DETECTING MICROSEISMIC ACTIVITY IN AMERICAN SAMOA WITH SURFACE AND DEEP BOREHOLE STATIONS

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Keywords: *Seismic monitoring, geothermal exploration, borehole seismometers, volcano-tectonic earthquakes, American Samoa.*

ABSTRACT

American Samoa is located at the eastern end of a ~500 km-long chain of islands formed by hotspot volcanism. The original shield volcano edifices of the islands are recent structures that formed from submarine volcanoes <5 Ma. Various theories explaining the origin of widespread recent and historic rejuvenated volcanism throughout the Samoa chain are based on limited seismic and geochemical data. This paper presents the deployment status and preliminary results obtained from a new network of borehole and surface seismometers.

American Samoa's remote location adjacent to the Pacific and Australian Plate Boundary place it at risk of intensely active tectonic processes. To supplement the only existing broadband recording station in Apia, Upolu (120 km northwest of American Samoa) an unprecedented seismic monitoring network has been installed on Tutuila and Ta'u islands: 6 highly-sensitive monitoring stations have been set up with 3 borehole sensors placed at 60-670 m (205-2,020 feet) depth and 3 movable surface seismometers placed at strategically important locations. The network is designed to detect local seismicity associated with volcanic activity, to help reassess the island's geothermal potential, provide structural and stratigraphic information and to mitigate geologic hazards.

To accurately constrain earthquake locations throughout the islands a 1-D velocity model is needed. A new technique that utilizes the ever-present, high natural background noise created by the Pacific Ocean to extract information about the subsurface velocity has been tried. However, this ambient seismic noise technique has not produced the required results to constrain the velocity structure. Therefore, earthquake data from the existing 6-station SLISE network between 2005 and 2009 and the new stations is being processed to derive an initial 1-D velocity model.

1. INTRODUCTION

1.1 Geological Setting

The Samoan and American Samoan islands are located 200-400 km northeast of the Tonga-Kermadec trench, where active plate subduction has produced many large earthquakes (Needham et al., 1982; Lay et al., 2010; Beavan et al., 2010). The Tonga-Kermadec trench is part of the Pacific Ring of Fire – a plate boundary zone, where the Pacific Plate subducts westward beneath the Australian Plate. The average plate velocity of the Pacific plate is 71.3 mm/yr (Beavan et al., 2002). At the northern end of the trench, the Pacific plate is tearing laterally and the trench itself becomes a transform boundary (Natland, 2003). This crustal tearing may facilitate volcanic rejuvenation extraneous to the Samoan hotspot (Thornberry-Ehrlich, 2008). American Samoa is located at the eastern end of a ~500 km-long chain of islands formed by hotspot volcanism (Thornberry-Ehrlich, 2008; Hart et al., 2004). It is composed of volcanic centers, islands, atolls and sea mounts that are 10-50 km apart (Natland, 2003). The age of the original shield volcano edifices forming the Samoan and American Samoan islands increases from east to west in accordance with movement of the crust across the current hotspot (Keating, 1992; Nemeth and Cronin, 2009). However, rejuvenated volcanism is present on all major islands (Hart and Jackson, 2014). Subaerial deposits on the Samoan and American Samoan islands range from Pleistocene (5 Ma) to Historic at Savai'i (~100 yrs). The easternmost subaerial volcano Ta'u has been active for the past 70 kyr including the post glacial maximum (less than 20 kyr; Hart and Jackson, 2014) and a historic 1865 submarine eruption occurred between the islands of Ta'u and Olosega. The youngest active structure is the Vailulu'u submarine volcano ~50 km further east of Ta'u. Submarine eruptions have been documented and the seamount grew ~100 m in height during the last decade. It is expected to show explosive volcanic activity as it approaches the water surface (Konter et al., 2004).

The composition of the islands is mostly alkalic olivine basalt (Keating, 1992). Ta'u and Ofu/Olosega have ≤49% silica content, and the highest documented He^3/He^4 ratio of any of the Pacific islands (Hart and Jackson, 2014).

1.2 Previous Seismic Monitoring

American Samoa's remote location adjacent to the Pacific and Australian Plate Boundary place it at risk of intensely active tectonic processes (Thornberry-Ehrlich, 2008). The only existing seismic monitoring station is located in Apia, Upolu, approximately 120 km northwest of American Samoa. It is a broadband station that was established in 1902 and important earthquake recordings go back to the year 1917. Additional temporary monitoring stations were installed on the submarine volcano Vailulu'u in 2000/2001 (Konter et al., 2004) and throughout the island chain during the research experiment SLISE from 2005 to 2009 (Browning et al., 2013). The station spacing at Vailulu'u was ~0.5 km and 50–120 km for SLISE. Both networks recorded local seismicity (about four earthquakes per day at Vailulu'u) but their station spacing was insufficient to assess and monitor the micro-seismicity throughout American Samoa. Global earthquake catalogues show a cluster of M 4.2–4.9 normal-faulting earthquakes in 1995 (Konter et al., 2004) and some M>3.4 activity in the area of interest during the deployment period of the SLISE stations (Figure 1).

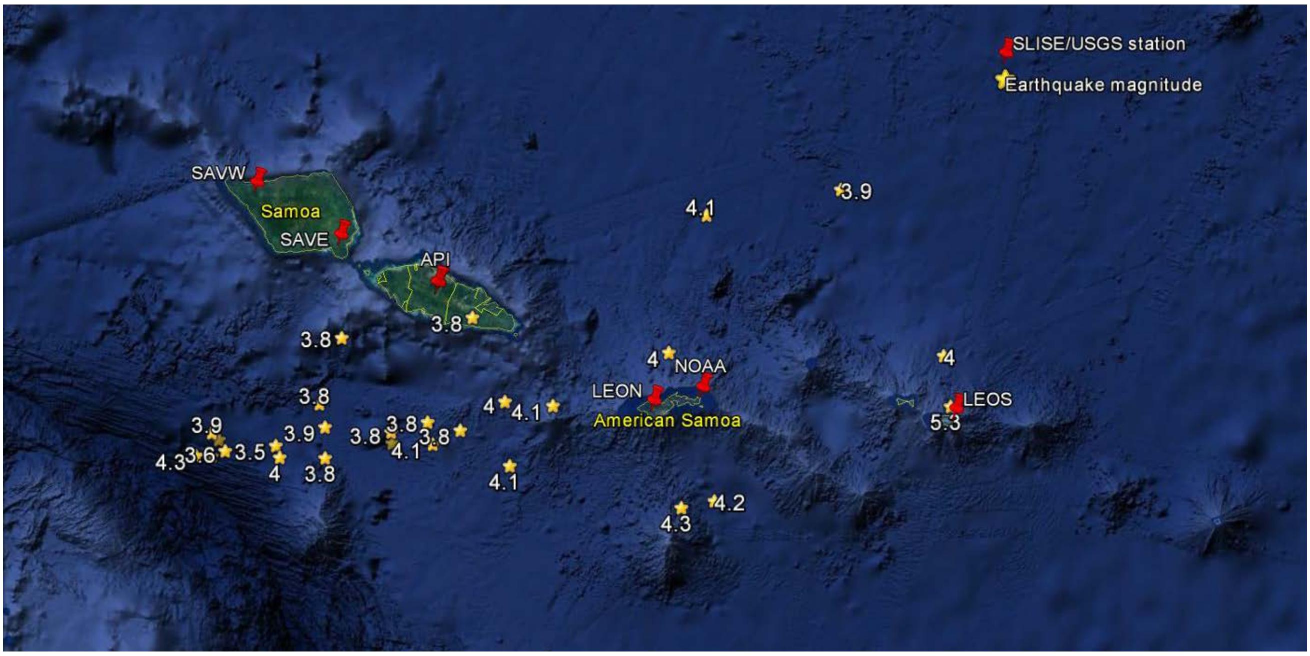

Figure 1: The islands of Samoa and American Samoa with SLISE station locations marked by red symbols and earthquakes recorded during 2005 to 2009 shown by yellow stars. Station name and earthquake magnitude are annotated to the symbols.

2. AMERICAN SAMOAN SEISMIC MONITORING NETWORK

During the time period 28 June to 10 July 2016, six seismic monitoring stations were installed on the American Samoan islands Tutuila and Ta'u (Figure 2 and 3). Three of the sensors were placed between 60 and 670 m deep in existing boreholes to form permanent, long-term monitoring stations. The other three sensors were installed at strategically important locations at the surface and were designed to be highly portable. Two borehole and three surface stations were installed to span the length of Tutuila to monitor microearthquakes associated with geothermal and volcanic processes. The three portable stations are currently being moved to suitable locations identified on the Manu'a Islands Ta'u and Ofu/Olosega to supplement the permanent borehole station there (Figure 3). The data from two of the permanent stations is transferred in real-time to a secure IESE cloud server in New Zealand.

Training was provided by IESE to two ASPA staff in Pago Pago and one Environmental Protection Agency (EPA) staff in Ta'u village. Therefore, the stations can be serviced and maintained locally when needed.

The equipment used at the stations are 2 Hz, 4.5 Hz and 15 Hz borehole and surface seismometers manufactured by International Earth Sciences (IESE) Ltd., combined with low-noise Reftek 130/130S data loggers, GPS and power supply. Station location details are listed in Table 1 and station setup is shown in Figures 2 and 3. All stations record with sampling rates of 250 Hz using Steim2 compression. The permanent sites are also have telemetry equipment to facilitate real-time data transfer and data analysis.

Name	Description	Latitude	Longitude	Elevation
T01	Malaeloa Valley	S14:20:00.39	W170:46:08.25	59
T02	Ta'u Highscool	S14:13:38.39	W169:30:42.39	72
T03	Ili’ili	S14:20:50.28	W170:45:08.16	87
T04	Poloa Tank	S14:19:10.14	W170:49:50.56	173
T05	Fale Pule	S14:17:11.77	W170:40:41.47	88
T06	Lemafa Tank	S14:16:01.22	W170:35:03.51	157

Table 1: Station equipment installed in American Samoa at the station locations shown in Figure 1.

3. METHODS

3.2 Velocity model determination

To accurately locate earthquakes requires information on the velocity structure between the earthquakes and the stations. Ambient noise tomography can be used to generate a large-scale, low-resolution shear-wave velocity model by resolving the coherent energy in background noise generated by natural processes and recorded by regional station networks. The coherent seismic signal is found applying continuous waveform cross-correlation.

Noise cross-correlations between all pairs of stations were calculated for the SLISE data for each day and stacked for as many days of recording as available. This was done to increase the signal-to-noise ratio for a velocity move-out curve. If a move-out curve can be obtained the phase

Figure 2: Seismic monitoring station setup and locations on Tutuila.

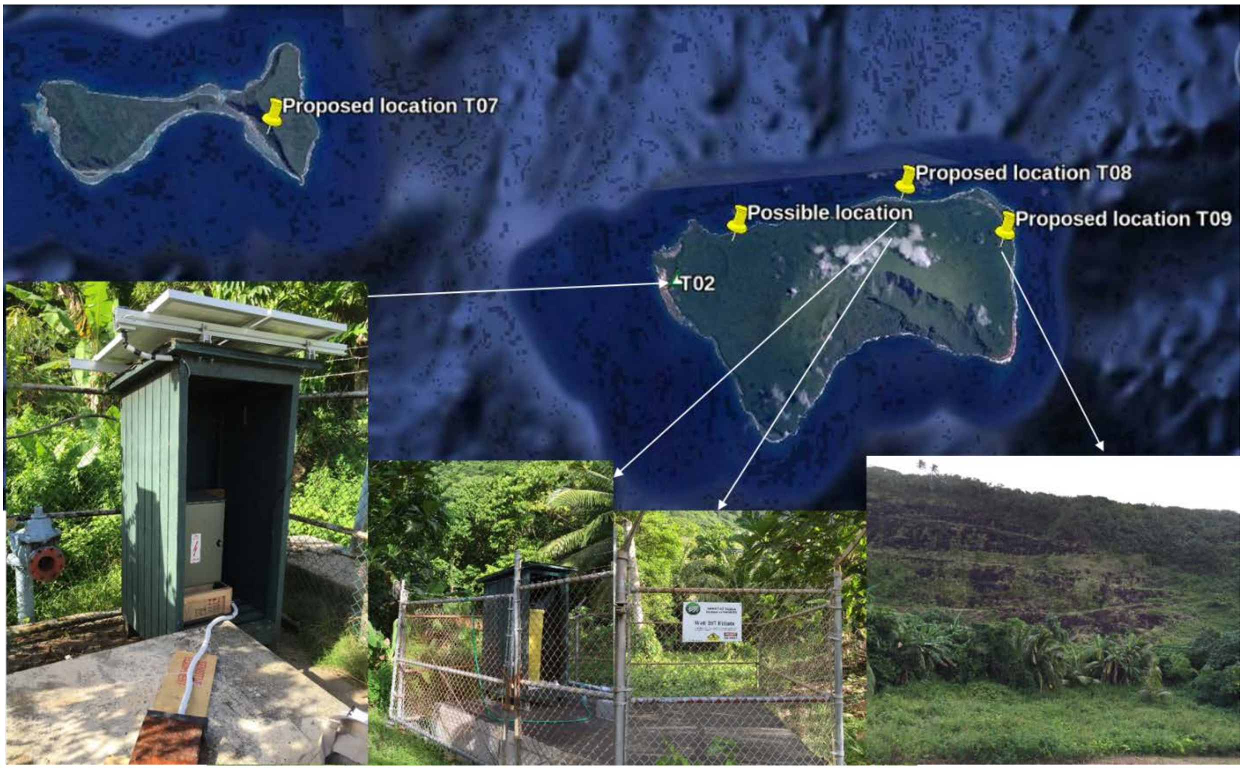

Figure 3: Seismic monitoring station setup on Ta'u. Also shown are proposed surface station locations for the next phase of monitoring.

velocities of Rayleigh waves can be measured and inverted for 1-D phase velocity maps.

Earthquake tomography resolves information on the velocity structure from the travel time of the seismic phase arrivals between the earthquake sources and the receivers. A large number of crossing ray-paths are required to resolve 3-D velocity variations.

3.3 Station orientation determination

During the installation of a borehole seismometer the sensor rotates on the cable. This results in an unknown orientation of the horizontal components of the borehole seismometer at the final installation depth. The orientation can be determined by comparing the expected orientation for recorded regional and teleseismic earthquakes with the measured orientation (from particle motion of the borehole sensors).

4. RESULTS

An initial dataset of 30 days from July/August 2016 from the surface and borehole stations on Tutuila was analysed. This showed that the surface stations and one permanent station recorded an abundance of regional earthquakes. A total of 15 impulsive regional events have been identified as suitable to determine an initial estimate of the borehole sensor orientation. Uncertainty estimates for the orientation will be derived once more data is available. Some problems at the second permanent station on Tutuila were identified that were resolved by replacing the data logger. Data from the third permanent station at Ta'u have not been obtained at this time.

Few local microseismic events were identified after basic processing. Events could be masked by pump noise recorded at some of the stations. With more data being recorded daily and more sophisticated processing being underway, we will update local seismicity maps.

Existing data from the SLISE network has been processed to identify previous local and regional earthquakes in American Samoa. The locations displayed in Figure 1 reveal some interesting activity near Tutuila and Ta'u that is the subject of further investigation.

Ambient noise tomography has not been able to resolve a coherent noise signal between the station pairs. The reason for this is currently unclear. Given the earthquake distribution recorded by SLISE as shown in Figure 1, earthquake tomography is currently applied to obtain information on the seismic velocity structure. This velocity model will be further improved once more data from the new stations is acquired.

5. DISCUSSION

The two TGH boreholes on Tutuila used for installation of seismic borehole sensors were drilled during Phase 3 of geothermal resource exploration conducted between 2013 and 2016. The locations were selected as the best locations identified from Phase 1 (geoscientific data evaluation and a surface reconnaissance in the Holocene Rift Zone), and Phase 2 (geological, geophysical and geochemical investigations, and conceptual modeling of a possible geothermal system). The results of Phase 2 indicated local conductivity anomalies as identified from magnetotelluric (MT) investigations, surface faulting identified from aerial imagery and LiDAR lineament mapping, and elevated non-biogenic carbon dioxide from soil gas surveying. The conceptual model suggested upflow zones and a possible shallow geothermal system.

Both boreholes drilled in the Holocene Rift Zone exhibited a low temperature gradient consistent with the general crustal average making them unsuitable for geothermal use. Further temperature gradient drilling was cancelled and the course of the resource investigations changed to reasses the geothermal potential elsewhere in Tutuila.

The aim of the microseismic investigations is twofold: to monitor seismic activity over a broad area to identify fracture systems and possible fluid-rock interactions associated with volcanic and geothermal activity; and to subsequently focus the monitoring on a new suitable target area.

The geothermal potential in comparable settings at Puna, Hawaii and Montserrat, West Indies (Lucas et al. 2012, Ryan et al. 2013) had been successfully identified by combining microseismic activity information with other geophysical and geochemical data. Geothermal exploration projects are underway in locations on Vanuatu and Fiji, which have been assessed with a high geothermal potential according to McCoy et al. (2011).

6. CONCLUSION

Six new seismic stations were successfully installed on the islands Tutuila and Ta'u of American Samoa in July 2016. Telemetry equipment was installed at the three permanent sites. The network comprises two borehole stations at 300 and 670 m depth, which are likely to be the deepest borehole stations in the South Pacific region. Training on maintenance, servicing and installation was provided to local staff for long-term station operation.

The analysis of existing and newly acquired datasets is work in progress that will further understanding of the seismicity associated with volcanic activity, structural and stratigraphic units, and potential geothermal areas of American Samoa.

ACKNOWLEDGEMENTS

We thank ASPA and EPA staff for providing access and support during installation and the owners Dean and Isabelle of Moana o Sina resort and Fale Pule guest house for their help.

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