been changed. The dredge system was dredging in the boat channel further towards the reefs (Figure 7) and the sediment-seawater mixture was pumped into a barge instead of directly to shore. Due to the regular boat service that uses the wharf, dredging has recently been carried out at night, when there were no boats coming in and out of the channel. A lot of wastewater has been generated and spilled overboard during dredging.

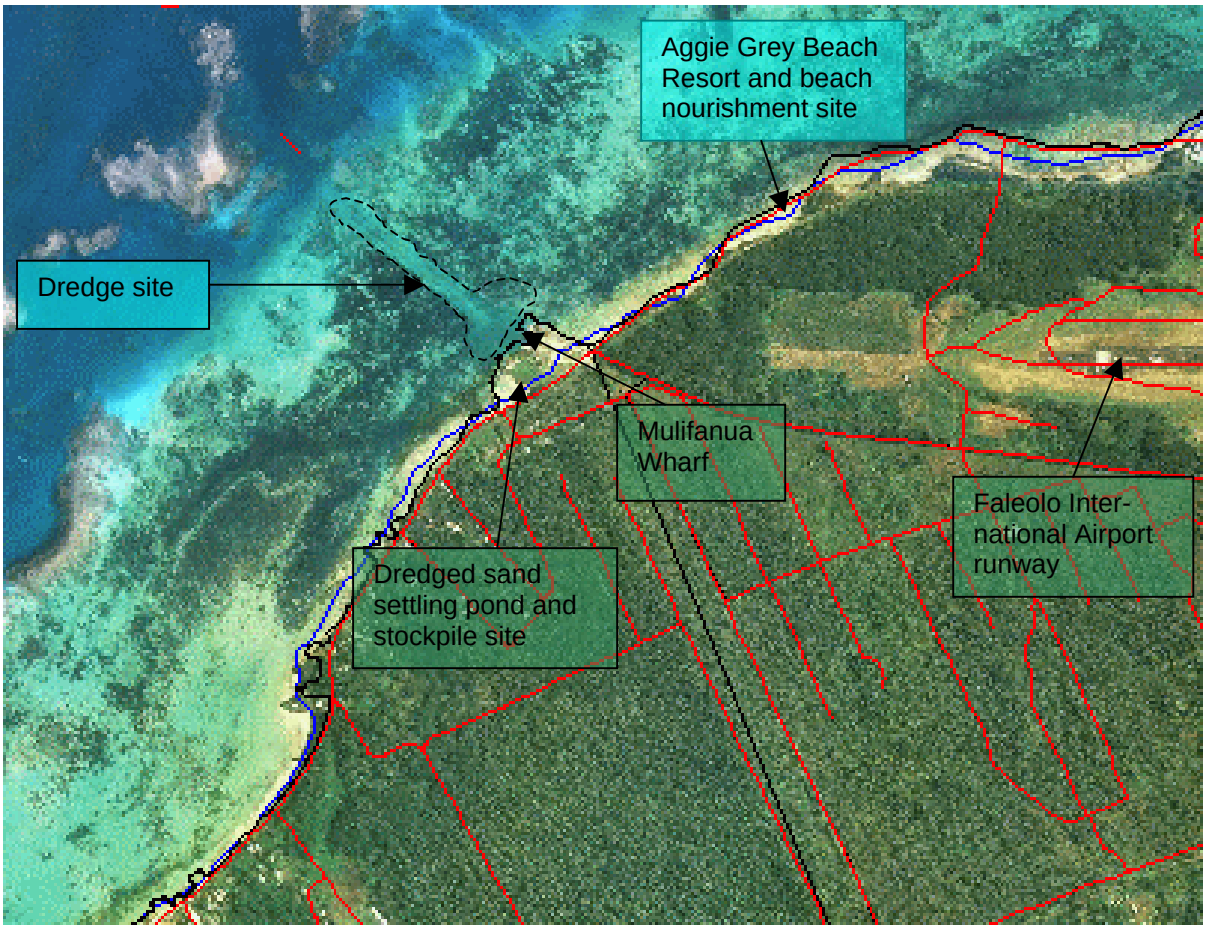

Figure 7. A satellite image of the Mulifanua dredge site and surrounding areas.

Siltation

In comparison to the water clarity level during the first site visit in February 2004, there is a marked increase in intensity and aerial coverage of the turbid water around the wharf in October 2005. This can be attributed to the ongoing dredging activity. In a number of visits to the wharf in October 2005, it was observed that the water remained turbid even during the daytime when dredging ceases. In the sand sampling process in the lagoon, it was found that very fine sediment particles are in suspension in the water column, causing the turbid appearance of the water.

The analysis results of sand samples collected in 2004 revealed the significant presence of halimeda and forams in the Mulifanua sand. They make up an average of about 40 % of the total sample. It is most likely that these friable materials could easily disintegrate into finer sediment during pumping, stockpiling and transportation. This has been supported by the fact that the dredged sand stockpile at the wharf contains a large amount of muddy sand (Figure 8b). This material is unsuitable for making concrete but can be used for landfill and reclamation.

Potential Impact

The impact of ongoing sand dredging in Mulifanua (Figure 8a) should be thoroughly investigated at the earliest opportunity. Definite and potential effects of dredging on marine life should be assessed and mitigating measures applied. Responsible authorities (Samoa Port Authority and the Ministry of Natural Resource, Environment and Meteorology) should make an effort to initiate a monitoring programme that would minimise or avoid severe environmental repercussions.

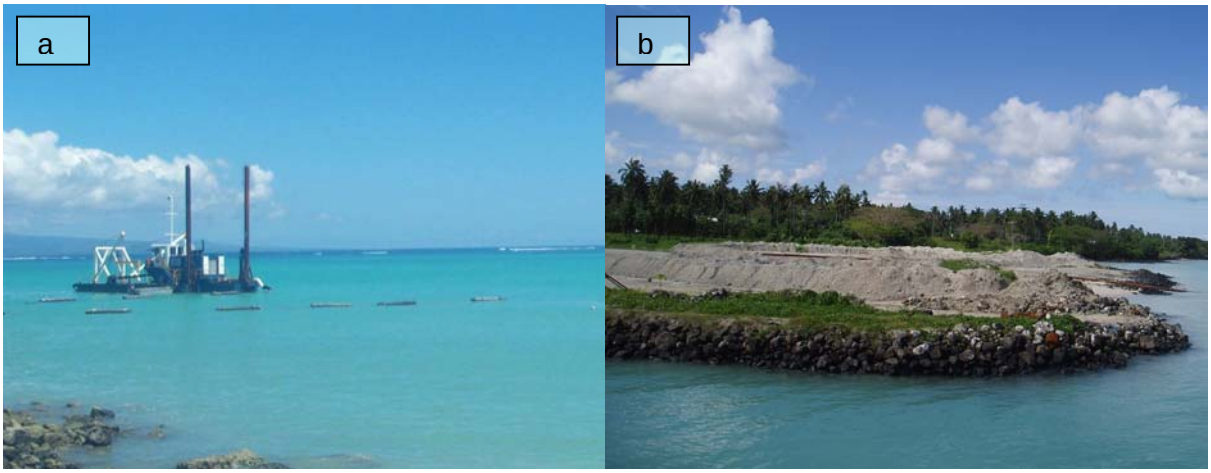

Figure 8. The Mulifanua dredge site. a) Dredge operation in progress off Mulifanua Wharf. b) Dredged sand stockpile at Mulifanua Wharf.

Sand particles were observed on seagrass and coral reefs during the surface sediment sampling exercise. Attempts to collect sand on the eastern side of the channel proved almost impossible due to the fact that very little sand occurs around that area. This notable absence of sand may be attributed to the dredging of the channel. Strong east-to-west current coupled with the draw-down effect of dredging could have altered the natural sediment transport process. This resulted in the rapid filling of the channel, as opposed to the slow natural rate of sand replenishment from the surrounding sources.

This chain of events, if continued for a little while longer, could possibly result in the erosion of the coast, especially the eastern shoreline between the wharf and the new Aggie Grey Beach Resort (Figure 7)

Aleipata Wharf

The Aleipata Wharf and the surrounding lagoon areas were also surveyed by NZOI in 1988. The survey included bathymetry, sediment sampling by jet probing, and recording of tidal variation. According to the report (Lewis et al, 1989), offshore aggregate dredging was also carried out at the wharf to deepen the boat channel that links the reef opening and the wharf.

As witnessed during this recent survey, the shallow lagoon areas to the north and south of the wharf have vast sand deposits with occurrence of coral heads in places. This has confirmed what was highlighted in the Lewis et al. (1989) study.

The Aleipata site has been identified as a potential, alternative dredge site that can supply the demand of sand in Apia and nearby areas. In addition, due to the location of this site, it has been earmarked as a potential source of extracting and exporting sand to American Samoa.

The aggregate assessment that was recently carried out around the Aleipata Wharf was intended to supplement the 1989 survey data and to further ascertain the characteristics of the sediment that occurs in the immediate vicinity of the wharf. Eight hand-dug samples were collected on the south, east and north of the wharf. A GPS was used to locate each sampling position.

Any future dredging operation at Aleipata should be carefully planned with wider consultations and advanced scientific studies. While this survey will assist stakeholders to realise both the quality and quantity of sand and gravel that occurs in the lagoon; and highlight both the potential adverse impacts and benefits of such an operation in terms of environmental, economical and social issues – it should not be considered as a substitute for appropriate additional surveys, such as an Environmental Impact Assessment (EIA), which would also need to be undertaken.

ON-LAND AGGREGATE SOURCES

As in the case of Savai'i, selected on-land aggregate sources on Upolu Island were inspected and tested using the Schmidt Hammer.

Fagaloa Volcanics

The older Fagaloa Volcanics is one of the major volcanic formations that occur in Upolu and it crops out extensively on the northeastern part of the island. This part of Upolu was the area studied by Fepuleai (1997) in partial fulfilment of his Master of Science (M.Sc.). As reported, olivine-rich basaltic lava flows are the predominant rocks of this part of Upolu, and are often associated with marine tuffs, volcanic breccia and alluvial deposits.

The on-land aggregate source investigation was concentrated on potential, accessible areas on the eastern half of Upolu. This exercise was able to identify three areas that have the potential to support large-scale quarry operations. These three sites are:

1) Outcrops between Laulii and Solosolo villages;
2) Inland outcrops at the location of the Lemafa Quarry; and
3) Tuialemu Quarries and Outcrops.

Except for the rocks that occur at Tuialemu, the other two sites are host to massive basalt lava flows of the Fagaloa Volcanics Formation.

Laulii-Solosolo Outcrops

Along the northeastern coast of Upolu, rock outcrops are common, especially between the villages of Laulii and Solosolo (Figure 6). These basaltic exposures are all part of the Fagaloa Volcanics. The best two outcrops are found between Namo Village and Cape Utumau'u (Figure 9a). These two massive outcrops exhibit a 40:60 % breccia-to-lava ratio with an average 120 m of horizontal distance and a 30 m height.

This volcanic formation generally occurs in different strata of homogeneous lava flows that are often separated by tuff and volcanic breccias. This breccia unit is moderately to highly weathered and relatively porous. On the other hand, the lava flow is more resistant to weathering, compact and fresh. The basal breccia layer that occurs at the foot of the rock cliff is highly to intensely weathered and is a common feature of similar types of outcrops in both Savai'i and Upolu. This could be attributed to the constant outflow of water at the near-ground level of the cliff, which signifies the approximate position of the water table.

The strength of the rock was tested using the Schmidt Hammer.

The site assessment of the coastal areas between Laulii and Solosolo revealed the following:

Rock Strength: Lava Flow (Very good)
Breccia (Poor)

Aggregate Resource: Approximately 60 % aggregate and 40 % waste.

Locality: Close to Apia and surrounding areas. However, too close to the main highway.

Rating: Good.

Due to the proximity of the site to the main highway, these coastal outcrops will be difficult and expensive to develop. In that regard, in-land aggregate sources of the same material should be investigated. A quarry should be set up at an isolated location that is some distance from the main road and nearby villages.

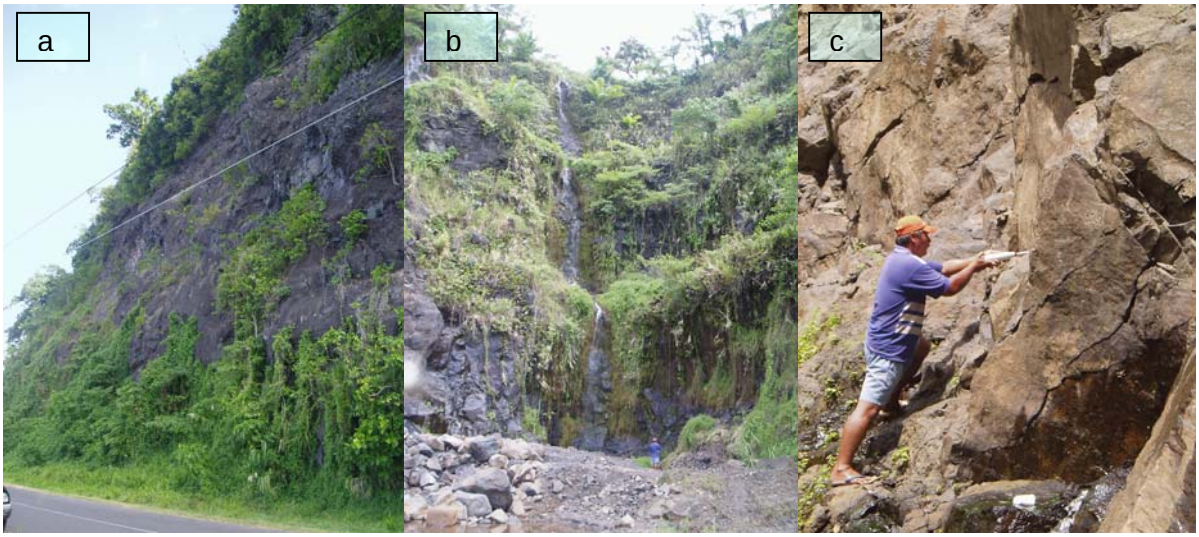

Figure 9. The Fagaloa Volcanics Outcrops. a) A massive basaltic outcrop west of Namo Village. b) The quarried lava flow at Lemafa Quarry. c) Rock strength test using the Schmidt Hammer at Lemafa Quarry.

Lemafa Rocks

The so-called Lemafa Rocks are found inland in the Lemafa area closer to the contact between the Fagaloa Volcanics and the Salani Volcanics (Figure 6). This series of outcrops that occurs along the eastern-most inland road is part of the Fagaloa Volcanics. The composition of the outcrops is slightly different from the ones that are found along the coast between Laulii and Solosolo Villages. They are predominantly composed of lava flows with much less volcanic breccia component.

The best outcrops at Lemafa are found at the Lemafa Quarry (Figure 9b), due to overburden clearance and rock extraction at the site. The quarry is located on the eastern side of the road and the rock face is about 50 m by 40 m in dimension. Upon inspection, the rock face consists mainly of massive, but moderately fractured lava flows. The breccia unit is only about 5-10 % of the total rock mass. Hand specimen of the lava indicates that it is fresh, compact with visible grains of olivine in the groundmass.

The strength test of in-situ lava flows at the quarry was carried out with the aid of the Schmidt Hammer.

The site assessment of the Lemafa rocks revealed the following:

Rock Strength: Lava Flow (Excellent)

Aggregate Resource: Approximately 95 % aggregate and 5 % waste.

Locality: Close to the inland road but relatively at a distance from Apia.

Rating: Very Good.

Due to the excellent strength exhibited by the rocks at the quarry and the isolation of the quarry site, it is suggested that further geo-technical tests have to be carried out on rock samples from this site to fully ascertain their engineering behaviour. This massive lava flow can support a larger-scale quarry operation to supplement sand and gravel production in Upolu, particularly to meet the constant demand from the Apia area.

Petrographic Analysis

Fepuleai (1997) did some mineralogical studies of the Fagaloa Volcanics Formation by conducting petrographic analysis of the samples collected. The lavas of the Fagaloa rocks are described as holocrystalline and fine-grained to porphyritic. Phenocryst phases are commonly pyroxene, plagioclase and olivine, and the size of crystals generally ranges between 0.5 to 20 mm in diameter.

Olivine is abundant in rocks of the lower part of the Fagaloa Volcanics Formation, which is also dominated by pyroxene. The pyroxene proportion in the upper part of the Fagaloa Volcanics Formation is lower than in the lower part but plagioclase is abundant with almost equal proportion in both the upper and lower parts of the Formation (Fepuleai, 1997).

The significant presence of silica-bearing minerals in the Fagaloa Volcanics should be further investigated since there is potential for the presence of reactive silica in the groundmass (e.g. strained quartz) and in minor structures such as shears and fractures (e.g. opal).

Tuialemu Quarries

The Tuialemu Quarries 1 and 2 are located to the southeast of Upolu (Figure 6). Most of the rocks that occur on this part of the island belong to the Salani Volcanics and some of these aggregate sources were used during the upgrading/sealing of the main road. Massive rock cliff exposures along the southeastern coast are composed of lava flows and volcanic breccias. The breccia unit forms the major part of this volcanic rock formation.

Quarry 1 is an old quarry that has been inactive since the completion of the road-sealing project in southeastern Upolu. Fresh lava flows and rock clasts in the breccia exhibit relatively good strength when tested with the Schmidt Hammer. On the other hand, Quarry 2 is still active but on a small scale of operation. Extraction at this site is on a when-required basis, mainly for domestic use. The current rock face exhibits highly-weathered breccia where the rock matrixes are easily disintegrating. However, the clasts generally exhibit onion-skin weathering pattern but most of them are still fresh.

The site assessment revealed the following:

Rock Strength: Lava Flow (Very Good)
Breccia (Poor)

Aggregate Resource: Approximately 50 % aggregate and 50 % waste.

Locality: Close to the eastern inland road but far from Apia.

Rating: Good.

These massive outcrops of the Salani Volcanics can be further investigated as a permanent source of sand and gravel in this part of Upolu. This could potentially be an alternative source of aggregate if major infrastructure developments are planned for this part of the island. In order to obtain relatively good quality sand and gravel, screening has to be done to get rid of the weaker and finer grained components.

Coastal Development

The construction of coastal defences is one of the major uses of volcanic rock boulders in Samoa (Figure 10a). Generally, the size of a boulder that is used for this purpose is no less than 20 cm in diameter. This is a familiar sight around the coastline in Upolu and to a lesser extent in Savai'i. Rocks are arranged in such a way that the structure is in a landward slanting position (Figure 10a).

The construction of these structures is part of community preparedness towards the storm surge and gigantic waves that are associated with cyclones. According to the local people, the most common natural disaster that they are familiar with is a cyclone, which comes with destructive strong winds, heavy rain and huge ocean waves. In the recent past, gigantic waves that accompanied cyclones have had devastating effect on coastal zones in Samoa, which include the lagoon, soft coasts, coastal infrastructure, and houses that are built close to the shoreline.

A classic example was the destruction of Falealupo Village, a coastal village in eastern Savai'i during Cyclone Ofa in February 1990. Gigantic waves totally decimated the whole village including their cemetery. After the cyclone, the local people gathered the remains of their properties and moved to another site where they still live today.

Figure 10. Coastal development in Samoa. a) The use of volcanic rock boulders for coastal defences is common in Samoa. b) Reclaimed coast along Aggie Grey Beach Resort that has been nourished with dredged sand from Mulifanua.

While the construction of artificial coastal defence is welcomed as a second line of defence (apart from fringing reefs) from tidal waves, it is sad to lose some of Samoa's beautiful white, sandy coastlines. Due to past bad experiences with cyclones, community initiatives on building seawalls must be commended. However, the effectiveness of these coastal defences in decreasing the destructive force of gigantic waves and saving lives and properties remains to be seen. Should these structures be effective in at least partially neutralising the waves, then there is no doubt that the cost of lives and properties saved from the destructive gigantic waves will far outweigh the cost of building those structures and the benefits of having white sandy beaches.

In another development, reclamation of the coast is becoming increasingly prevalent in some parts of Upolu. The majority of this type of development is in the form of hotel constructions to meet the increasing number of tourists visiting Samoa. Material normally used for the reclamation /landscaping work are boulders, gravel, sand and soil. Beach and dredged sands have been used for beach nourishment along the shorefront in hotel developments, as observed at the newly-built Aggie Grey Beach Resort and at Laulii.

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