



CRUISE REPORT
Research vessel of the French Oceanographic Fleet

CRUISE REPORT OF THE SAMOA-SPT CRUISE

R/V *ALIS*

Tutuila Island

August 27 – September 10, 2015



Report recipients

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Cruise Summary Report

CRUISE NAME: SAMOA-SPT

Research vessel: *Alis*

CHIEF SCIENTIST:

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RESEARCH UNIT:

Université de Bordeaux, CNRS-UMR 5805 EPOC

PARTNERS:

Université de La Rochelle, CNRS-UMR 7266 LIENSs
University of New South Wales Australia, Sydney, Australia
USGS Santa Cruz, U.S.A.

Date beginning: 08/27/2015

Date end: 09/10/2015

Number of days at sea : 13

Departure port: Apia (Western Samoa) **Arrival port:** Apia (Western Samoa)

OBJECTIVES OF THE CRUISE:

Tsunamis and tropical cyclones are major natural hazards that concern coastal areas of islands and continents located around the oceans. The September 29, 2009 tsunami affected numerous areas of the Pacific South-West, in particular Wallis and Futuna, Samoa and American Samoa islands. Tropical cyclones appear less deadly but are more frequent: e.g. Cyclone Ofa in 1990, Cyclone Val in 1991, Cyclone Evan in 2012. Tsunami and storm-surge flooding leads to the deposition of onshore marine and coastal sediments. The analysis of these tsunami and storm deposits is crucial for the understanding and scaling of the related hazards. However, the preservation potential of on land deposits in coastal areas is limited because of subsequent erosion and reworking. The backwash directly after the tsunami or storm surge flooding transports sediment from land to sea and deposits it in shallow areas. Because of heavy precipitations that accompany tropical cyclones, the related backwash deposits should a priori contain a higher content of particles of terrestrial origin. The characteristics of these submarine deposits remain poorly known and need to be better documented. The "SAMOA-SPT (South Pacific Tsunami)" project attempts to identify these deposits and to use them as sedimentary markers of tsunamis and tropical cyclones to construct a chronology of past events. This project offers a unique opportunity to recognize and reconstruct the record of past catastrophic events for a long time interval in the South Pacific zone. This novel and original approach will be applied in the shallow marine areas around the island of Tutuila (American Samoa). Besides the analysis of submarine tsunami deposits, this campaign might potentially provide a sedimentary record of tropical cyclones for the past thousands years and important information about the recent and present-day climate change in the South Pacific, a central objective for COP21. The oceanographic campaign SAMOA-SPT on board R/V Alis (IRD research vessel of the IRD, Nouméa, New Caledonia) has allowed the recognition of the acoustic (multibeam bathymetry and imagery), seismic (high resolution seismic) and sedimentary (interface and Kullenberg piston coring) characteristics of the backwash-related submarine tsunami and storm (tropical cyclone) deposits. Thus, it will be possible to use these data to establish sedimentary budgets of the on land related erosion, to compare both types of event deposits, and to determine the frequency of these hazardous phenomena in the area. Consequently, we attempt to improve the knowledge and understanding of hazards related to tsunamis and tropical cyclones in the South Pacific.

The SAMOA-SPT cruise occurred from August 27, 2015 and September 10, 2015 (Apia-Apia, Western Samoa). Works at sea were conducted within 6 selected bays around the island of Tutuila (American Samoa). These bays were chosen as they appear to be optimal for the preservation of submarine tsunami deposits, because of their shape and of the importance of the runups during the submersion of the 2009 tsunami. During the cruise, swath bathymetry (and acoustic imagery), sediment echo-sounding surveys and various corings were performed within the 6 selected bays.

During the post-cruise research, we attempt (1) to analyze the morpho-sedimentary effects of the tsunamis (and eventually of tropical cyclones), (2) identify the sedimentary deposits related to the backwash of tsunamis and distinguish them from cyclone-related deposits, (3) calculate the land to sea sedimentary budgets that occur during tsunamis and (4) establish the chronology of past events from the cored sedimentary archives. This last task is the ultimate objective of the project, because the time data are crucial for a better knowledge of the tsunami hazard in the area, especially since no historical writing related to these events is available before 1837.

STUDY AREA:

South Pacific – Tutuila island (American Samoa)

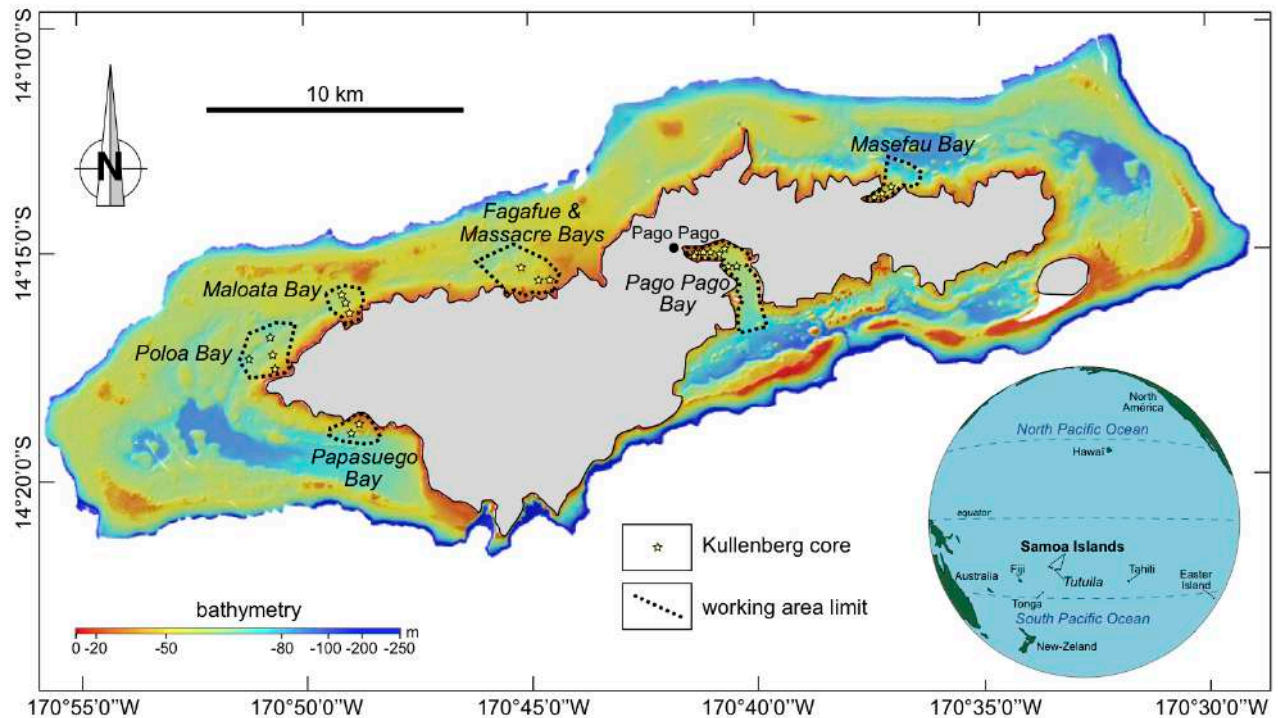


Figure 1. Map of the work areas with location of the 6 studied boxes (swath bathymetry, acoustic imagery, sediment high-resolution echo sounding, corings) corresponding to the 6 selected bays for the SAMOA-SPT cruise.

Geographic limits of the study area:

North: S14°10 **South:** S14°25 **West:** W170°55 **East:** W170°30

WORKS AT SEA:

- 1) Swath bathymétrie and acoustic imagery EM1002 (*Alis*). Surveys within 6 boxes (*cf.* map above)
- 2) High-resolution sediment acoustic echo-sounding SEISTEC. 6 days of survey within 6 boxes (*cf.* map above).....
- 3) Kullenberg coring. 27 cores within 6 boxes (*cf.* map above).....
- 4) Interface coring. 10 cores within 6 boxes (*cf.* map above).....
- 5) Dives and manual coring. 6 cores within 6 boxes (*cf.* map above)
- 6) Beach and river bed sediment samplings (Pago Pago, Fagafue and Masefay Bays)

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QUANTITATIVE OPERATIONS ASSESSMENT:

Operations	Operations		
	Planned	Realized	% of success Realized/Planned
Swath bathymetry EM 1002	6 days	6 days	100%
Sediment echo-sounding SEISTEC	6 days	6 days	100%
Interface coring	20 cores	11 cores	55%
Kullenberg coring	17 cores	26 cores	153%
Interface coring (dives	12 cores	6 cores	50%

SHIPBOARD SCIENTIFIC TEAM:

Name	Quality	Laboratory	Responsibility
SCHNEIDER Jean-Luc	Professor	UMR 5805 EPOC	Chief scientist, sedimentology
CHAUMILLON Eric	Professor	UMR 7266 LIENSs	Geophysics
CORRÈGE Thierry	Professor	UMR 5805 EPOC	Sedimentology, palaeoclimatology, scientific diver
CHAGUÉ-GOFF Catherine	Senior Lecturer	UNSW, Sydney, Australia	Geochemistry, datings
BUJAN Stéphane	Research Engineer	UMR 5805 EPOC	Logistics, Chief of the scientific divers
BUTSCHER John	Technician	IRD Nouméa	Scientific diver

FOREIGN RESEARCHERS ASSOCIATED TO THE PROJECT:

Dr. Catherine CHAGUE-GOFF (UNSW Australia, Sydney, Australie, shipboard scientist)
Pr. James GOFF (UNSW Australia, Sydney, Australia)
Dr. Bruce JAFFE (USGS, Santa Cruz, U.S.A.)

RESEARCH TOPIC:

Geosciences: analysis of submarine event deposits related to the backwash of tsunamis in the shallow areas around the island of Tutuila (American Samoa).

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DESCRIPTION OF THE WORKS AT SEA:

The table 1 below summarizes the works at sea during the SAMOA-SPT cruise.

Day	Work area	Operations
08/27/2015	Apia (Western Samoa)	Mobilization of the vessel.
Day 2	Pago Pago Bay	Transit to Pago Pago, register with harbor master.
Day 3	Pago Pago Bay	Sampling of beach and river bed sediments (Pago Pago). Swath bathymetry in the bay. 24 SEISTEC profiles.
Day 4	Pago Pago Bay	Dive n°1 (1 manual interface core). 5 Kullenberg cores.
Day 5	Pago Pago Bay	Dive n°2 (1 manual interface core). 2 Kullenberg cores and 7 interface cores. 4 SEISTEC long profiles.
Day 6	Pago Pago Bay	3 Kullenberg cores and 2 interface cores. Swath bathymetry of the outer part of the bay. Public and press conference in Pago Pago (J.-L. Schneider).
Day 7	Fagafue and Massacre Bays	Transit to Fagafue and Massacre Bays. Swath bathymetry in both bays. 7 SEISTEC profiles. Dive n°3 (3 manual interface cores).
Day 8	Fagafue and Massacre Bays	8 SEISTEC profiles. 3 Kullenberg cores.
Day 9	Fagafue, Massacre and Poloa Bays	Sampling of beach and river sediments in Fagafue bay. Transit to Poloa Bay. Swath bathymetry in Poloa Bay. 4 SEISTEC profiles. 4 Kullenberg cores.
Day 10	Masefau Bay	Transit To Masefau Bay. Swath bathymetry of the bay. Port call in Masefau (boarding of C. Chagué-Goff, meeting with the village matai. Sampling of beach and river sediments. 3 SEISTEC profiles. 3 Kullenberg cores. Dive n°4 (2 manual interface cores).
Day 11	Maloata and Afao Bays	Transit to Maloata Bay. Swath bathymetry of the bay. 9 SEISTEC profiles. 3 Kullenberg cores. Transit to Afao Bay. Swath bathymetry of the bay (no complementary studies in this area).
Day 12	Pago Pago Bay	Transit to Pago Pago Bay. 15 SEISTEC profiles (outer part of the bay). 2 Kullenberg and 3 interfaces cores. Dive n°5 (3 interface cores).
Day 13	Papasuego Bay	Transit to Papasuego Bay. Swath bathymetry of the bay. 6 SEISTEC profiles. 2 Kullenberg cores. Transit to Pago Pago port (port formalities). Transit to Apia.
09/10/2015	Apia (Western Samoa)	Demobilization of the vessel.

Table 1. SAMOA-SPT cruise work summary.

PRELIMINARY RESULTS:

The two main objectives of the campaign were (1) the reconnaissance of recent deposits related to the tsunamis backwash, particularly for the 2009 event and (2) to collect sediments by various coring operations to identify older similar event deposits to establish their chronology. The identification of submarine tsunami backwash deposits is based (1) on their acoustic (morphology of the subaqueous deposits, acoustic reflectivity) and echo-sounding signatures (sedimentary bodies geometry, peculiar reflectors), and (2) their sedimentary facies characteristics (elementary sedimentary intervals, grain size, composition and biogenic content). It is also necessary to distinguish these deposits from the deposits related to the effects of tropical cyclones in the area.

All the objectives of the campaign were reached. Works at sea were conducted within 6 boxes corresponding to the 6 selected bays (identified to be the more favorable for submarine tsunami deposits preservation) around the island of Tutuila. For each box, a similar study protocol has been followed: swath bathymetry, acoustic imagery, high-resolution sediment echo-sounding profiles and coring were conducted. The deepest and more protected bay, the Pago Pago bay, has been the main target of the SAMOA-SPT campaign. The preliminary results indicate that submarine tsunami-related deposits are present within some of the studied bays, particularly in the Pago Pago Bay.

Post-cruise research is now necessary. The final goals are to establish sedimentary budgets of the on land related erosion, to compare both types of event deposits, and to determine the frequency of these hazardous phenomenon in the area.

1 – Data

The location of the study areas around the Tutuila Island and of the collected Kullenberg cores is displayed on Figure 1.

Shipboard data

Swath bathymetry and acoustic imagery:

A multibeam EM1002 device has been used onboard for the swath bathymetry and acoustic imagery surveys in the 6 selected bays (Figure 1). Moreover, bathymetric surveys have been conducted during transits. The device has been used exclusively during daytime.

High-resolution sediment echo-sounding:

High-resolution sediment echo-sounding (IKB-SEISTEC profiler) profiles have been performed in the 6 selected bays. The device has been used exclusively during daytime at a speed of 2 knots during short periods (20 min) interrupted by periods of silence of at least 20 min. Longer profiles have been performed within the Pago Pago Bay, the main target of the campaign. A total of 27 nautical miles (50 km) of echo-sounding profiles has been obtained during the cruise (11.75 nautical miles in the Pago Pago Bay).

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Sampling

Three types of coring were performed during the SAMOA-SPT cruise: (1) interface cores were taken to collect undisturbed superficial sediments for a length of about 1 m, (2) interface cores collected manually by the scientific divers in the very shallow areas and (3) Kullenberg cores (3 m long) to collect longer sedimentary intervals. The interface cores (total: 10 cores) have been collected within the most favorable area for the preservation of tsunami backwash deposits, *i.e.* within the Pago Pago Bay. A total of 27 Kullenberg cores has been sampled to reach the oldest deposits. Some Kullenberg cores have been collected on the same places as for the interface cores to allow an optimal sediment sampling. Table 2 below presents the characteristics of the interface and Kullenberg cores collected during the SAMOA-SPT campaign. Moreover, the scientific divers have taken 10 interface cores in shallow waters and areas inaccessible by the vessel.

Type	Core number	Location	Latitude	Longitude	Depth (m)	Length (m)
Kullenberg	SAMOA-SPT-K01	Pago Pago Bay	S14°16.433	W170°41.220	28.7	2.89
Kullenberg	SAMOA-SPT-K02	Pago Pago Bay	S14°16.422	W170°41.473	27.7	2.38
Kullenberg	SAMOA-SPT-K02-Bis	Pago Pago Bay	S14°16.422	W170°41.473	27.7	2.61
Kullenberg	SAMOA-SPT-K03	Pago Pago Bay	S14°16.413	W170°40.980	45.5	2.69
Kullenberg	SAMOA-SPT-K04	Pago Pago Bay	S14°16.377	W170°41.400	28.8	2.55
Kullenberg	SAMOA-SPT-K04-Bis	Pago Pago Bay	S14°16.377	W170°41.400	28.8	2.49
Kullenberg	SAMOA-SPT-K05	Pago Pago Bay	S14°16.378	W170°41.367	27.9	2.57
Kullenberg	SAMOA-SPT-K05-Bis	Pago Pago Bay	S14°16.378	W170°41.367	27.9	2.43
Kullenberg	SAMOA-SPT-K06	Pago Pago Bay	S14°16.470	W170°41.064	45.9	2.59
Kullenberg	SAMOA-SPT-K07	Pago Pago Bay	S14°16.474	W170°41.391	35.5	1.75
Kullenberg	SAMOA-SPT-K08	Fagafue Bay	S14°16.973	W170°45.334	50	1.44
Kullenberg	SAMOA-SPT-K09	Fagafue Bay	S14°16.925	W170°45.585	50	1.27
Kullenberg	SAMOA-SPT-K10	Fagafue Bay	S14°16.703	W170°45.787	60	2.67
Kullenberg	SAMOA-SPT-K11	Poloa Bay	S14°18.982	W170°50.530	32.5	1.50
Kullenberg	SAMOA-SPT-K12	Poloa Bay	S14°18.792	W170°50.695	50	1.50
Kullenberg	SAMOA-SPT-K13	Poloa Bay	S14°18.148	W170°50.811	70	1.00
Kullenberg	SAMOA-SPT-K14	Poloa Bay	S14°18.767	W170°51.269	70	1.01
Kullenberg	SAMOA-SPT-K15	Masefau Bay	S14°15.188	W170°37.364	44.4	1.47
Kullenberg	SAMOA-SPT-K16	Masefau Bay	S14°15.164	W170°37.343	44.4	1.63
Kullenberg	SAMOA-SPT-K17	Masefau Bay	S14°15.108	W170°37'166"	51	1.94
Kullenberg	SAMOA-SPT-K18	Maloata Bay	S14°17.842	W170°49.031	31.2	0.56
Kullenberg	SAMOA-SPT-K19	Maloata Bay	S14°17.624	W170°49.003	50.9	1.10
Kullenberg	SAMOA-SPT-K20	Maloata Bay	S14°17.494	W170°49.017	52.2	1.18
Kullenberg	SAMOA-SPT-K21	Pago Pago Bay	S14°16.670	W170°40.623	54.4	1.65
Kullenberg	SAMOA-SPT-K22	Pago Pago Bay	S14°16.675	W170°40.380	55.7	1.72
Kullenberg	SAMOA-SPT-K23	Papasuego Bay	S14°20.203	W170°48.552	37	0.45
Kullenberg	SAMOA-SPT-K24	Papasuego Bay	S14°20.424	W170°48.554	68	0.78
Interface	SAMOA-SPT-CA1	Pago Pago Bay	S14°16.44	W170°41.23	28.7	0.36
Interface	SAMOA-SPT-CA2	Pago Pago Bay	S14°16.41	W170°41.47	27.7	0.42
Interface	SAMOA-SPT-CA3	Pago Pago Bay	S14°16.41	W170°40.98	45.5	0.57
Interface	SAMOA-SPT-CA4	Pago Pago Bay	S14°16.38	W170°41.40	28.8	0.70
Interface	SAMOA-SPT-CA5	Pago Pago Bay	S14°16.365	W170°41.37	27.9	0.63
Interface	SAMOA-SPT-CA6	Pago Pago Bay	S14°16.470	W170°41.064	45.9	0.62
Interface	SAMOA-SPT-CA7	Pago Pago Bay	S14°16.474	W170°41.391	33.5	0.67
Interface	SAMOA-SPT-CA8	Pago Pago Bay	S14°16.474	W170°41.380	34	0.70
Interface	SAMOA-SPT-CA9	Pago Pago Bay	S14°41.532	W170°16.455	27	0.70
Interface	SAMOA-SPT-CA10	Pago Pago Bay	S14°16.422	W170°41.058	47	0.70

Table 2. List of the Kullenberg and interface cores collected during the SAMOA-SPT campaign.

The total cored length is 31.85 m for the Kullenberg cores, 3.27 m for the interface cores and 2.80 m for the interface cores collected manually.

Finally, when possible, beach and river sediments were collected on land (Pago Pago, Fagafue and Masefau Bays).

Post-cruise planned analyses

- (1) ***Bathymetry and acoustic imagery data processing and analyses.*** Data will be processed (waves and tide corrections) at UMR 5805 EPOC (Bordeaux, France) before the end of 2015. The analysis of the data will provide information about the sedimentary transit axes and the main sedimentation areas. These data are crucial for further numerical modeling of the tsunami waves propagation within the bays.
- (2) ***Echo-sounding profiles processing and analyses.*** The echo-sounding profiles will be processed to improve the signal. The study of these profiles will allow the identification of various acoustic units, particularly in the Pago Pago Bay where about the half of the profiles have been collected. A geometric analysis of the erosional surfaces and of the sedimentary infills will be realized.
- (3) ***Sediment cores and sediments analyses.*** The study of the various sedimentary cores will provide the most important information for the SAMOA-SPT project. We are searching specific sedimentary intervals related to tsunami backwash processes and, eventually, to tropical cyclones around Tutuila Island. The analyses will be based on the sequential characteristics and on the composition of the sediments. Indeed, the sediment composition will allow recognizing the terrestrial influx into the marine environment. In the case of a tsunami backwash, we expect the presence of both marine particles remobilized from the offshore area and sediments of terrestrial origin (vegetal organic matter, soil sediments, volcanoclastic particles) and, for the most recent deposits, particles of anthropogenic origin. The following analysis protocol will be applied to the cores: (1) visual description, (2) digital photography of the core sections, (3) X-ray radiography of the core (to visualize peculiar structures), (4) magnetic susceptibility, (5) semi-quantitative geochemical analyses with a XRF core scanner. Dating and evaluation of the sedimentation rates will be based on radiochemical analyses (^{210}Pb and ^{137}Cs radioisotopes) and with ^{14}C (on organic particles). Samples will be collected for high-resolution grain size analyses, biogenic and anthropogenic particles extraction and analysis, analysis of sedimentary fabrics (anisotropy of the magnetic susceptibility), and geochemical analyses (ICP-AES). Large-scale thin sections will be prepared after the induration of the soft-sediments for petrographic observations. A peculiar interest will be paid for the coral and calcareous algae (Halimeda) that are abundant in the deposits. Their potential as paleothermometers (palaeoclimatology purposes) will also be tested using geochemical analyses (Mg/Ca, Sr/Ca). All these analyses will be performed during the year 2016.

2 – Preliminary results

Bathymetry and acoustic imagery:

Bathymetric and acoustic imagery data have been collected within the 6 selected bays (cf. Appendix). As an example, Figure 2 presents the bathymetric box of the Pago Pago Bay where important work has been conducted during the cruise. The north-western termination

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of the bay corresponds to the most protected area around the shorelines of Tutuila Island, and then the most convenient for tsunami deposits preservation. Figure 3 displays the acoustic imagery data for the inner part of the Pago Pago Bay, *i.e.* the most proximal area. The data suggest that softer sediment (characterized by lower reflectivity) is present in the most inner part of the bay, suggesting the presence of tsunami backwash-related deposits, a deposit that could be related to the 2009 event. Numerous more reflective mounds are also present. They could correspond to indurated clay deposits (to be verified). Observations during dives have shown the absence of significant coral bodies in this part of the bay, the sedimentation of which being mainly controlled by fluvial influx. Numerous cores were collected within the Pago Pago Bay.

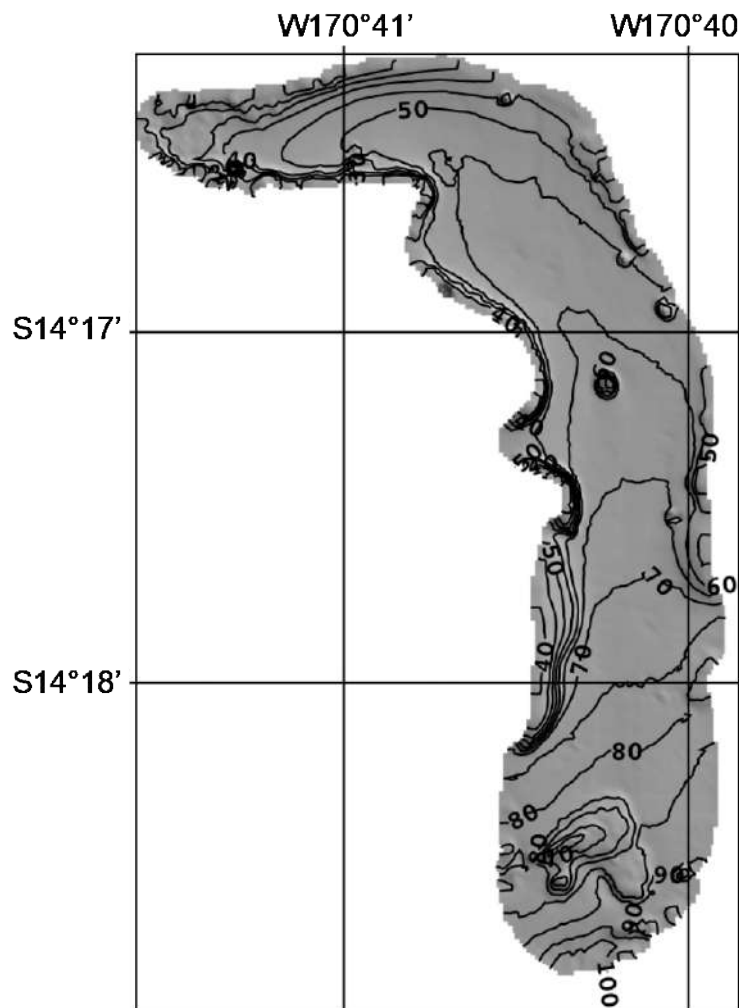


Figure 2. Bathymetric box of the Pago Pago Bay (non-processed data, EM1002, R/V/ Alis SAMOA-SPT cruise).

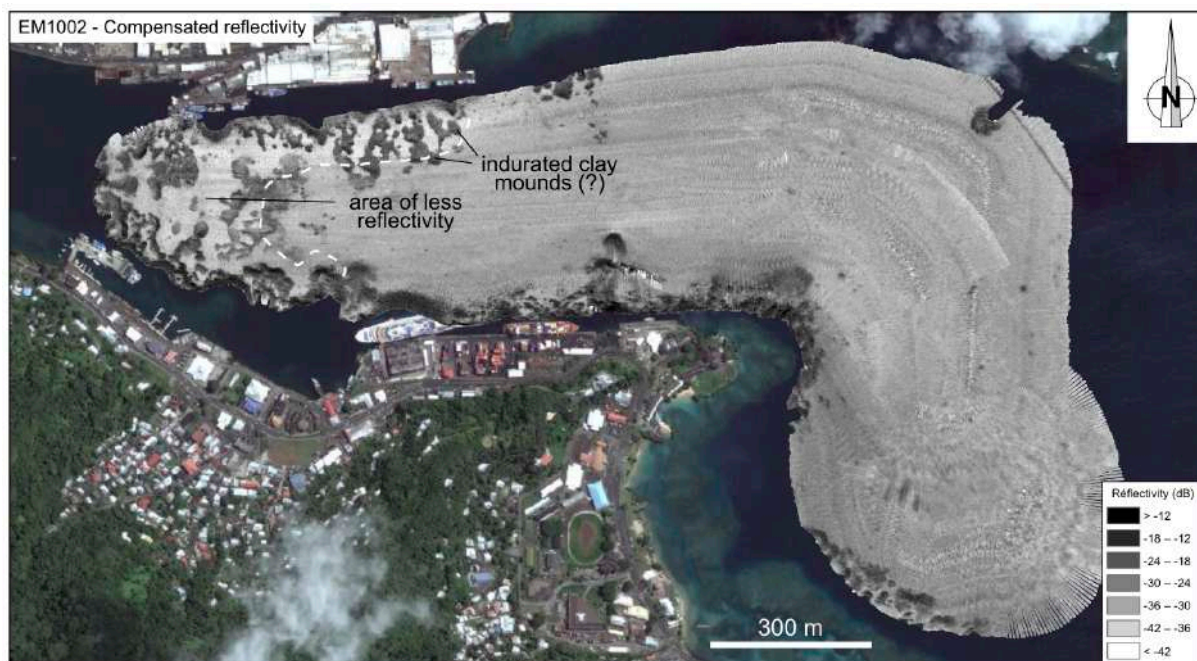


Figure 3. Map of the acoustic reflectivity of the bottom sediments of the inner part of the Pago Pago Bay. Note the presence of less reflective sediment in the most inner part of the bay. This suggests the presence of a soft water-rich sediment that could correspond to the 2009 tsunami backwash deposit.

High-resolution sediment echo-sounding:

High-resolution sediment echo-sounding profiles were obtained by using a IKB-SEISTEC profiler. Profiles display a sedimentary layer covering the volcanic substratum. Figure 4 displays an example of echo-sounding profile collected in the inner part of the Pago Pago Bay. The sedimentary infill covers the volcanic substratum and a superficial depositional unit is recognizable. It shows a distal pinch out contact with the underlying sediments. Coring performed within this top interval indicates the presence of coral fragments of distal origin (from the outer bay or even the foreshore area). These types of corals are apparently absent within the inner part of the bay suggesting that the top sedimentary interval could correspond to a tsunami backwash deposit (2009 event?).

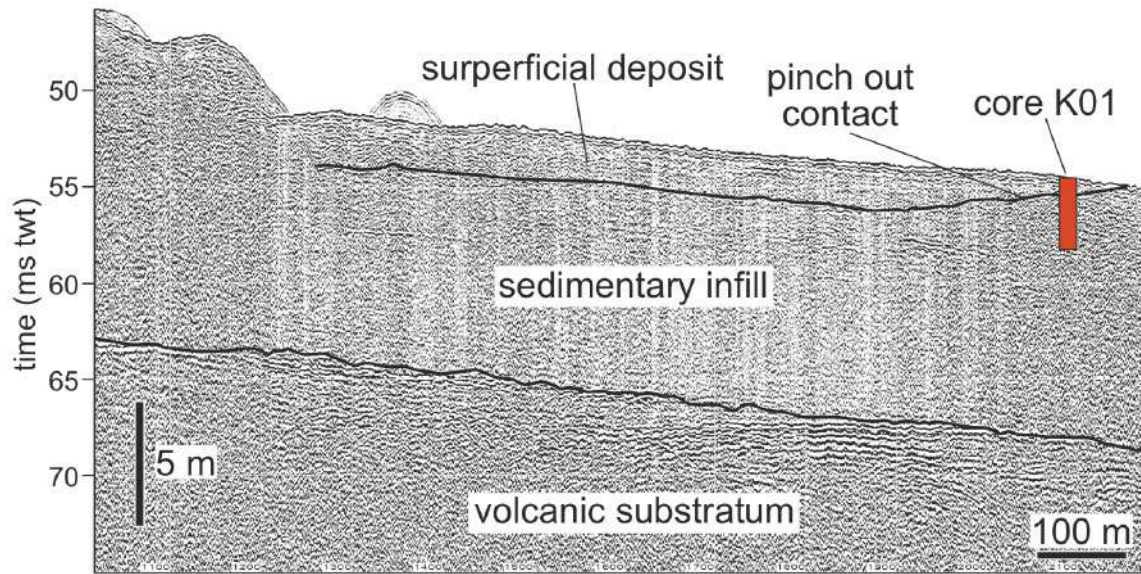


Figure 4. Part of the echo-sounding profile "Pago Pago 21" (inner part of the Pago Pago Bay; West is toward the left of the profile). The volcanic substratum, the sedimentary infill and the superficial sedimentary layer are visible. The top unit displays a distal pinch out contact.

Sediment cores:

The sediment cores have been collected in the various bays according the morphologic characteristics of the sea floor and the potential of occurrence and preservation of the tsunami backwash deposits. Cores were mainly collected in very proximal areas at a depth below the wave action, and also in more distal deeper depressions. For example, Figure 5 illustrates the location of the Kullenberg cores taken off Fagafue Bay (north coast of Tutuila Island).

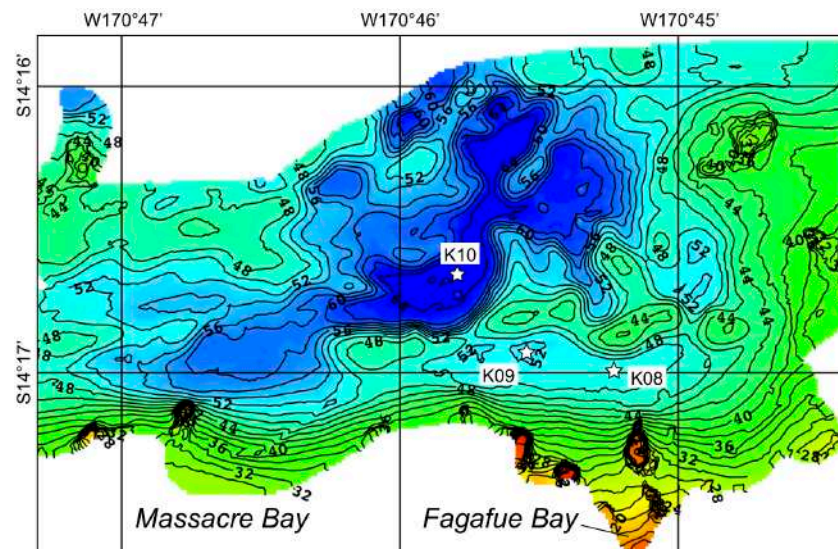


Figure 5. Bathymetric map of the Massacre et Fagafue Bays (northern coast of Tutuila Island) with location of the three Kullenberg cores collected in the depressions (white stars). Isobaths are in meters.

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These cores are located within bathymetric depressions that could collect tsunami backwash deposits.

Numerous cores were taken in the Pago Pago Bay. One interface core (SAMOA-SPT-CA07, Table 2) has been studied on board during the campaign. The sediment present in this core seems to attest the presence of a tsunami backwash deposit. Indeed, a pluri-decimeter thick deposit is present. It displays a crude normal grading and contains at its base coral fragments (of species that are not normally present in the inner part of the bay as confirmed by the observations of the divers), plant fragments and anthropogenic particles (asphalt fragments). A darker deposits is present at the top of this sedimentary interval. It could correspond to a decantation interval emplaced at the end of the event. This was the only core studied on board, but the observations allow being confident about the presence of similar deposits in other cores.

It is now necessary to further analyze the data collected during the SAMOA-SPT cruise. The analyses will mainly concern the study of the sedimentary intervals collected within the cores and their dating. The bathymetric and acoustic data are also important to reconstitute the depositional environments and to determine the sedimentary budgets. The chronology of the past events, behind the historical available data, is crucial to better understand the natural hazards that concern the this area of the South Pacific.

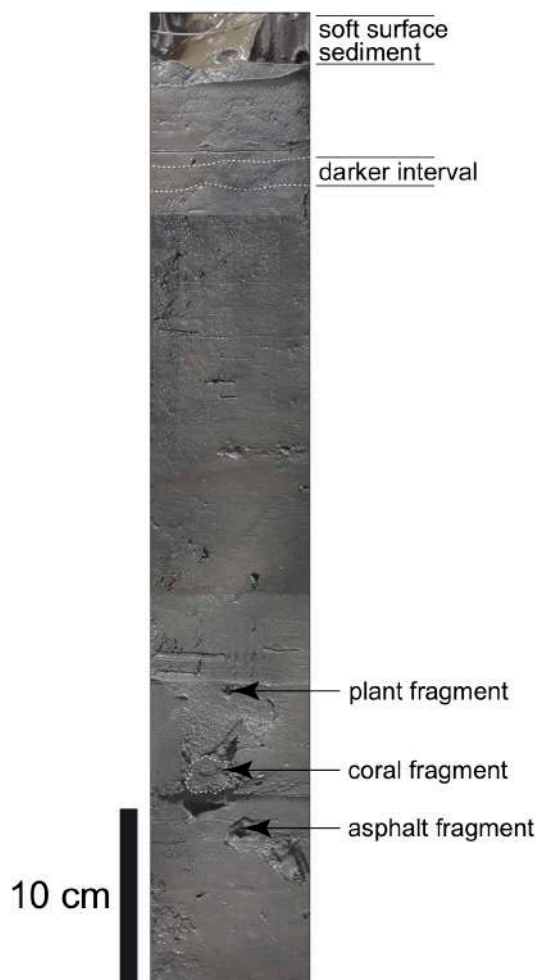
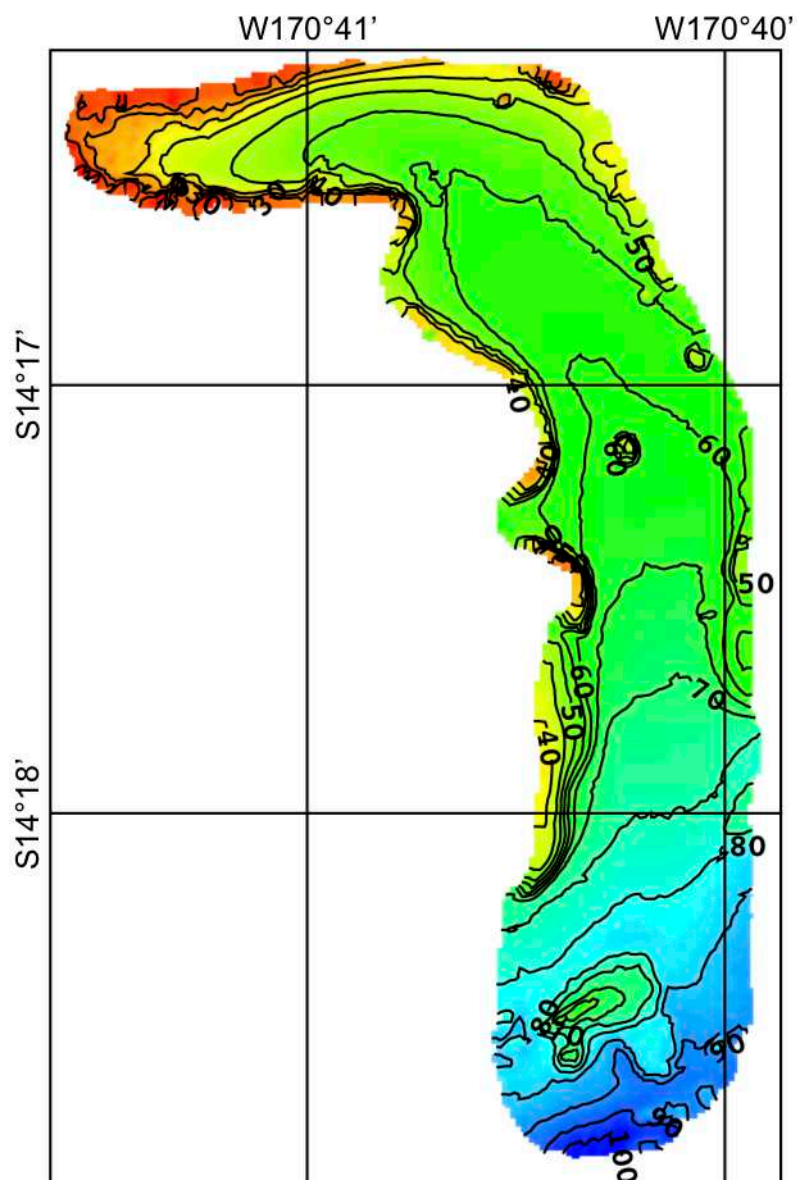


Figure 6. Photograph of the interface core SAMOA-SPT-CA07 collected in the inner part of the Pago Pago Bay. The darker interval is not clearly visible on the photograph.

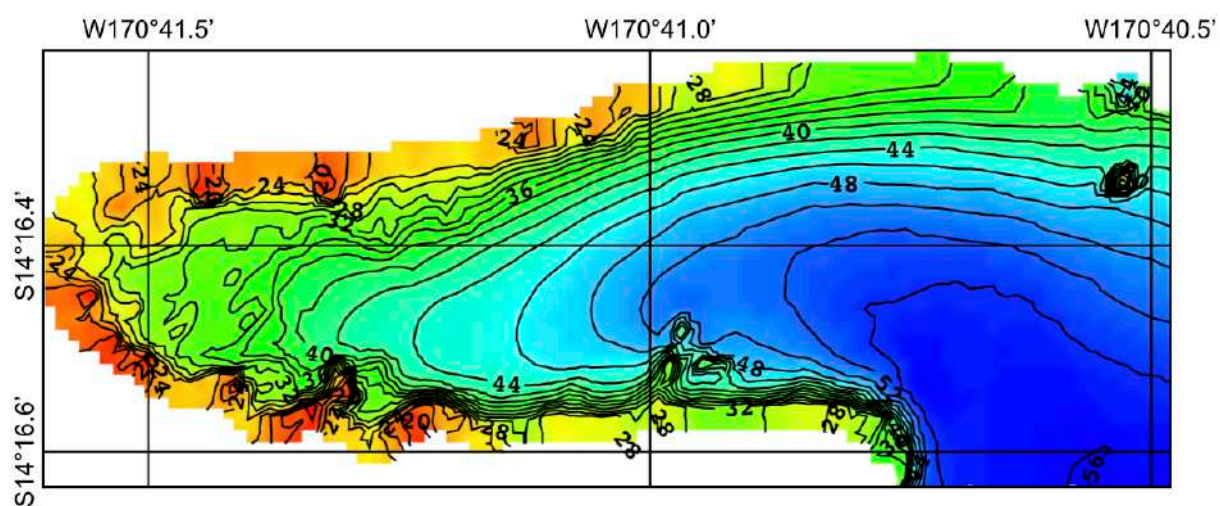
APPENDIX

BATHYMETRIC MAPS OF THE STUDIED BAYS TUTUILA ISLAND

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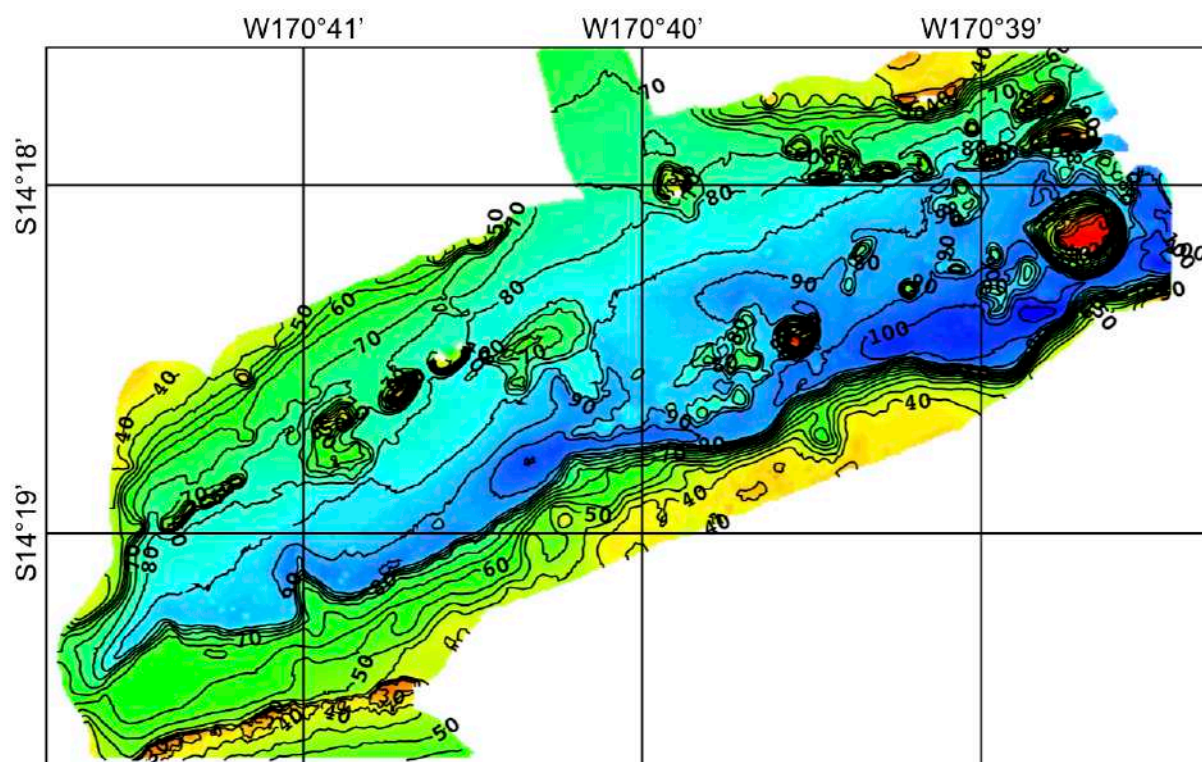


Bathymetric map of the Pago Pago Bay (Tutuila Island). Isobaths in meters.

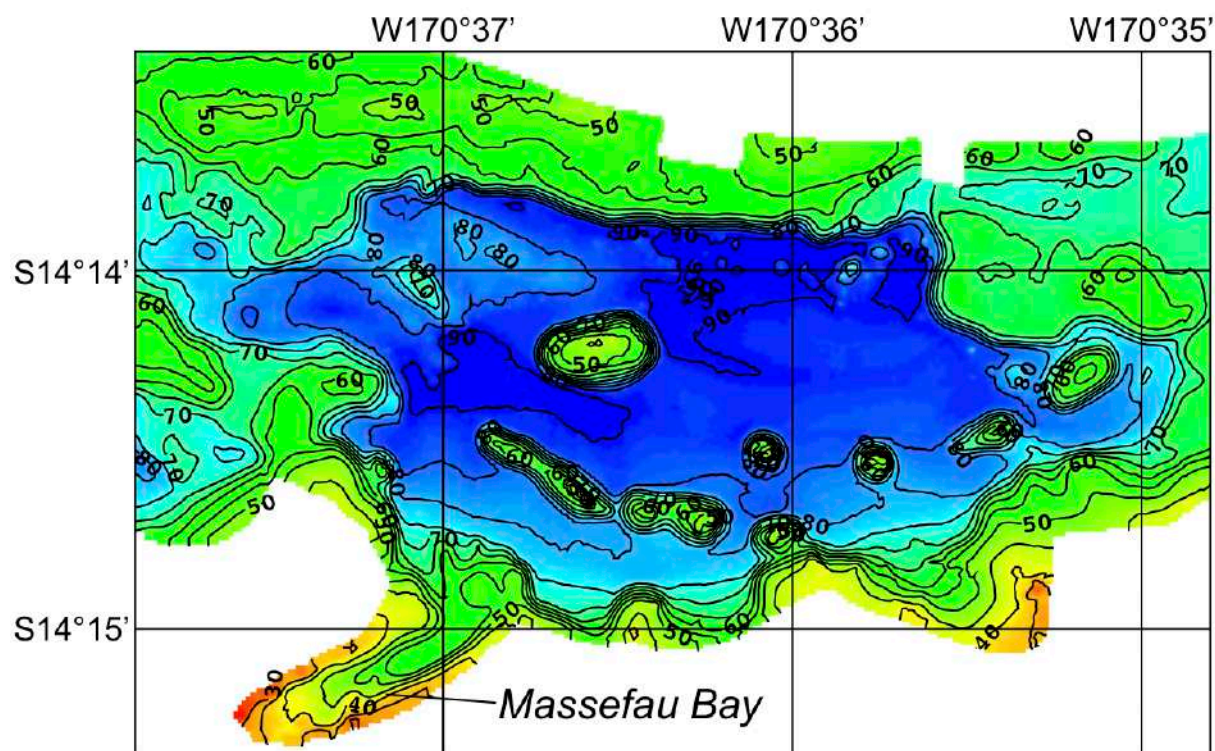


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Bathymetric map of the inner part of the Pago Pago Bay (Tutuila Island). Isobaths in meters.

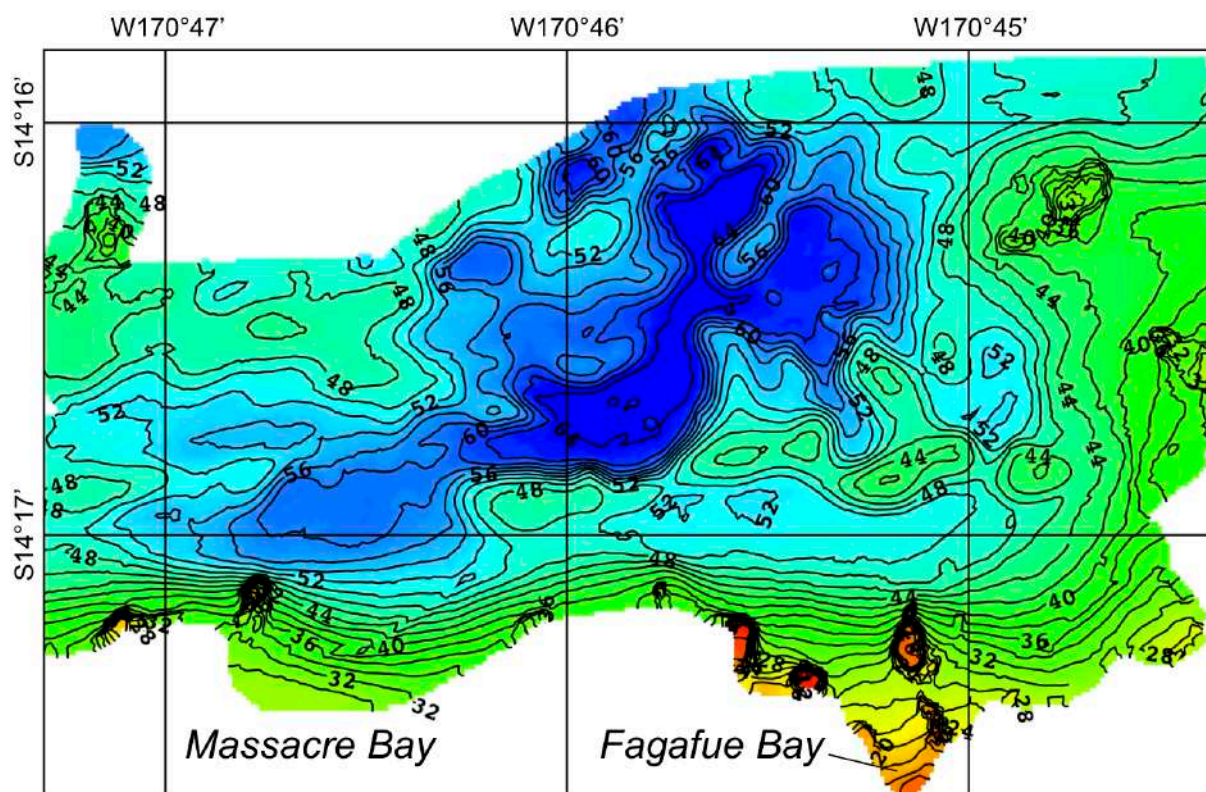


Bathymetric map of the outer part of the Pago Pago Bay (Tutuila Island). Isobaths in meters.

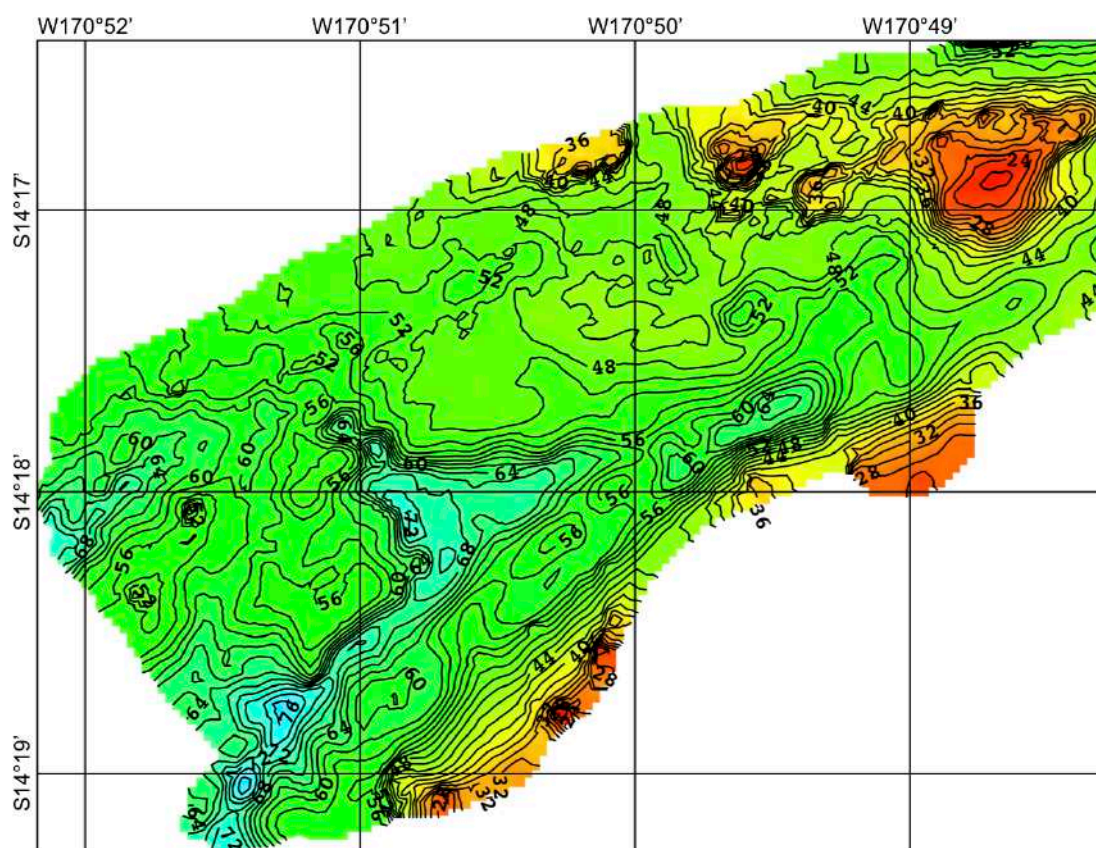


Bathymetric map of the Masefau Bay (Tutuila Island). Isobaths in meters.

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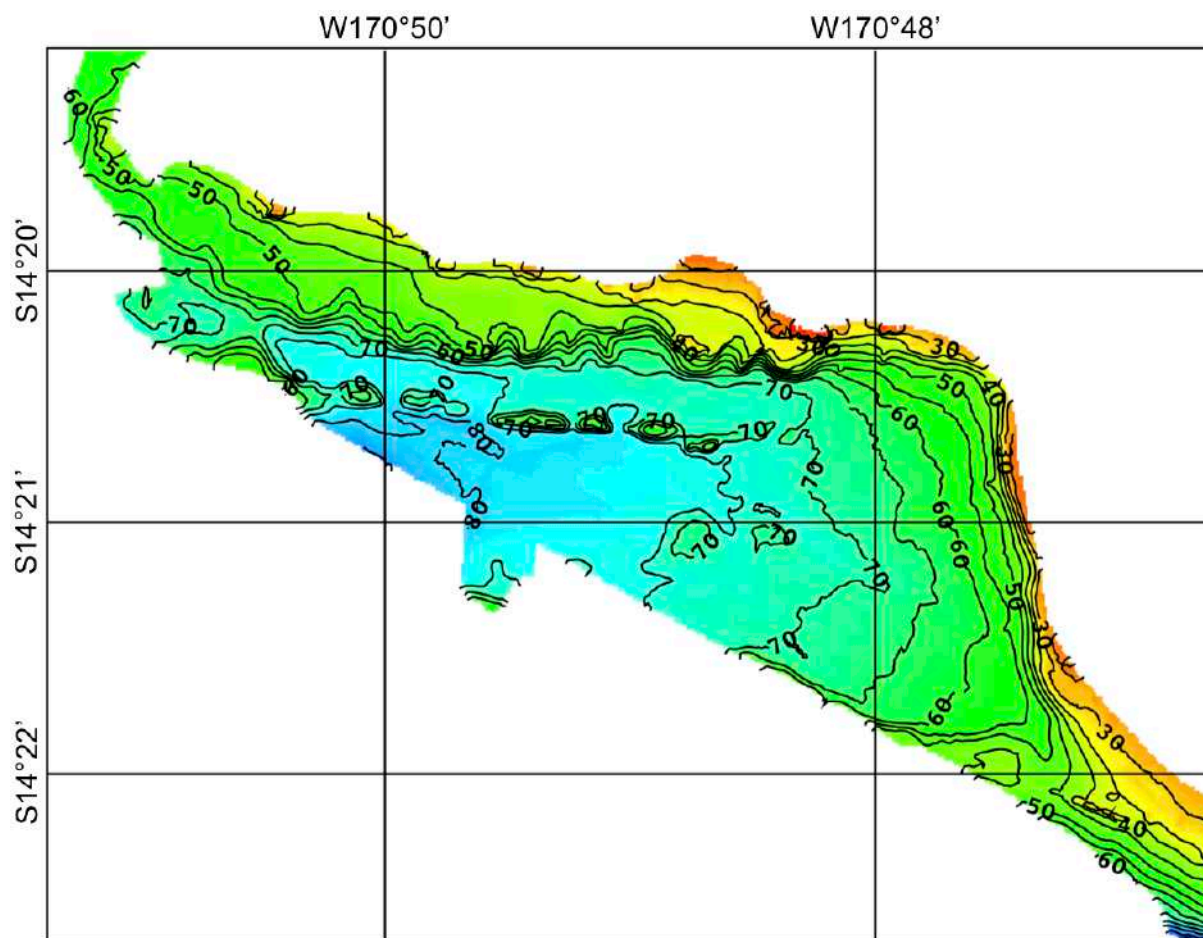


Bathymetric map of the Massacre and Fagafue Bays (Tutuila Island). Isobaths in meters.



Bathymetric map of the Poloa Bay (Tutuila Island). Isobaths in meters.

CRUISE REPORT
Research vessel of the French Oceanographic Fleet



Bathymetric map of the Afao Bay (Tutuila Island). Isobaths in meters.