Ocean Exploration and Research

MAPPING DATA ACQUISITION AND PROCESSING SUMMARY REPORT

CRUISE EX-17-03: Howland/Baker PRIMNM and PIPA (ROV/Mapping)

Derek C. Sowers[1]

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[1]ERT Corp. at NOAA Ocean Exploration and Research

1. Introduction

NOAA's Office of Ocean Exploration and Research (OER) is the only federal organization dedicated to exploring our unknown ocean. OER works with partners to identify priority areas for exploration; support innovations in exploration tools and capabilities; and encourage the next generation of ocean explorers, scientists, and engineers. The publicly available data and information gained from our expeditions and the research we fund gives resource managers, the academic community, and the private sector the information they need to identify, understand, and manage ocean resources for this and future generations of Americans.

NOAA Ship *Okeanos Explorer* is the only federal vessel dedicated to exploring our largely unknown ocean for the purpose of discovery and the advancement of knowledge about the deep ocean. America's future depends on understanding the ocean. We explore the ocean to make valuable scientific, economic, and cultural discoveries, and we explore because ocean health and resilience are vital to our economy and to our lives. Exploration supports NOAA mission priorities and national objectives by providing high-quality scientific information about the deep ocean to anyone who needs it.

In close collaboration with government agencies, academic institutions, and other partners, OER conducts deep-ocean exploration expeditions using advanced technologies on the *Okeanos Explorer*. From mapping and characterizing previously unseen seafloor to collecting and disseminating information about ocean depths, this work helps to establish a foundation of information and fill data gaps. Data collected on the ship follow federal open-access data standards and are publicly available shortly after an expedition ends. This ensures the delivery of reliable scientific data needed to identify, understand, and manage key elements of the ocean environment.

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2. Report Purpose

The purpose of this report is to briefly highlight the mapping data collection and processing methods used during the cruise.

This report focuses solely on the mapping data collected during exploration expedition EX-17-03. The full cruise report can be found in the NOAA Central Library.

3. Cruise Objectives

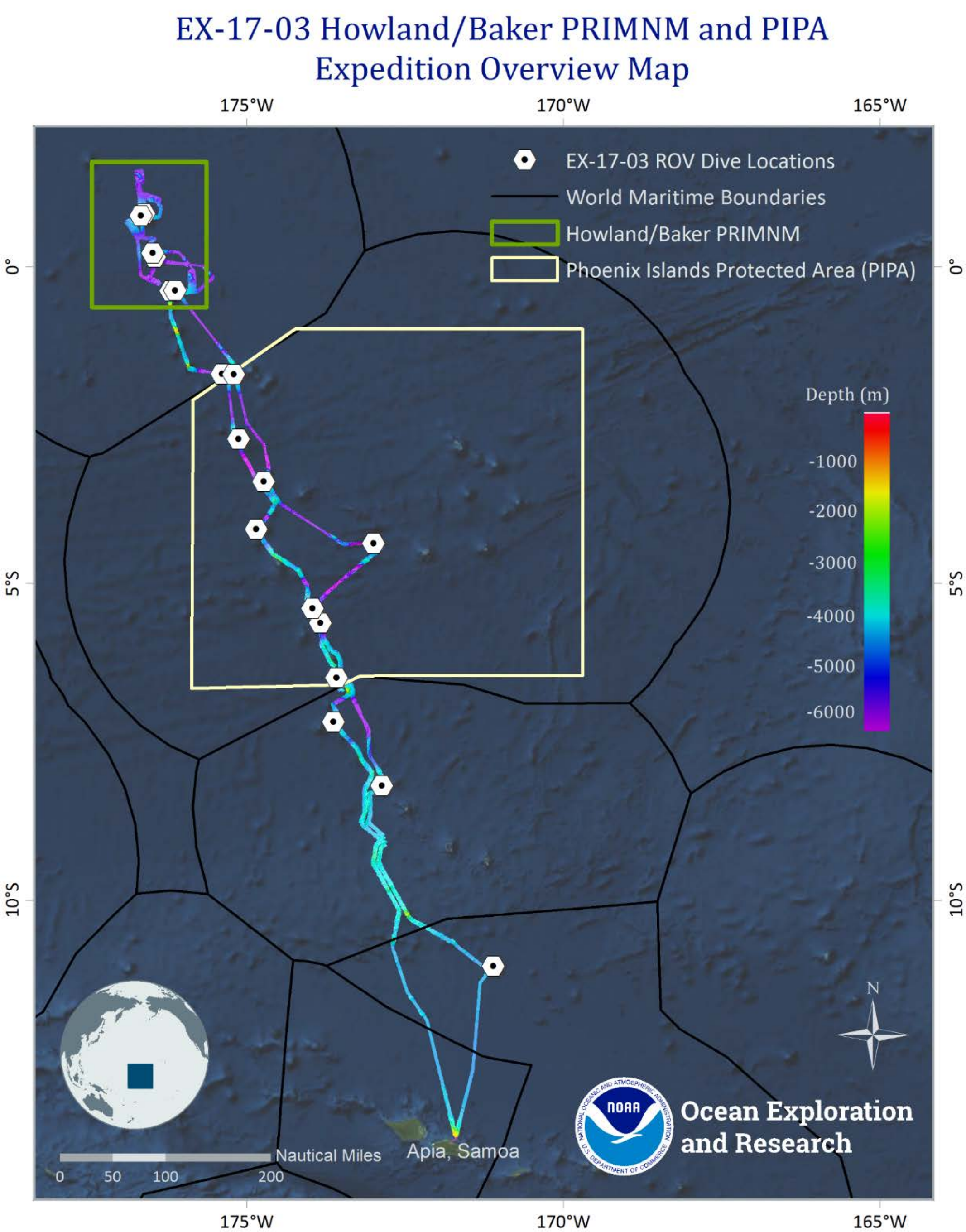
Operations for this cruise were conducted 24 hours/day and included exploration within several marine protected areas. The expedition commenced on March 7th, 2017 in Apia, Samoa and concluded on March 29, 2017 in Apia, Samoa (13°51.03' S, 171°45.08'W). Operations used the ship's deep water mapping systems (Kongsberg EM302 multibeam sonar, EK60 split-beam fisheries sonars, Acoustic Doppler Current Profilers [ADCP], and Knudsen 3260 chirp sub-bottom profiler sonar), NOAA's two-body 6000 m remotely operated vehicles (ROVs *Deep Discoverer* and *Seirios*), and the ship's high-bandwidth satellite connection for real-time ship-to-shore communications. ROV dives were conducted during the day to collect high-resolution visual surveys and limited rock and biologic specimen sampling. Mapping operations were conducted during long transits, overnight transits, and when the ROVs were on deck.

Exploration mapping occurred in Tokelau waters, the Kiribati's Phoenix Islands Protected Area (PIPA), the Howland and Baker unit of the Pacific Remote Islands Maine National Monument (PRIMNM), the National Marine Sanctuary of American Samoa, and within the waters of the Independent State of Samoa. This expedition helped establish a baseline of information in the region to catalyze further exploration, research, and management activities.

The specific objectives for this cruise were defined in EX-17-03 Project Instructions, which are archived in the NOAA Central Library.

4. Summary of Mapping Results

Cruise Overview Map



Overview map showing seafloor bathymetry and ROV dives completed during cruise EX-17-03, part of a three year NOAA Office of Ocean Exploration's Campaign to Address the Pacific monument Science, Technology, and Ocean NEeds (CAPSTONE). Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 1. Cruise map showing overall EX-17-03 operations. Generated in ArcMap.

This cruise greatly increased the coverage of high quality multibeam sonar bathymetry coverage for the Tokelau Seamount Chain and within the Howland and Baker Islands region of the Pacific Remote Islands Marine National Monument (PRIMNM). Coverage was collected to reveal details of the most prominent seamounts in the Tokelau Seamounts Chain, as well as prominent ridge features in the region that lacked existing multibeam coverage. The cruise contributed multibeam sonar bathymetry coverage to portions of 26 seamounts, with substantial additional 60m resolution coverage added to Howland and Baker Islands. New high quality multibeam sonar was also collected on seven prominent ridge features within the Tokelau Seamount Chain region.

Overnight transit mapping was focused on adding coverage to seamounts and ridge features mapped on EX-17-01 as the *Okeanos Explorer* had transited from the Kingman/Palmyra region to American Samoa (figure 2). Edge matching mapping was also done on older previously collected multibeam sonar coverage available through the NCEI archives. Background data used for exploration mapping included multibeam data collected on *Okeanos Explorer* cruise EX-17-01, the SRTM30 grid, and all multibeam data archived with the National Center for Environmental Information (NCEI) gridded using NCEI's Auto Grid online tool.

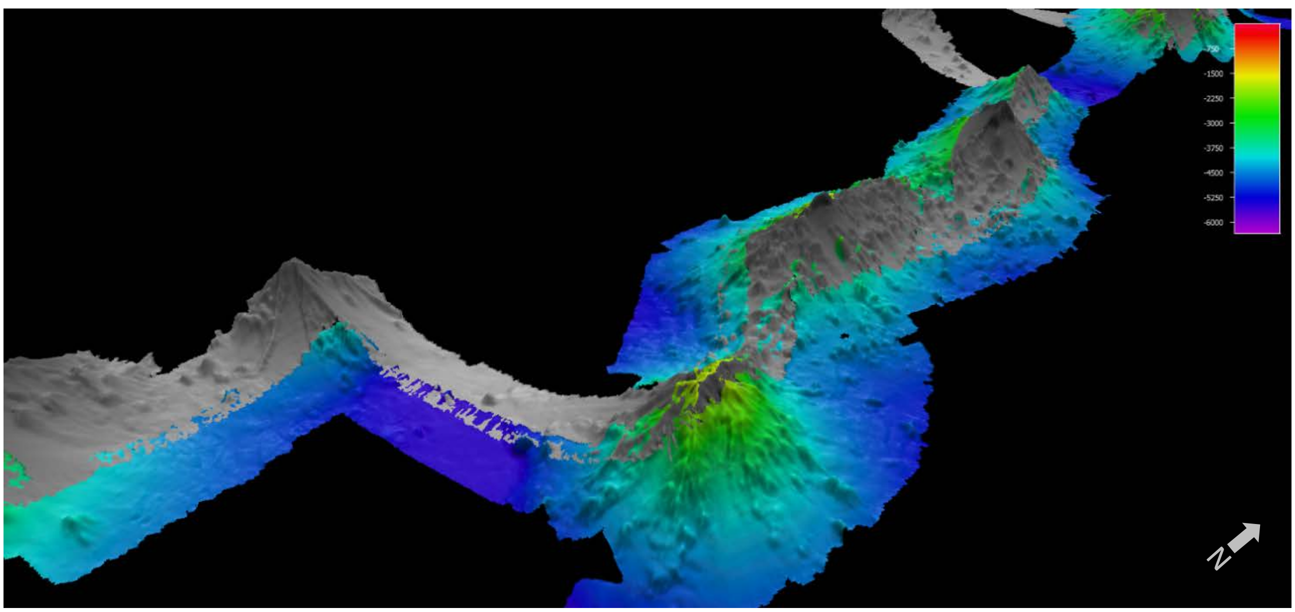


Figure 2. Example of complementary overlap mapping coverage of multibeam sonar bathymetry data from cruises EX-17-01 (grayscale color ramp) and EX-17-03 (rainbow color ramp). Example image centered at approximately -173° 34.5' W, -6° 28.5' S. Image made in QPS Fledermaus software, 3x vertical exaggeration.

The region surveyed contained many prominent seamount features. The seamounts surveyed were interesting in that many of them had steep pointed summits, but some of them were flat-topped guyots that indicated exposure to sea level erosion as some point in their geologic history.

The following section of this report highlights a small subset of some of the interesting prominent features mapped during the cruise. All of the data collected during the cruise is publicly accessible.

Example Highlight Features Within the Phoenix Islands Protected Area (PIPA)

Mapping work within PIPA focused primarily on transiting along the main axis of the Tokelau Seamount chain, punctuated with daily ROV dives on seamounts during daylight hours. Portions of ten seamounts and two prominent ridge features were mapped within PIPA (figure 3). Coverage sought to edge match existing quality multibeam data, re-survey portions of prominent seamounts with poor multibeam data, or cover portions of seamounts, ridges, and troughs as possible during transits to ROV dive sites.

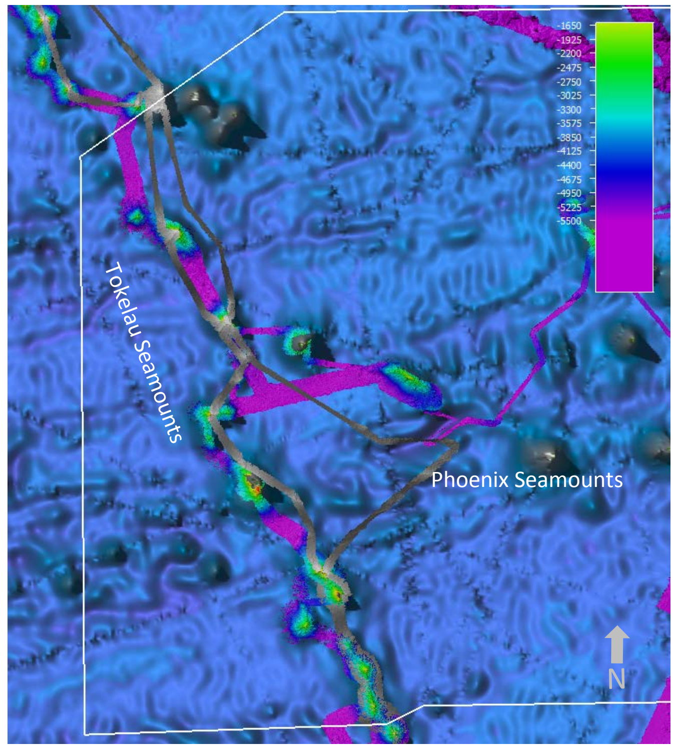


Figure 3. Multibeam coverage within PIPA. Coverage prior to EX-17-03 is shown in rainbow color ramp. Coverage collected during EX-17-03 is shown in the grey scale color ramp. The white line shows the boundary of PIPA.

<u>Un-named Seamount ("Maibua")</u>

One of the most interesting features mapped during this cruise and EX-17-01 was an un-named seamount called "Maibua" for ROV dive planning purposes. The seamount is located at -173° 57.0' W, -5° 24.6' S within the Tokelau Seamount chain. The seamount has three separate prominent and very steep summit features, and an extensive area of apparent mass wasting slumping on its southern slope.

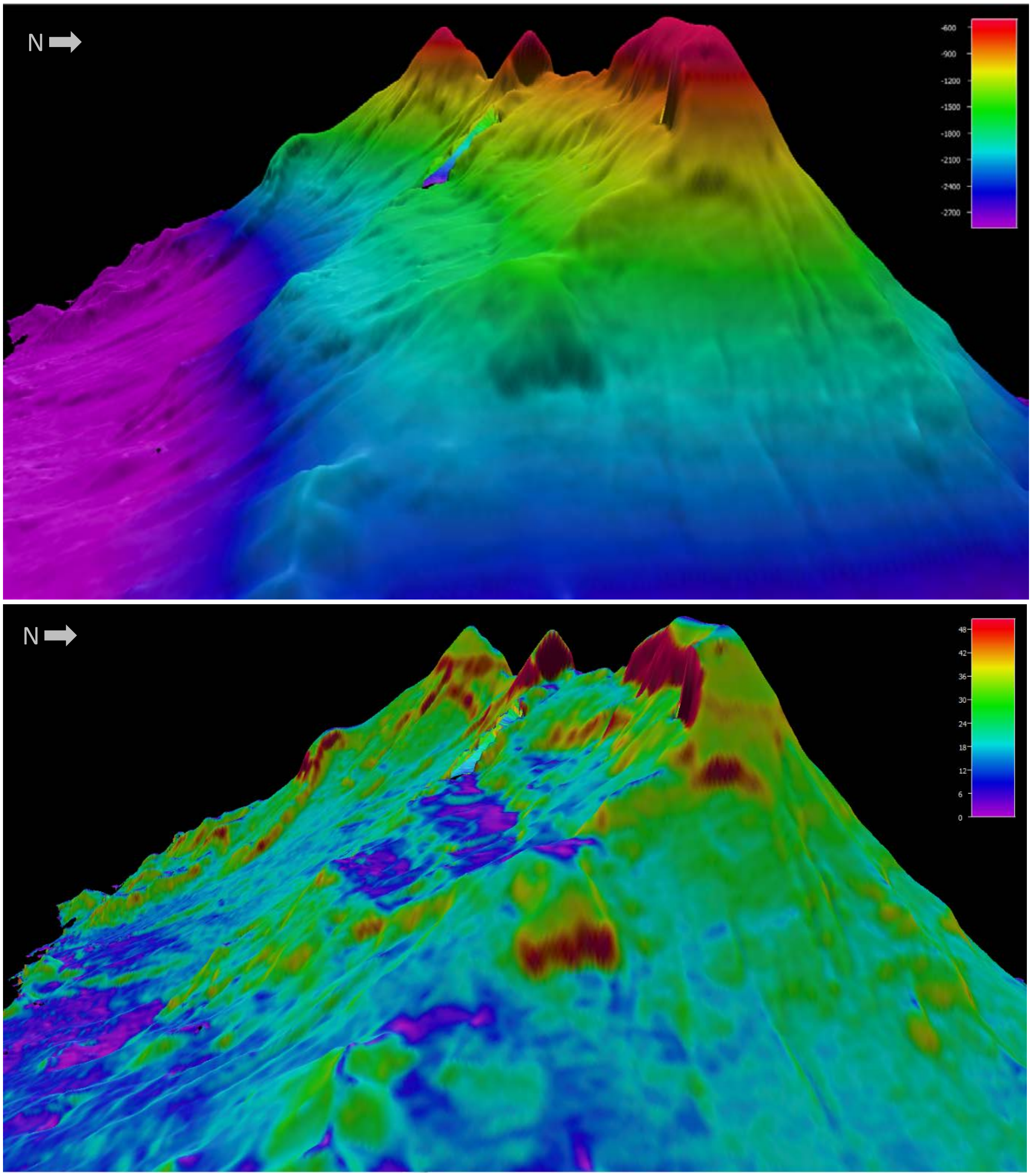


Figure 4. 3D oblique view of multibeam bathymetry of the "Maibua" seamount (top) and derived percent slope for the feature (bottom). Note the very steep (>40%) summit scarps and the stepped slump features clearly shown in the slope map. Figure made in QPS Fledermaus software at 3x vertical exaggeration.

Hadal Trough Feature

Close to the center of PIPA is an unusually deep trough feature in the shape of a gentle S-curve. The feature is approximately 105 km in length and located at -173° 02.0’ W, -4° 19.0 S. The deepest depths measured by the multibeam sonar indicate that the feature is up to 6,350 m deep. Given the depth of the feature it was nicknamed “Hadal Trough” or “Hadal Hole” during cruise planning. The ROV dive site called “Kinono” was conducted on the southern wall of the feature down to the maximum depth range of the ROVs (6000 m).

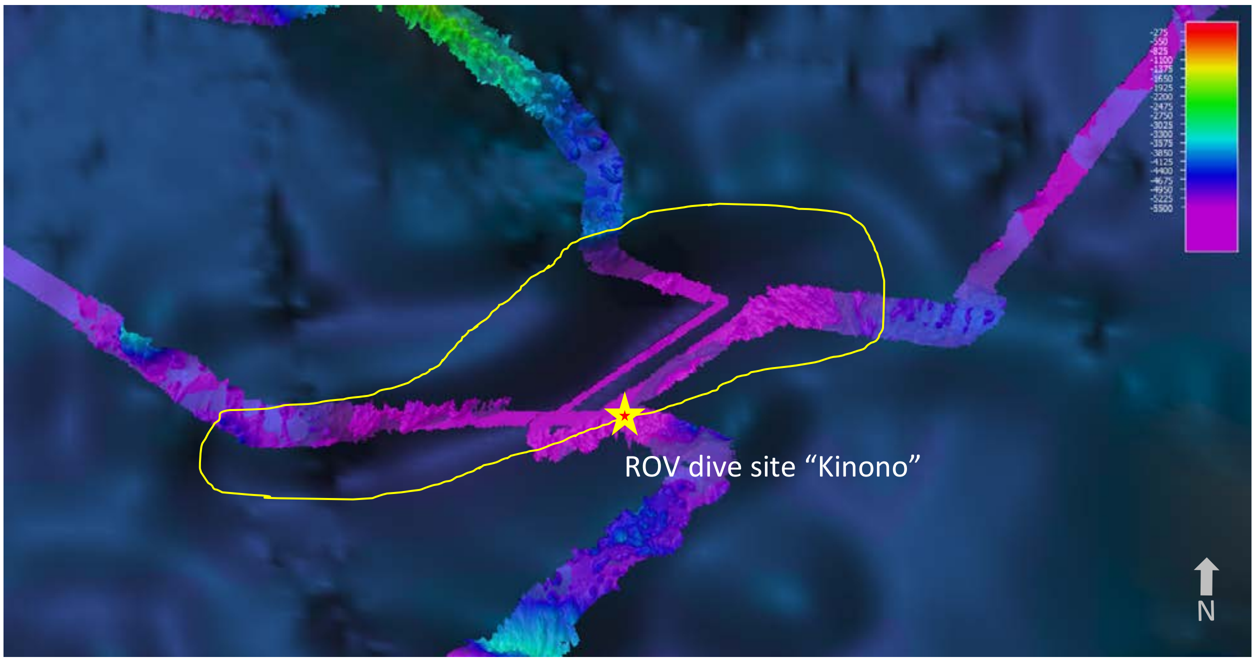


Figure 5. Bathymetry data from the Okeanos Explorer (rainbow color ramp) shown with the background SRTM30 grid. The yellow outline shows the general vicinity of the isolated deep trough feature referred to during the cruise as “hadal hole” or “hadal trough”. The ROV dive location is marked with a star.

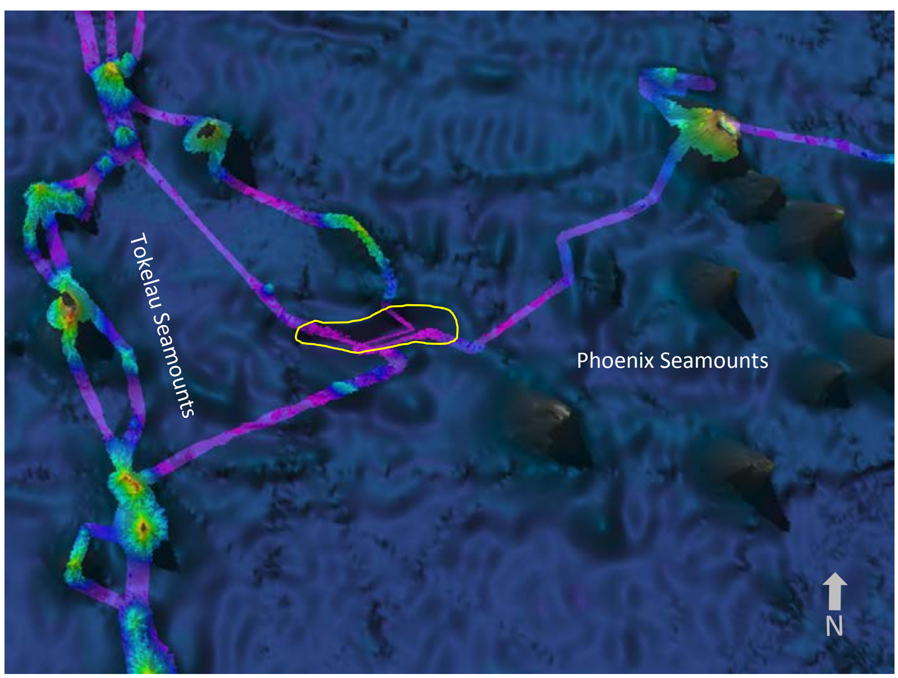


Figure 6. The location of the deep feature relative to the surrounding Phoenix and Tokelau seamounts groups.

Winslow Reef

One of the least explored (and potentially one of the most interesting) areas within PIPA is in the vicinity of Winslow Reef at the far northwest portion of the protected area. While safety and time constraints on this expedition prevented the mapping and exploring of Winslow Reef itself, the ship did have the opportunity to map about half of a prominent un-named seamount feature immediately west of Winslow Reef (-175° 12.4’ W, -1° 36.8’ S). This seamount is divided approximately in half by the boundary between PIPA (Kiribati EEZ) and the United States EEZ surrounding Howland and Baker Islands, and ROV dives were conducted on the seamount on both sides of the boundary. Based on the SRTM30 bathymetry grid available for the area the seamount looked like one feature with an elongated summit. Mapping with the ship’s multibeam revealed a very different morphology, with a distinct southern round summit feature and a much shallower and steeper northern summit feature (figures 7 and 8).

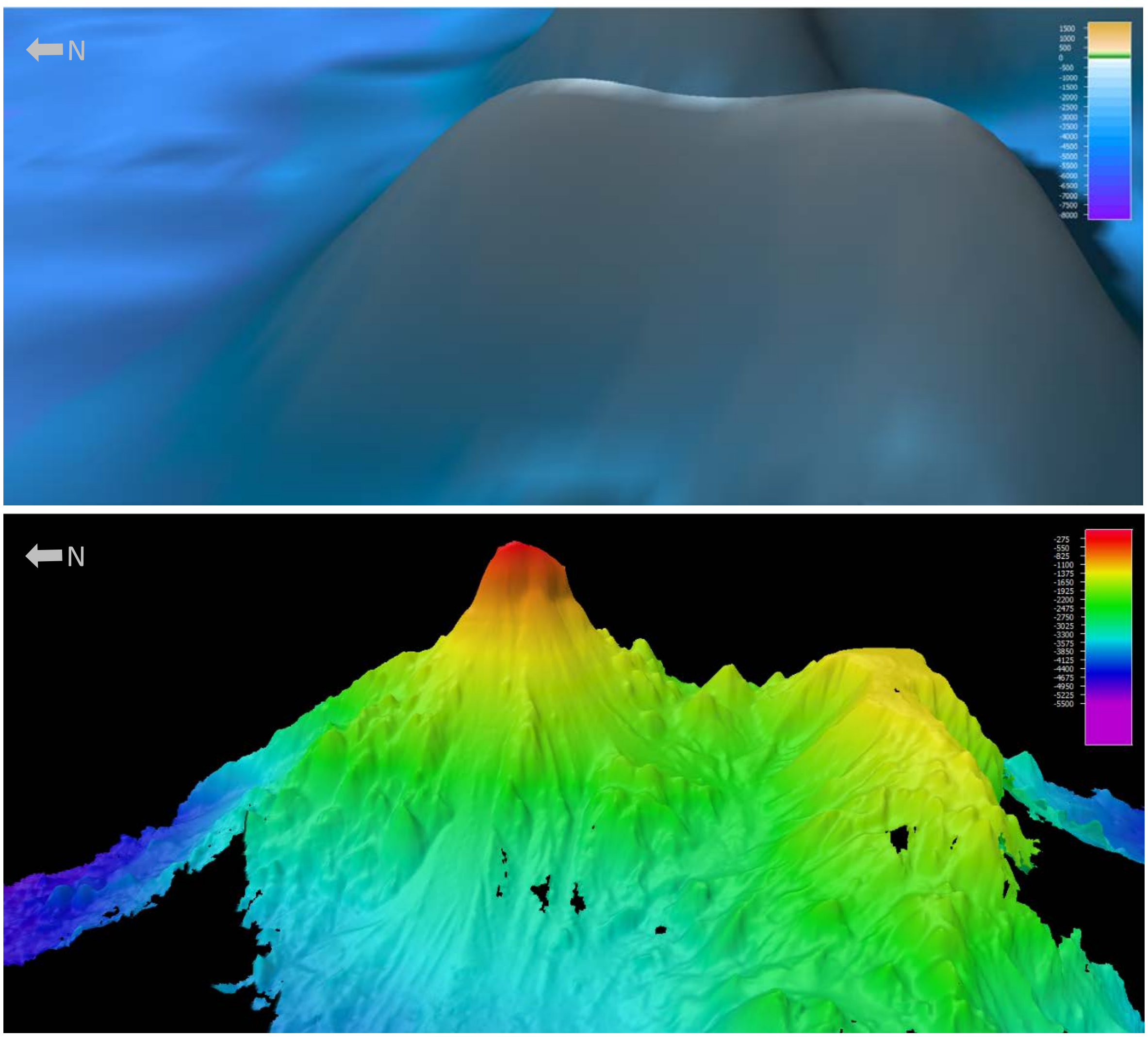


Figure 7. Un-named seamount west of Winslow Reef as shown in the satellite data-derived SRTM30 bathymetry grid (top) compared to multibeam sonar bathymetry grid collected during EX-17-03. The northern summit feature of the seamount reached as shallow as 230 m below sea level. Image made in QPS Fledermaus software, 3x vertical exaggeration.

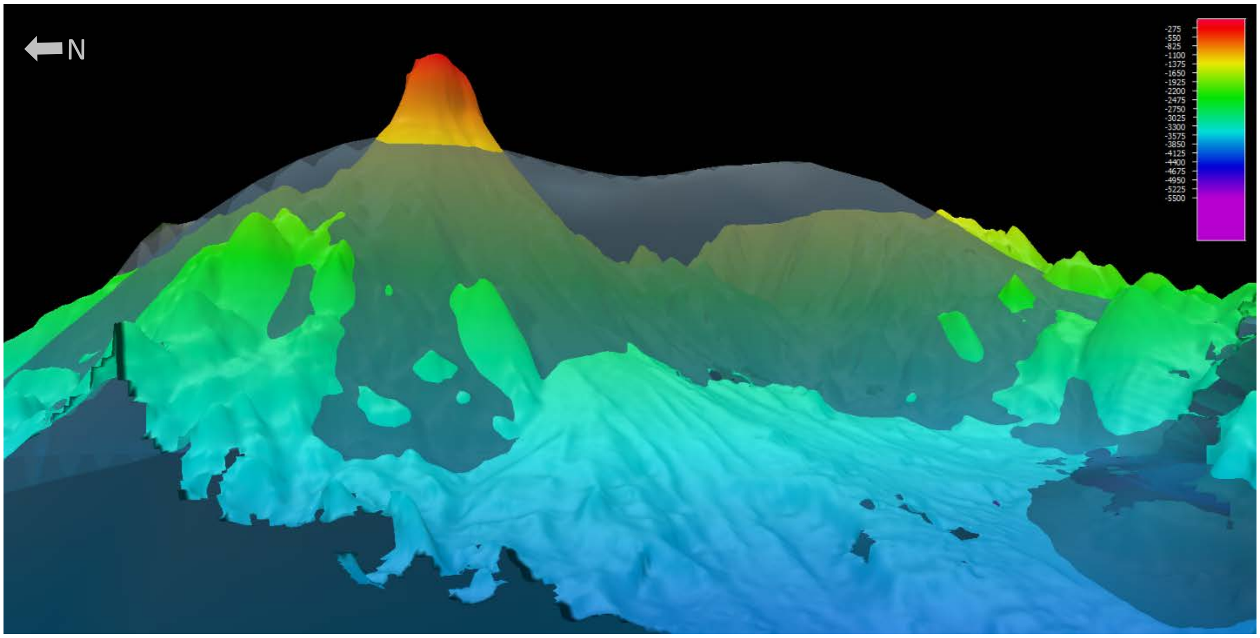


Figure 8. Comparison of the SRTM30 grid (transparent grey) and EX-17-03 bathymetry (rainbow color ramp). Note the 950m difference between the actual top of the seamount and the estimated seamount depth surface from the SRTM30 model. Previous comparisons between the Okeanos ship-based multibeam measurements and the SRTM30 grid have noted up to 1400m of difference in predicted depth elevations due to grid resolution constraints of the satellite/gravity models. The depth scale bar is for the EM302 multibeam data collected by the *Okeanos Explorer*. Image made in QPS Fledermaus software, 3x vertical exaggeration.

Example Highlight Features Within the Howland and Baker Islands Unit of the Pacific Remote Islands Marine National Monument (PRIMNM)

Howland Island, Baker Island, and Titov Seamount are by far the most prominent features within PRIMNM, and were the focus of mapping and ROV dive work within the monument. High quality multibeam data grids for Howland and Baker Islands previously completed by the Pacific Islands Benthic Habitat Mapping Center (CRED, 2006) were very useful for ROV dive planning. Additional multibeam sonar mapping work was completed overnight in between daily ROV dives around Howland, Baker, and Titov. Surveying time was used to supplement coverage along the deeper base of these features as well as surveying adjacent previously unmapped seafloor areas as time allowed. Figure 9 shows previously collected and new EX-17-03 multibeam sonar coverage (mostly) within the boundaries of the Howland/Baker PRIMNM.

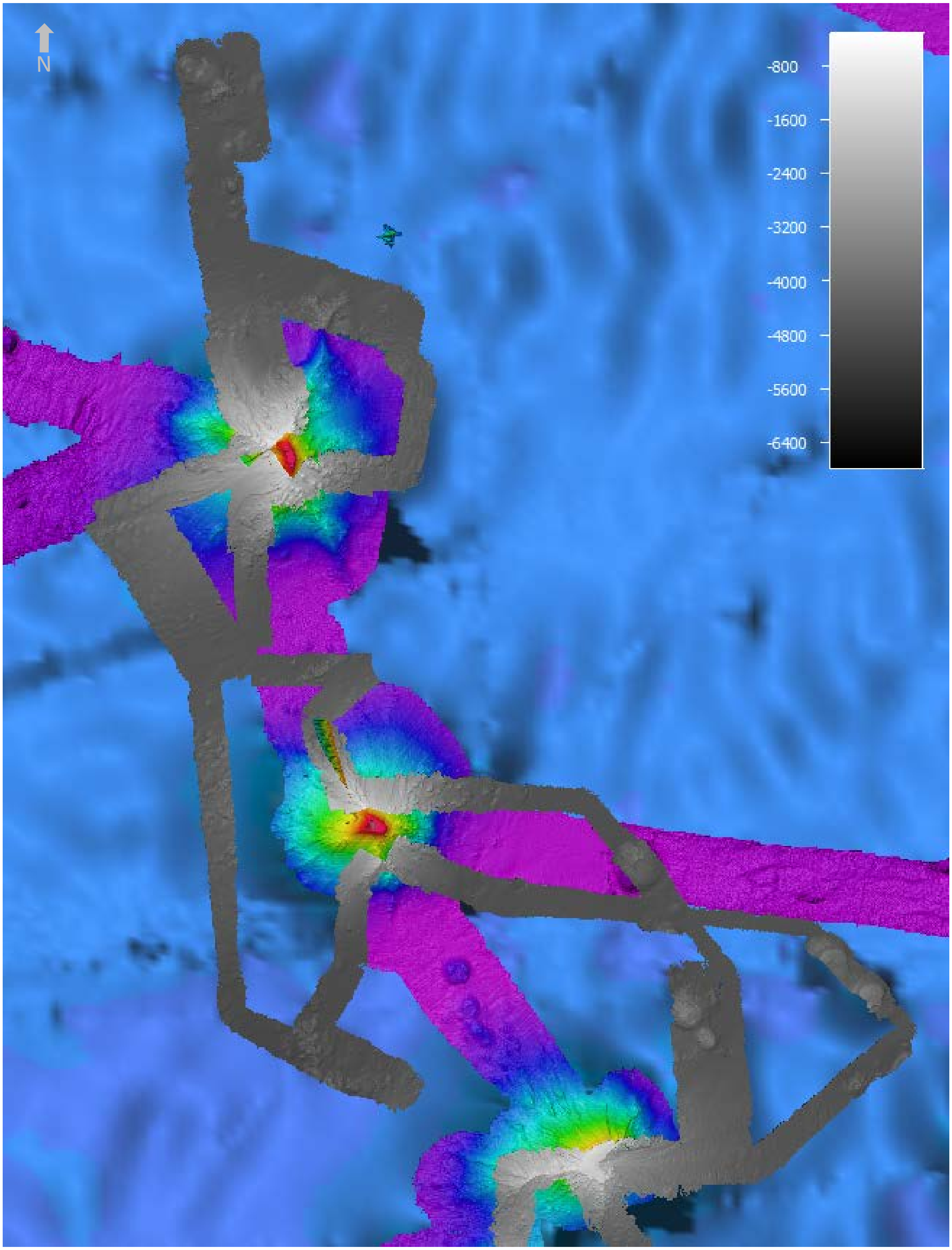


Figure 9. Coverage map of multibeam sonar bathymetry data from EX-17-03 (grayscale color ramp) and previously collected multibeam bathymetry data (rainbow color ramp). Example image centered at approximately -173° 34.5' W, -6° 28.5' S. Older data has some artifact features that should be ignored.

Titov Seamount:

Titov Seamount was one of the most impressive seamount features explored during the cruise, with a unique crescent-shaped 8 km wide flat-topped summit. The summit is located at -176° 07.5’ W, -0° 07.5’ S, within the southeastern region of PRIMNM. Two ROV dives were conducted on the seamount during the cruise, which explored a ridge crest on the western side of the seamount as well as the western edge of the guyot summit. The summit was approximately 1100 meters deep.

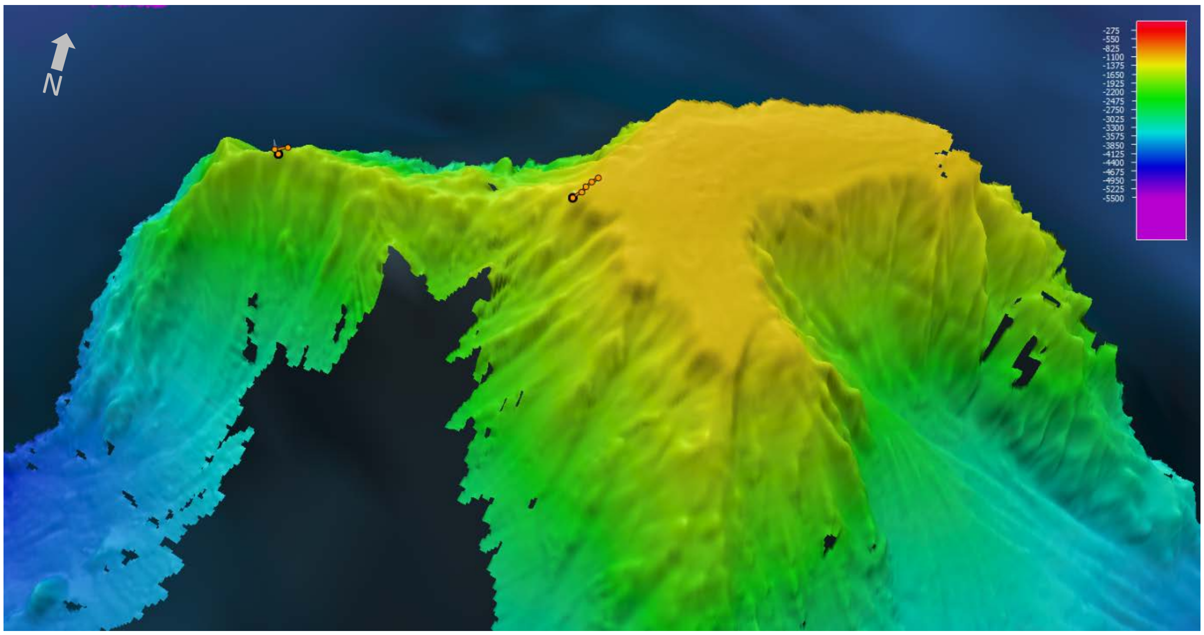


Figure 9. Oblique 3D perspective view of Titov Seamount bathymetry data collected during EX-17-03. Orange point/line features on the figure show the locations of the two ROV dives conducted on the seamount during the cruise. Figure created in Fledermaus software with 3x vertical exaggeration.

Baker Island:

Baker Island is a small uninhabited island owned by the United States and managed as a National Wildlife Refuge by the U.S Fish and Wildlife Service. It is an extremely important island for seabird populations in the region. The island is located at 0°11’41”N 176°28’46”W. Underneath the ocean surface, the island topography is very steep, with the atoll rising dramatically from the surrounding abyssal seafloor base depth of around 5400m. ROV dives were conducted at a relatively shallow site near the island, as well as along a deeper ridge.

Figure 10 (right). Aerial image from Google of Baker Island. The whole island is very low relief. Just outside the shallow light blue waters the terrain drops off steeply.

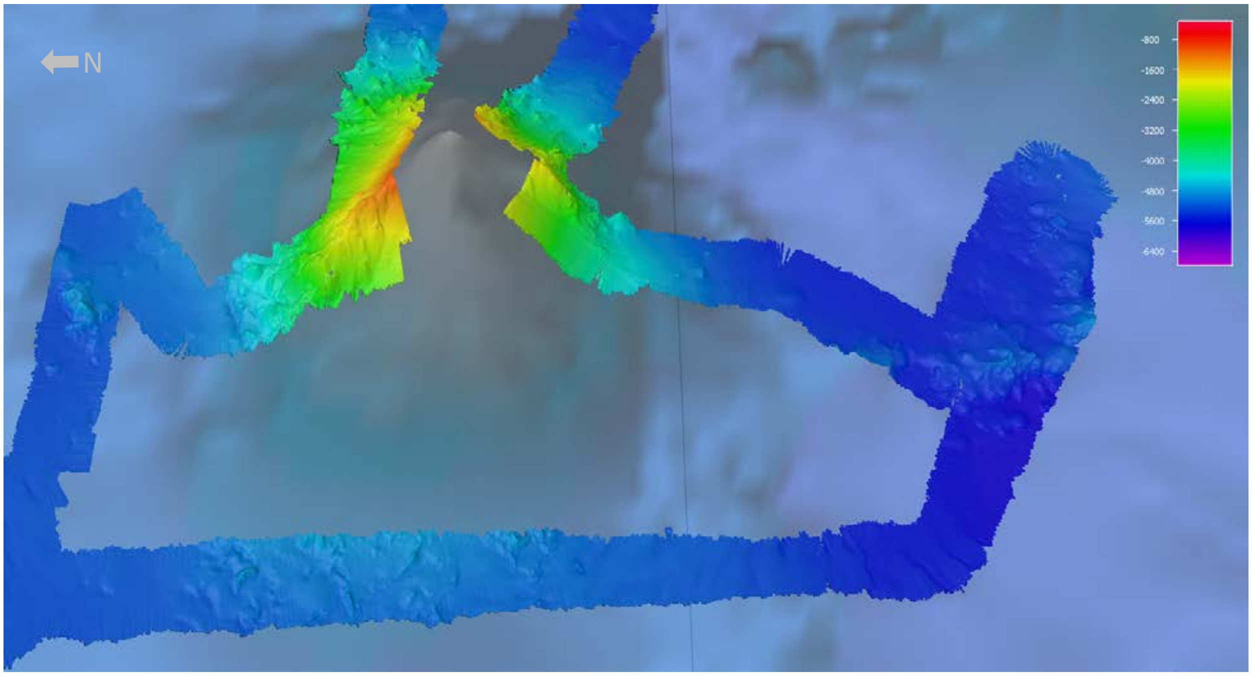


Figure 11. Oblique 3D perspective view of Baker Island bathymetry data collected during EX-17-03. Background bathymetry is the SRTM30 grid. Figure created in Fledermaus software with 3x vertical exaggeration.

Howland Island:

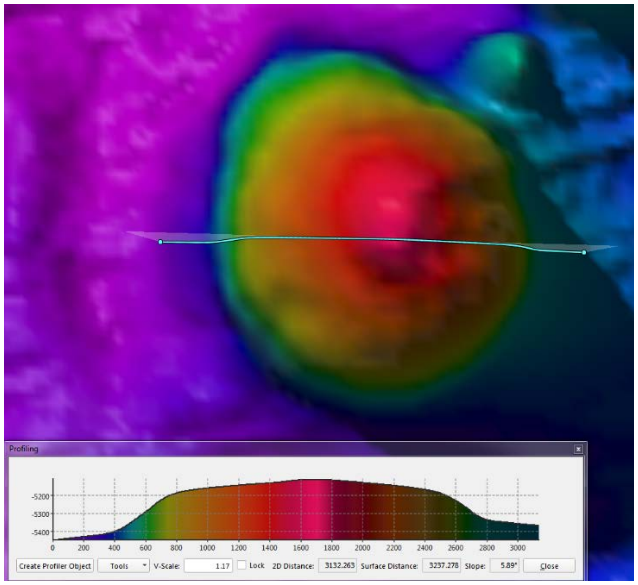
Approximately 41 miles north of Baker Island lies Howland Island – another small uninhabited island owned by the United States and managed as a National Wildlife Refuge by the U.S Fish and Wildlife Service. It is also an extremely important island for seabird populations in the region. The island is located at 0°48′24″N 176°36′59″W. Like Baker Island, the undersea topography is very steep, dropping off quickly into deep water. Three ROV dives were completed near the island – two deep and one shallow dive. Groups of unidentified dolphins or porpoises were spotted on the north side of the island during the shallow ROV dive.

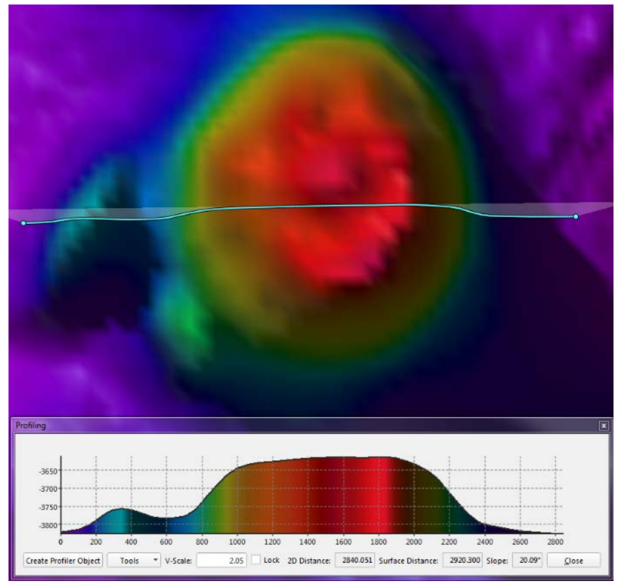
Figure 12 (right). Aerial image from Google of Howland Island.

"Pancake Dome" Features

At various locations during the cruise low relief isolated geological features with steep sides, and broad circular flat-topped summits were mapped at abyssal ocean depths. Some of the features show crater structures at their summits. Features like these have been frequently mapped by the *Okeanos Explorer* in the Pacific Ocean. Although common, these features appear to be poorly explored or characterized. A 1995 paper in Geophysical Research Letters by

Bridges compared the morphology of these features to pancake dome volcano structures that have been mapped on the surface of the planet Venus. A selection of the features are shown below as examples.



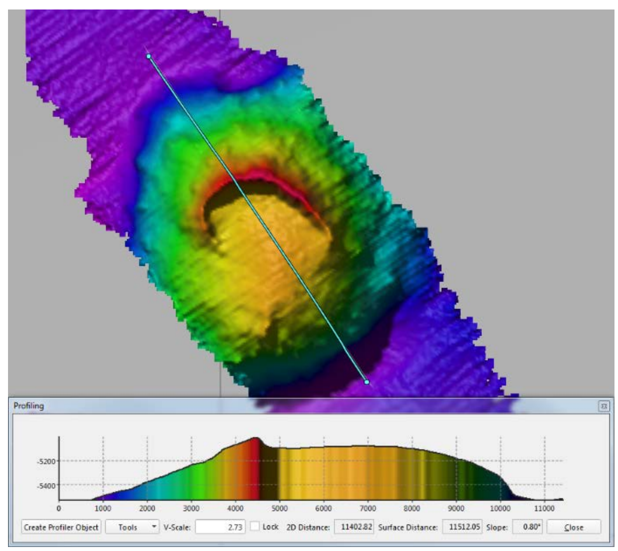


Figures 13 (top left), 14 (top right), and 15 (bottom right). Examples of "pancake dome" structures mapped during EX-17-03. Each bathymetry image is shown in plan view, with the blue line indicating a cross-section profile of the bathymetry. The inset windows show the profile, with horizontal distance in meters along the x-axis and vertical distance in meters along the y-axis.

The feature in figure 13 is located at -176°41.0'W, 1°16.6'N.

The feature in figure 14 is located at -172°21.2'W, -10°19.8'S.

The feature in figure 15 is located at -175°59.0'W, 0°06.6'N.



Summary of Mapping Accomplishments by Jurisdiction

Table 2. Approximate area mapping statistics within each of the ocean management jurisdictions traversed during the cruise.

Jurisdiction	Square Kilometers Mapped
Samoa	2,100
American Samoa	2,500
Tokelau	8,000
Kiribati (PIPA)	9,200
U.S. EEZ	8,300
Howland/Baker PRIMNM (subset of U.S EEZ area)	(6,600)
Total	30,100

5. Mapping Statistics

Dates	**March 7 – March 29, 2017**
Linear kilometers of survey with EM302	**5,100**
Square kilometers mapped with EM302	**30,100**
Number / Data Volume of EM 302 raw bathymetric / bottom backscatter multibeam files	**405 files/ 20.6 GB**
Number / Data Volume of EM 302 water column multibeam files	**405 files / 75.6 GB**
Number / Data Volume of EK 60 water column singlebeam files	**165 files / 27.1 GB**
Number / Data Volume of subbottom sonar files	**487 files / 4.53 GB**
Number of XBT casts	**46**
Number of CTD casts (including test casts)	**0**

6. Mapping Sonar Setup

Kongsberg EM302 Multibeam Sonar

The NOAA Ship *Okeanos Explorer* is equipped with a 30 kHz Kongsberg EM 302 multibeam sonar capable of mapping the seafloor in 0 to 8000 meters of water. The system generates a 150° beam fan containing up to 432 soundings per ping in waters deeper than 3300 meters. In waters less than 3300 meters, the system is operated in multiping, or dual swath mode, and obtains up to 864 soundings per ping, by generating two swaths per ping cycle. The multibeam sonar is used to collect seafloor bathymetry, seafloor backscatter, and water column backscatter. Backscatter represents the strength of the acoustic signal reflected from some target, whether the seafloor or bubbles in the water column.

Kongsberg EK-60 Split-Beam Sonars

The ship is also equipped with four Kongsberg EK 60 split beam fisheries sonars, 18, 70, 120, and 200 kHz. The 18 kHz transducer and transmits a 7° beam fan. These sonars are quantitative scientific echosounders calibrated to identify the target strength of water column acoustic reflectors - typically biological scattering layers, fish, or gas bubbles – providing additional information about water column characteristics and anomalies.

Knudsen Sub-bottom Profiler

Additionally the ship is equipped with a Knudsen 3260 subbottom profiler that produces a frequency-modulated chirp signal with a central frequency of 3.5 kHz. This sonar is used to provide echogram images of shallow geological layers underneath the seafloor to a maximum depth of about 80 meters below the seafloor. The Sub-bottom profiler is normally operated to provide information about the sedimentary features and the bottom topography that is simultaneously being mapped by the multibeam sonar. The data generated by this sonar is fundamental in helping geologists interpret the shallow geology of the seafloor.

Teledyne ADCPs

The ship utilizes a 38kHz Teledyne RDI Ocean Surveyor Acoustic Doppler Current Profiler (ADCP), with a ~1000 m range; and a 300 kHz Teledyne RDI Workhorse Mariner ADCP, with a ~70 m range. The ADCPs gather data prior to ROV deployments in order to assess currents at the dive site in support of safe operations. They are kept running throughout the ROV dives. The ADCPs are typically not run concurrently with the other sonars due to interference issues.

7. Data Acquisition Summary

Mapping operations included EM 302 multibeam, EK 60 singlebeam, Knudsen subbottom profile, and ADCP data collection. The schedule of operations included overnight transit mapping and mapping whenever the ROV was on deck. Lines were planned to maximize either edge matching of existing data or data gap filling in areas where existing bathymetry coverage existed. In regions with no existing data, exploration transit lines were planned to optimize potential discoveries. Approximately 30,100 square kilometers of seafloor were mapped.

Throughout the cruise, multibeam data quality was monitored in real-time by acquisition watchstanders. Ship speed was adjusted to maintain data quality as necessary. Most of the mapping was conducted along transit lines, however in places where focused surveying was conducted, line spacing was planned to ensure at least ¼ swath width overlap between lines at all times. Cutoff angles in SIS were generally adjusted on both the port and starboard side to ensure the best data quality and coverage. Archived sonar data products are in Field Geographic WGS84 coordinates, with vertical reference in meters undefined since all of the depth measurements are relative to the water surface during the time of surveying. With the vast majority of surveying completed in very deep water, depth measurements were not adjusted for tides, as they are essentially insignificant as a percent of overall water depth.

8. Multibeam Sonar Data Quality Assessment and Data Processing

EM302 Built-in Self Tests (BISTs) were run throughout the cruise to monitor multibeam sonar system status and are available as ancillary files in the sonar data archives. Raw multibeam bathymetry data files were acquired by SIS, then imported into QPS Qimera multibeam sonar processing data. In Qimera, attitude and navigation data stored in each file were checked, and erroneous soundings were removed using Swath Editor, Slice Editor, and 3D Editor tools. Gridded digital terrain models were created and posted to the ship’s ftp site for daily transfer to shore. Bathymetric grids were used for detailed ROV dive planning and initial QC checks. Final bathymetry QC was completed post-cruise onshore at the Center for Coastal and Ocean Mapping at the University of New Hampshire.

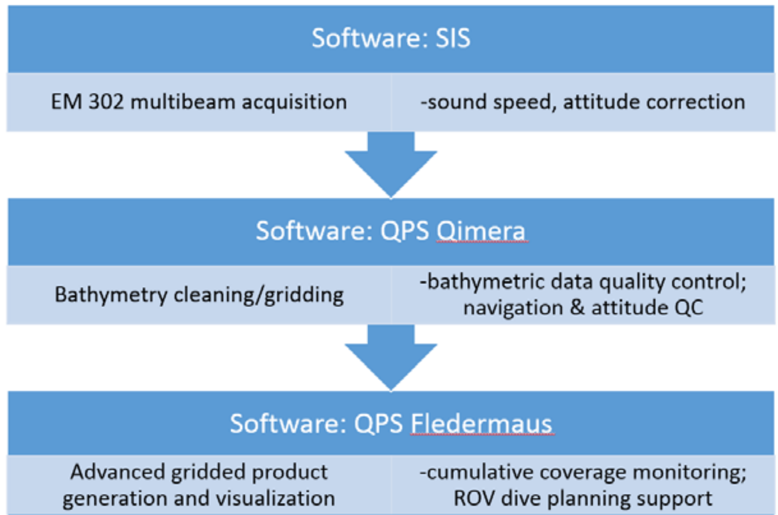


Figure 16. Shipboard multibeam data flow.

Crosslines

Comparing depth values from orthogonal survey lines is a standard hydrographic quality control measure to evaluate the consistency of the multibeam sonar data being collected during a cruise. Crossline analysis was conducted using the Crosscheck Tool in QPS Qimera software. This tool compares bottom detection soundings from the selected crossline with a dynamic surface digital terrain grid, and generates statistics to describe how closely they match. Two different crossline checks were examined for EX-17-03, one in very deep water (5340m) and one covering a variety of depth ranges between 3000-4600 m. Figures 17-20 provide plan views and data plots for the crosslines. Results of the crossline comparison indicate that the multibeam system was performing well during the cruise, and is well within International Hydrographic Organization (IHO) quality requirements for an Order 1 survey. Summary statistics results are shown below in Table 1. The larger range of differences in crossline comparison two are due to the much more complex and variable terrain surveyed.

Table 1: Depth difference statistics for EX-17-03 crossline comparisons 1 and 2.

Statistics	Crossline Comparison 1	Crossline Comparison 2
Mean	4.37 m	-8.50 m
Median	4.64 m	3.22 m
Minimum	-14.42 m	-91.6 m
Maximum	23.72 m	95.13 m
Standard Deviation	3.16 m	9.01 m
# of points compared	44,543	65,723
Meets IHO Order 1?	Yes	Yes

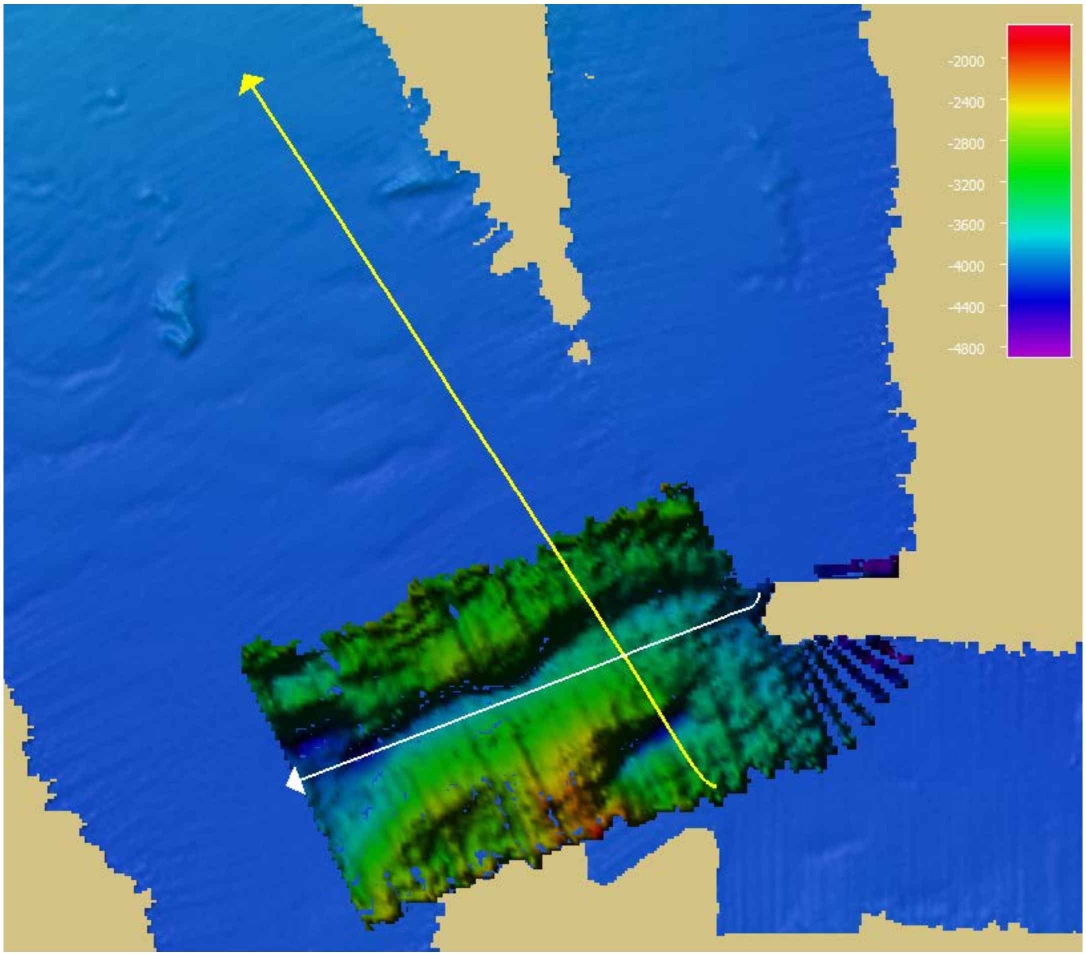


Figure 17. Crossline comparison 1. Plan view of 100m dynamic surface bathymetry grid created from multibeam data line 184 compared with data from line 244 (yellow line).

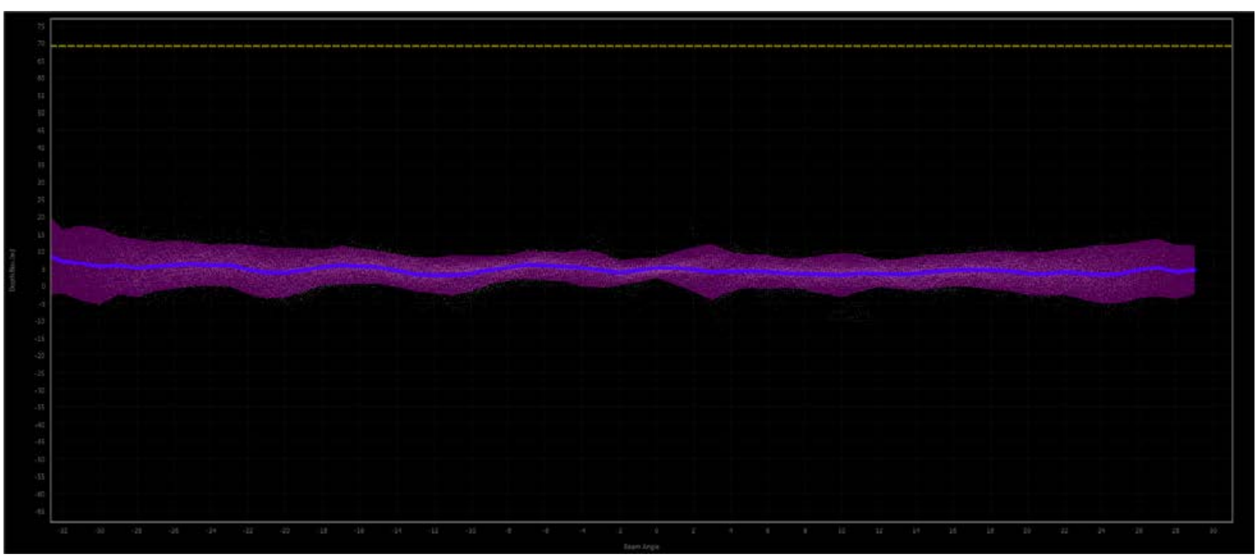


Figure 18. Scatter plot of differenced depth values from crossline comparison 1. X-axis is beam angle and y-axis is depth bias in meters. The blue line represents the mean value, purple area is the 95% confidence interval, and the yellow line represents the vertical tolerance limit defined for this depth according to IHO Order 1 requirements. Mean difference is 4.37m.

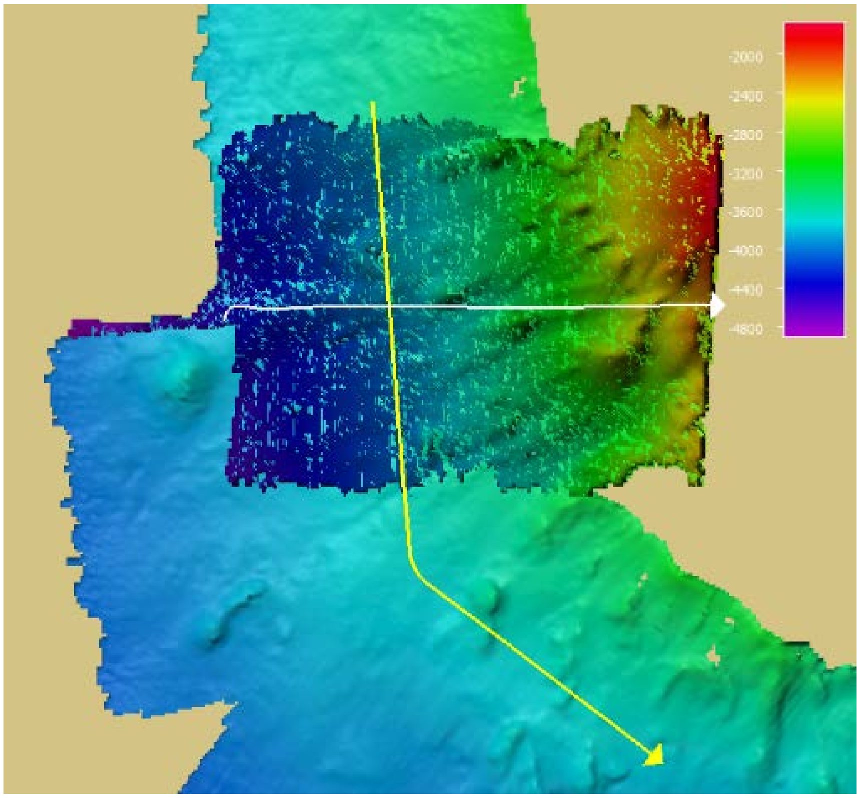


Figure 19 (left). Crossline comparison 2. Plan view of 75m dynamic surface bathymetry grid created from multibeam data line 346 compared with data from line 341 (yellow line).

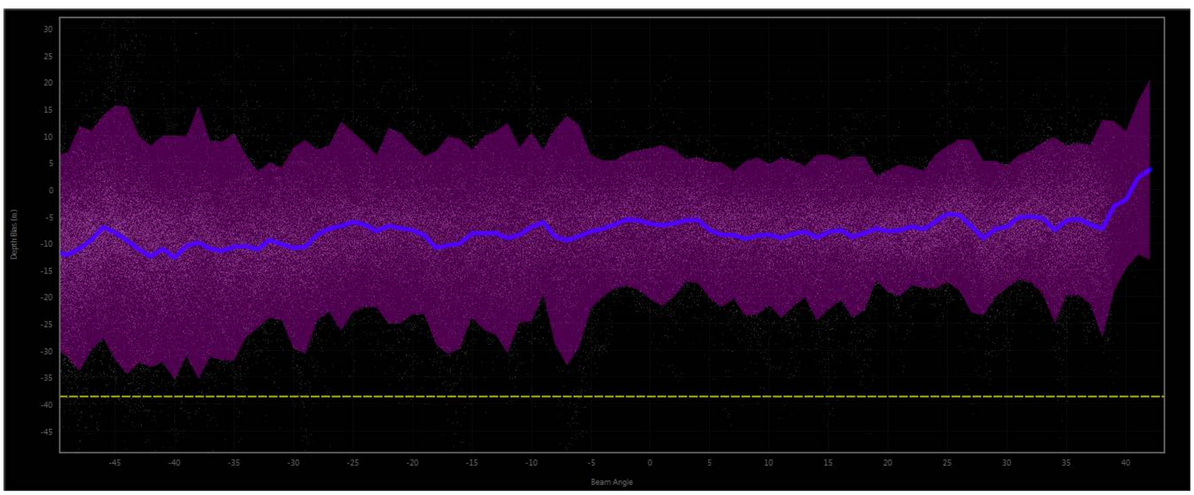


Figure 20. Scatter plot of differenced depth values from crossline comparison 2. X-axis is beam angle and y-axis is depth bias in meters. The blue line represents the mean value, purple area is the 95% confidence interval, and the yellow line represents the vertical tolerance limit defined for this depth according to IHO Order 1 requirements. Mean difference is -8.50 m.

9. Data Archival Procedures

All mapping data collected by *Okeanos Explorer* are archived and publically available within 90 days of the end of each cruise via the National Centers for Environmental Information (NCEI) online archives. The complete data management plan which describes raw and processes data formats produced for this cruise is available as an appendix in the project instructions.

10. Cruise Calendar

March 2017						
Sun	**Mon**	**Tues**	**Wed**	**Thur**	**Fri**	**Sat**
5	6	7 Start of cruise. Depart port from Apia, Samoa.	8 Overnight mapping. Swains Island ROV dive (dive 1).	9 Transit mapping en route to "PaoPao" dive site.	10 Overnight mapping, "PaoPao" ROV dive (dive 2).	11 Overnight mapping, ROV dive Carondolet Reef (dive 3).
12 Overnight mapping, ROV dive on "Athena" dive site on un-named seamount (dive 4).	13 Overnight mapping, ROV dive on "Polo" dive site on un-named seamount (dive 5).	14 Overnight mapping, ROV dive on un-named Seamount near Winslow Reef (US EEZ, dive 6).	15 Overnight mapping, 1st Titov Seamount ROV dive (dive 7).	16 Overnight mapping, Baker Island shallow ROV dive (dive 8).	17 Overnight mapping, Howland Island deep ROV dive (dive 9).	18 Overnight survey mapping near Howland, Howland Island shallow ROV dive (dive 10).
19 Overnight survey mapping near Howland, 2nd Howland Island deep dive (dive 11).	20 Overnight mapping, Baker Island deep ROV dive (dive 12).	21 Overnight mapping, 2nd Titov Seamount ROV dive (dive 13).	22 Overnight mapping, 2nd ROV dive near Winslow Reef (PIPA, dive 14).	23 Overnight mapping, "Teutana" ROV dive (dive 15).	24 Overnight mapping to "Hadal Trough" area, ROV dive on "Kinono" (dive 16).	25 Overnight mapping to area near Carondelet Reef, ROV dive at "Maibua" (dive 17).
26 Overnight mapping, ROV dive "Te Kaitira" (dive 18).	27 Overnight mapping, Ufiata ROV dive (dive 19).	28 Overnight mapping and daytime transit mapping.	29 Enter port in Apia, Samoa. End of cruise.	30 Demobilization.	19	20

11. Daily Cruise Log Entries

Generated from the daily expedition situation reports. All times listed are in local ship time (+13 hours from UTC)

March 7

All mapping sonars worked normally and without problems. The EM302 passed all BIST tests on the first attempt. Multibeam mapping was done as soon as we left the pier and data was gathered leaving the port. Multibeam data out to 12 nm was collected and isolated for the time being until territorial sea permission paperwork issue fully resolved. After 12 nm, EK60, SBP, and the multibeam were run normally as public data. The first day was all transit mapping out to Swain's Island. The dive target area at Swains was already well mapped, so dive maps were provided to the science and ROV Team ahead of time. Manual handheld XBT casts are being done for the first few days before we switch to the XBT autolauncher - this provides some time for equipment maintenance and avoiding XBT wax melting in the hot temperatures outside. The transit line for the 36 hour transit to the second dive site (PaoPao) was finalized and delivered to the bridge. The overnight mapping watch schedule was established. The UCTD winch that was sent back to Teledyne for repair had its clutch replaced and is being sent to the port office on Ford Island.

March 8

Seas were calm and ideal for survey operations all day. Upon arrival at the Swain's dive site, the ADCPs were switched from passive logging mode to active and run for the course of the dive. The ADCP speed plot for the ROV and Bridge worked normally (in contrast to problems experienced at times during the last cruise). Following dive ops, the mapping sonars all started and ran normally with high quality data, and the 36 hour transit to PaoPao was begun. There is an interference in the 38 kHz EK60 (likely the multibeam) that Derek is working to improve by modifying the synchronization settings in the EK80 software. The dive track for PaoPao was tentatively finalized, and a quick review of the proposed dive on Carondolet Reef was conducted with the Science Team.

March 9

Overnight data quality was high. Seas were mild and favorable. There was a display issue with SIS, with the swath pings not gridding as normal in the geographical display window. This was resolved with a quick open/close of SIS opportunistically completed during the man overboard drill ship maneuvers. Mapping was conducted all day while we continued the long transit to PaoPao dive site. One XBT was a dud late in the evening. Swath widths have been very good on the multibeam.

March 10

PaoPao seamount had mostly been mapped on EX1701, however the eastern section of the summit was unmapped. This was completed at the end of the overnight watch, revealing a very dramatic steep eastern wall. The data was quickly cleaned and gridded in Qimera and an early morning meeting was held to modify the dive plan based on the new bathymetry and updated current information from the ADCPs. Transit and dive plans for Carondelet Reef were completed, and a draft dive plan for the Athena dive site was determined on the dive planning call. Hypack survey would not open for our current project. We copied the project and re-tried it – worked normally. This problem may have been related to MS Windows updates which were pushed from shore onto mission computers last night. The ST is getting the XBT autolauncher maintained and ready for service on this cruise. Overnight mapping towards Carondelet Reef is planned.

March 11

Overnight mapping to Carondelet Reef went smoothly with good data quality even at high transit speed. The XBT autolauncher was used today. The first cast had a problem with large spikes and was not acceptable. The second cast worked perfectly. Following the ROV dive, we mapped holidays over unnamed seamounts northwest of Carondelet Reef – most of these features had been mapped on EX1701. Strong currents and some wind/waves prevented making the planned speed towards Athena dive site. The transit track was modified to save some time, but arrival may be a little bit late. The transit will map over a seamount unmapped with multibeam and shown as “Gardner” on the PIPA website map. Derek is working on a mission log about mapping for the webpage.

March 12

Mapping to dive site “Athena” went well, with an on-time arrival. We transited over an un-named seamount southeast of Nikumaroro Island with a summit at 2718 m. We then edge mapped multibeam data from EX1701 until reaching the dive site at Athena. The dominant eastern currents and waves have made for slower transit speeds than earlier in the expedition. All sonars are working well. The 38 kHz EK60 is in passive mode since it was getting interference from the multibeam even when synced. The XBT autolauncher and SSPManager software are working well. Processing in Qimera is working well too. Dive tracks for site Polo were completed, but may be revised in the morning based on overnight mapping of the seamount.

March 13

Overnight mapping passes were completed over the dive site on un-named seamount “Polo”. The dive track was adjusted slightly based on the updated bathymetry. Following the dive, we transited towards the Winslow Reef seamount complex. Sea state is picking up somewhat with occasional bubble sweepdown. The XBT autolauncher had two casts terminate early – this is believed to be due to wind pushing the copper wire to touch the wire cam off the stern.

March 14

Overnight mapping conditions were challenging near Winslow Reef with strong currents and winds, large crab angles, and inconsistent bottom tracking performance from the multibeam. The system had many holes in deep mode – pushing it into very deep helped improved bottom tracking. We filled an important gap between the US-side Winslow seamount and the PIPA-side seamount to the east, but was not able to map the top of the PIPA seamount. We also mapped the dive site. The last minute data for the dive site was not used for final ROV waypoints as it appeared to agree fairly well with the older data at first. However, the newer data ended up showing some different slopes and final ridge crest elevation – later verified by the ROV dive. This makes us trust the older data less and we are pushing to dive only on new EX data to the extent feasible. The XBT autolauncher again had a mix of failed and successful casts – not clear yet if the failures are due to dud probes, the launcher, or bad wind gusts pushing the copper wire against the ship and terminating casts early. When it works it is very convenient, and the workflow to generate a profile for the multibeam has been improved through the use of the SSP Manager software. Overnight transit mapping to Titov Seamount commenced, with a plan to survey the dive site for the final last-minute ROV map for tomorrow's operations. Sun photometer measurements have been taken as possible since the beginning of the cruise.

March 15

Overnight mapping to Titov Seamount was completed. The multibeam had trouble bottom tracking over rough terrain at the end of the night in water depths around 1900 – switching from auto to very deep mode helped it greatly. We obtained very good data over the Titov dive site and used it to modify the dive track slightly first thing in the morning in consultation with the science leads and dive supervisor. Evening mapping includes a transit to our shallow dive site at Baker Island and a small focused survey of a completely unmapped area east of Titov Seamount inside PRIMNM boundaries. The auto XBT success rate is around 50%. We are using Joyce Miller 40m grids for dive planning around Howland and Baker Islands – these were downloaded directly from the HI Mapping Group webpage. The dominant east-west surface current makes for significant crab angles in this region.

March 16

Overnight mapping to Baker Island was completed with good data quality. The large missing hole at the top of Titov Seamount was mapped, as well as the dramatic eastern slope and channel system. A focused survey of an unmapped region northeast of Titov was completed, revealing two new "pancake" volcanoes. The rest of the night was transit mapping to the Baker Island shallow dive site. XBT autolauncher is not having a good reliability track record is being troubleshot. Manual XBTs were done today. Following the ROV dive, mapping focused on the northwest ridge of Baker Island to support planning for the deep dive to take place there in 2-3 days. A focused survey southwest of Howland Island is planned for overnight mapping.

March 17
A focused survey on an unmapped area southwest of Howland Island was completed. The area was a gently sloping "pillowy" looking seafloor at the foothills of Howland Island, with complex backscatter patterns. Transit times are slower than normal given the strong westward current in the region. Data quality was moderate to good. The ETs and ST worked on the XBT autolauncher today and got it running normally. Some loose wiring may have been the problem with its lack of reliability. Following the deep Howland dive, we transited northward to complete a small focused survey on an unmapped feature. We noticed an issue with Qimera static surfaces and found an improved workflow to generate better final grids. We are collecting some very interesting sub-bottom data in this region. All sonars working well.

March 18
Overnight mapping completed a focused survey directly north of Howland Island, revealing some small "pancake" volcanoes and an 800 m mountain. We mapped another approach to the north side of Howland en route to the Howland shallow dive site. A CTD cast was completed after ROV recovery. The hour long cast demonstrated that the CTD and altimeter worked, but that the Niskin bottle trigger system did not work. Overnight mapping is surveying the northern and eastern foothills of Howland (outside 12nm). The XBT autolauncher worked normally today.

March 19
Overnight mapping surveyed along the northern and eastern foothills of Howland (outside 12nm), then transited to the second dive we did in a deeper range near Howland Island. Data quality was good overall. After ROV recovery surveying began on the west and southwest side of Baker Island (outside 12 nm). The backup NAS drive for the Mapping drive is planned to be brought online in several days to get it fully operational before the end of the cruise.

March 20
Overnight surveying focused on the west and southwest side of Baker Island (outside 12 nm). Data quality was good. Following ROV recovery we began a mapping plan eastward toward an unmapped small seamount feature northeast of Titov Seamount and over to the dive site at the edge of Titov's guyot top.

March 21
Overnight mapping completed mapping of a two small pancake volcanoes northeast of Titov Seamount, then transited to the dive site at the edge of Titov's guyot top. The multibeam swath

width narrowed down to only about 2,000 m wide (half of normal) on parts of the abyssal plain – with the sub-bottom revealing that this was due to deep soft sediments up to 150 m deep. Following ROV recovery the ship began a direct transit as fast as possible to the Winslow PIPA dive site on an unnamed seamount. An additional line of data will be gathered near the top of the seamount and a last minute dive site will be selected. Andy Obrien is planning to get the mapping backup NAS fully functional tomorrow. Any impacts to mapped drives on mapping mission machines will be addressed.

March 22

Overnight mapping was a direct transit to the second dive site on the Winslow Reef region to dive on an unnamed guyot within PIPA. We obtained one new line of mapping data that revealed two distinct seamounts that appeared to be just one in the satellite-derived bathymetry. For the northern seamount we mapped half of the summit which reached a shoal depth of 220m. The southern guyot has a depth of about 1050m. The dive site was selected at 0600 on a northern promontory of the seamount. Qimera continues to be very useful for quickly turning raw multibeam data into base maps suitable for ROV dives. The XBT autolauncher is working well under the stewardship of ST Wilkins. Andy O'Brien got the Mapping NAS backup server online yesterday and is copying all of the data on the primary mapping server (J drive) to the new NAS. He is currently working to configure access to this backup drive from mapping mission computers. This backup has been an important item on the to-do list for the year and Mapping Team greatly appreciates the effort to get this accomplished on the current cruise. Sun photometer measurements are being taken whenever there is a cloud-free sky. All sonars working well and data quality was very good.

March 23

Overnight transit mapping was completed to the next dive site at an unnamed seamount northwest of McKean Island – we called this dive site Teutana based on the suggestion from Randi Rotjan. Mapping was done mostly on seafloor lacking any multibeam. We mapped a major ridge on the approach up the unnamed seamount and also discovered a small (just over 1000 m tall) seamount rising from the abyssal plain. The dive plan for Hadal Trough (nicknamed Kinono) was finalized. We began a long survey transit to Kinono that is slated to take about 14 hours. We departed the Teutana site about 45 minutes early to give ourselves more time for this long transit. Weather and sea state has remained favorable for surveying and data quality is high.

March 24

The long transit to Hadal Trough dive site (re-named to Kinono) was completed on time. During the transit we mapped the side of an unmapped seamount. The top of the slope we mapped was 1900 meters above the abyssal plain, indicating the presence of a significant-sized seamount not expected from the satellite-derived bathymetry. This region seems likely to have the potential for many of these features. The transit obtained a new line of multibeam over the hadal trough, showing a maximum depth of 6348 meters – which is consistent with the results obtained over this trough during EX1701. Data quality was very good. We began surveying operations at 1900 (2 hours later than normal) due to the late dive recovery, and began the mostly direct transit to dive site “Maibua” - an unnamed seamount NW of Carondelet Reef. AutoXBT failure rate seems to be around 30%. Current theory is that strong gusts of wind can make the XBT copper wire (streaming off the ship) touch the nearby wire cam causing termination of the cast. This has not been directly observed, but several successful casts were observed and the wire did get within a foot of the wire cam. Re-locating the wire cam further away from the autolauncher would potentially solve this problem and minimize XBT waste. Merger multibeam data from EX1701 and EX1703 is fairly easy in Qimera and has been useful in building high quality grids for dive planning.

March 25
Overnight surveying completed a direct transit from Hadal Trough (Kinono) dive site to Maibua (un-named seamount NW of Carondelet Reef). Data quality was very good, and we made good speed. Following the recovery we began edge mapping multibeam from EX1701 and EX1703 toward the next dive site called Te Kaitira. We have noticed significant vertical offsets on steep slopes between the bathymetry grid and the ROV depths sensors (up to 50 m difference). We are investigating how the settings selected during grid making may affect this issue (e.g. shoal-biased, median, weighted average, etc.) and will compare these different grids with ROV positions during the dive tomorrow to see if a change in SOP is needed.

March 26
An edge matching survey was completed overnight to the Te Kaitira dive site (unnamed seamount). Data quality was excellent. Swath coverage of up to 9.2 kilometers on the multibeam have been obtained. Following recovery of the ROVs, a transit was begun doing some edge mapping then transiting over a completely unmapped area showing a long potential ridge feature. Dive maps for the last dive on Ufiata Seamount were completed. PS Sowers worked with Andy O’Brien on an updated file directory structure for the primary mapping data server and the new mapping backup server. The backup server is working well and the mapping team now has a full separate backup system in place thanks to Andy’s work and the NAS procurement this year. The ROV-recorded depths of selected points from today’s ROV dive track were compared with several different bathymetry grids in Fledermaus to compare the difference between ROV and bathymetry grid depths. Depth differences ranged between 6-63 meters. The shoal-biased grid was found to have up to twice as much difference as the median and mean weighted average grid products. Median and mean weighted average grids were almost identical. The mean weighted average grids are standard output from Qimera and still

appear to be the best choice for ROV dive planning. For tomorrow's dive (shallow dive) we produced a 35m grid (instead of the more typical 50m) to try to reduce observed differences between the dive map and the depth the ROV is reporting. Sun photometer measurements continue to be taken whenever possible. AutoXBT launcher tube 8 had a failed attempt today. Other tubes worked normally.

March 27
Overnight mapping was transit between Te Kaitira and Ufiata dive sites. An interesting ridge feature rising out of the abyssal plains was partially mapped. Following ROV recovery from Ufiata we began the 40 hour transit back to port in Apia. The multibeam had multiple failed BIST tests. We tried restarting SIS, rebooting the TRU, restarting the computer, and power cycling all of the above without improvement. ST Wilkins and the ETs reseated the TX36 board in slot zero, then we brought the system up again – all BISTs passed. Troubleshooting cost us about an hour of survey time. Once working, data quality was excellent again. ETs and ST Wilkins are planning a deck test for the CTD tomorrow to try to get the bottle triggering to work.

March 28
We had excellent data quality overnight transit mapping on the way to Apia. Most of the night/day was spent edge mapping and completing a long ridge feature that had been started on EX1701. We then departed on a more straightline transit over seafloor lacking any multibeam and have mapped several small seamounts/pancake volcanoes on the way. The wire camera was moved higher up the flagpole today to make sure it was not in a position that might cause early terminations of the autoXBT casts (via wind pushing the wire into the camera housing). As a bonus, the camera is temporarily aimed at the autolauncher so we can directly see launches occur. EC Kennedy and Knauss Fellow Copeland helped PS Sowers with watchstanding the sonars during the day.

March 29
Overnight mapping continued until the ship approached the sea buoy outside the port of Apia where the ship was meeting the pilot boat. All sonars secured for the entry to port and end of cruise.

12. References

The 2016 Survey Readiness Report can be obtained by contacting NOAA Ship *Okeanos Explorer* at oar.oer.exmappingteam@noaa.gov.

Bridges, Nathan T. 1995. Submarine Analogs to Venusian Pancake Domes. Geophysical Research Letters, Vol. 22, No. 20, Pages 2781-2784, October 15, 1995.

The following data was used as background data during the cruise:

1) CRED, 2006. Gridded (40 m cell size) bathymetry of the shelf and slope environments of Howland Island, Pacific Remote Island Areas, Central Pacific.Coral Reef Ecosystem Division (CRED), Pacific Islands Fisheries Science Center (PIFSC), NOAA and Pacific Islands Benthic Habitat Mapping Center, School of Ocean and Earth Science and Technology, University of Hawaii. <http://www.soest.hawaii.edu/pibhmc/pibhmc_pria.htm>

2) CRED, 2006. Gridded bathymetry of Baker Island, Pacific Remote Island Areas, Central Pacific (40m). Coral Reef Ecosystem Division (CRED), Pacific Islands Fisheries Science Center (PIFSC), NOAA and Pacific Islands Benthic Habitat Mapping Center, School of Ocean and Earth Science and Technology, University of Hawaii. <http://www.soest.hawaii.edu/pibhmc/pibhmc_pria.htm>

3) National Center for Environmental Information (NCEI) Autogrid Multibeam Bathymetry Data Web Mapping Tool. https://www.ngdc.noaa.gov/maps/autogrid/

4) Sandwell, D. T., and W. H. F. Smith, Global marine gravity from retracked Geosat and ERS-1 altimetry: Ridge Segmentation versus spreading rate, J. Geophys. Res., 114, B01411, doi:10.1029/2008JB006008, 2009.

13. Ancillary Data

Ancillary data files are archived with the sonar dataset. These include:

1. Project Instructions
2. EM 302 Processing Parameters in use during the cruise
3. EM 302 Built In System Test (BIST) Results
4. Tables of Data File Logs
5. Daily Watchstander Log
6. Weather Log

Appendix A: Acronyms

AERONET – Aerosols Robotic Network
AHB – Atlantic Hydrographic Branch
ASCII – American Standard Code for Information Interchange
AUV - autonomous underwater vehicle
BIST – built in system test
CDR – Commander
CO – Commanding Officer
CTD – conductivity, temperature, depth
dB - decibel
DNP – do not process
EEZ - Exclusive Economic Zone
ERT – Earth Resources Technology Corp.
ET – Electronics Technician
EX – NOAA Ship Okeanos Explorer
FM – frequency modulated / modulation
FTP – file transfer protocol
FV - free vehicle
GB - gigabytes(s)
KB - kilobytes(s)
kHz – kilohertz
km – kilometer
kts – knots
LT – Lieutenant
LSS - light scattering sensor
m - meters
MAN – Maritime Aerosols Network
MB – multibeam sonar
MB – megabytes(s)
ms – millisecond
NASA – National Aeronautics and Space Agency
NCDDC – National Coastal Data Development Center
NCEI - National Center for Environmental Intelligence
NCCOS - National Centers for Coastal Ocean Science
NGDC – National Geophysical Data Center
NMEA – National Marine Electronics Association
NOAA – National Oceanic and Atmospheric Administration
NODC – National Oceanographic Data Center
OER – NOAA Office of Ocean Exploration and Research
OMAO – NOAA Office of Marine and Aviation Operations
OPS – Operations Officer
PRIMNM - Pacific Remote Islands Marine National Monument
PRT - Puerto Rico Trench
ROV – remotely operated vehicle
SBP – subbottom profiler

SCS – scientific computer system
SIS – Seafloor Information System
SST - Senior Survey Technician
SVP – sound velocity profile
TRU – transceiver unit
TSG - thermosalinograph
TX – transmit
UCAR - University Corporation for Atmospheric Research
UPRM - University of Puerto Rico, Mayaguez
USGS – United States Geological Survey
W - watt
XBT – expendable bathythermograph
XO – Executive Officer