A Monumental Mapping Mission:
A Collaborative Investigation of the Johnston Atoll Unit of the U.S. Pacific Remote Islands Marine National Monument

– Final Project Report for R/V *Falkor* cruise FK161229 –

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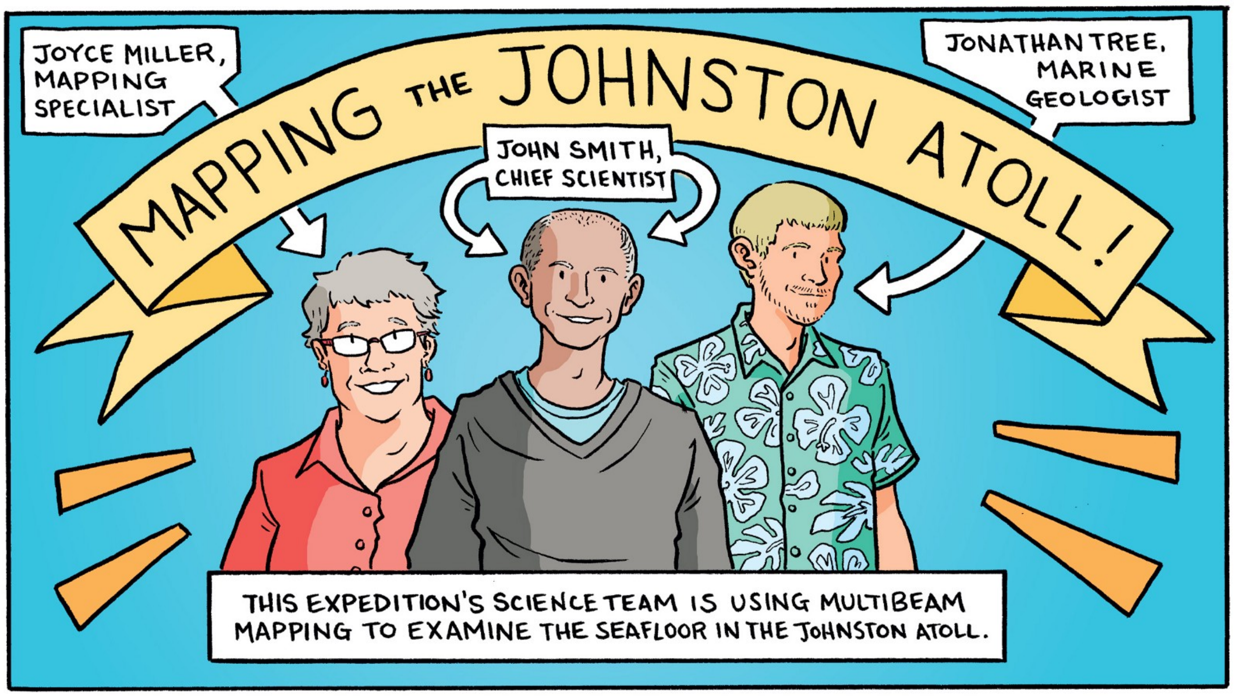


Fig. 1. The primary mapping science team members as depicted by Artist-at-Sea Lucy Bellwood.

Introduction and Background

Recent mapping and ROV telepresence-enabled expeditions to several of the U.S. Marine National Monuments in the Pacific Ocean have received great attention by the research community, school groups, and the general public. The NOAA Ship *Okeanos Explorer* (*EX*) and her ROV *Deep Discoverer* (*D2*) carried these out as part of NOAA's Office of Ocean Exploration's Campaign to Address Pacific monument Science and Technology NEeds (CAPSTONE) program, a collaborative effort to explore the deep waters of these monuments with support from other NOAA line offices. One of these areas, the Johnston Atoll Unit (JAU) of the Pacific Remote Islands Marine National Monument (PRIMNM), was the focus of this project (Fig. 1). The JAU was expanded from a box with 50 nm sides centered on the atoll to the full 200 nm Exclusive Economic Zone (EEZ) in 2014. It now encompasses a vastly greater number of seamounts and ridges (Fig 2). Even with three dedicated EX cruises (in 2015, 2017) and two Extended Continental Shelf (ECS) mapping cruises to the area (in 2014, 2017), much of JAU had not been mapped or explored prior to the *Falkor* cruise, so many of its features, organisms, and other resources are still presently unknown.

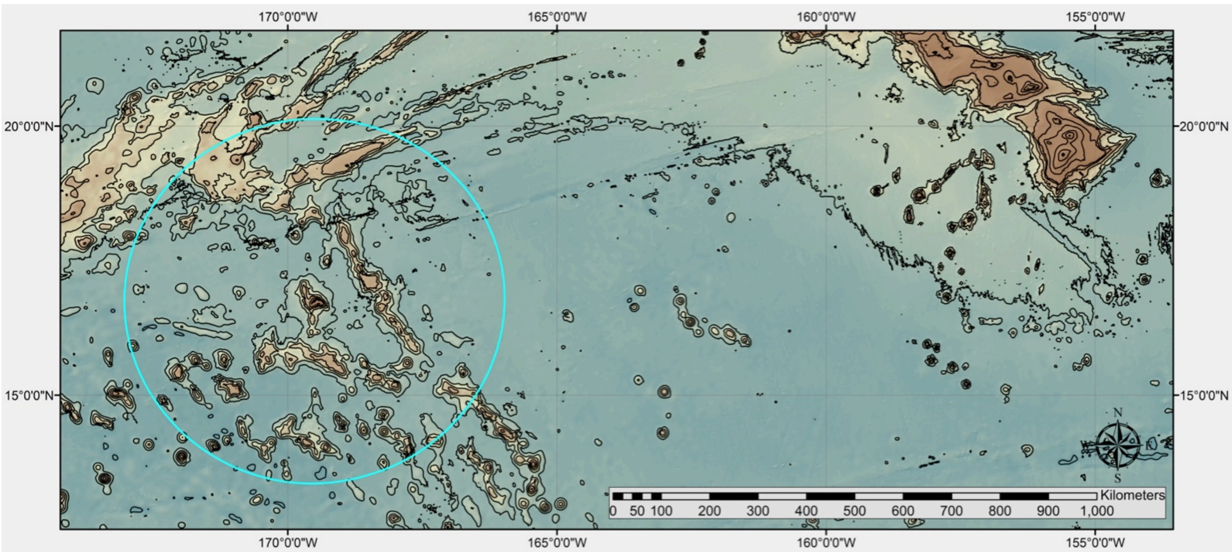


Fig. 2. Location of the JAU relative to the Hawaiian Islands, 700 nm away. The blue circle designates the monument unit's boundaries, expanded to the full 200 nm EEZ centered on the atoll.

The JAU lies in the midst of the Prime Crust Zone (PCZ), an area of the Pacific with the highest expected concentration of deep-sea minerals, including economically valuable metals and rare earth elements. We also know the region harbors high-density deep-sea coral and sponge communities, with some unusual creatures presently under study that were video-documented and/or sampled during 11 dives by *D2* in September 2015 and 14 in July 2017. Johnston Atoll is regarded as a key stepping stone for a number of central and south Pacific marine species to colonize the Northwestern Hawaiian Islands (NWHI). For example, table coral (*Acropora cytherea*) is common throughout the tropical Pacific and at Johnston, but in Hawaiʻi its distribution is limited to French Frigate Shoals and neighboring features in the NWHI, <500 nm to the northeast of Johnston. While Johnston Atoll has been identified as a stepping-stone for colonization of the Hawaiian Archipelago, conversely, it may also represent the farthest outpost south for some species common in Hawaiʻi. And because of the remoteness of this marine protected area, it may contain some of the most pristine ecosystems on earth, including extensive deep-water habitats that have remained largely unexplored. As a result, any further data collection in this hard-to-get-to region represents an enormous opportunity for scientific research, undoubtedly leading to new discoveries in an ecosystem that is largely isolated from human perturbations.

The field component of the project occurred near the end of the Guam to Hawaiʻi repositioning transit, making this SOI's first official "transruise." What made this project logistically attractive is that the JAU mission required only a minimal diversion from the great circle route to Hawaiʻi (Fig. 3). In summary, seven seamounts of various sizes were surveyed in approximately 5.5 days on site, corresponding to a mapped area of 11,241 km^2, which does not include the two weeks of transit data. There still remain many seamounts and related features to map within the extended monument boundaries (Fig. 4).

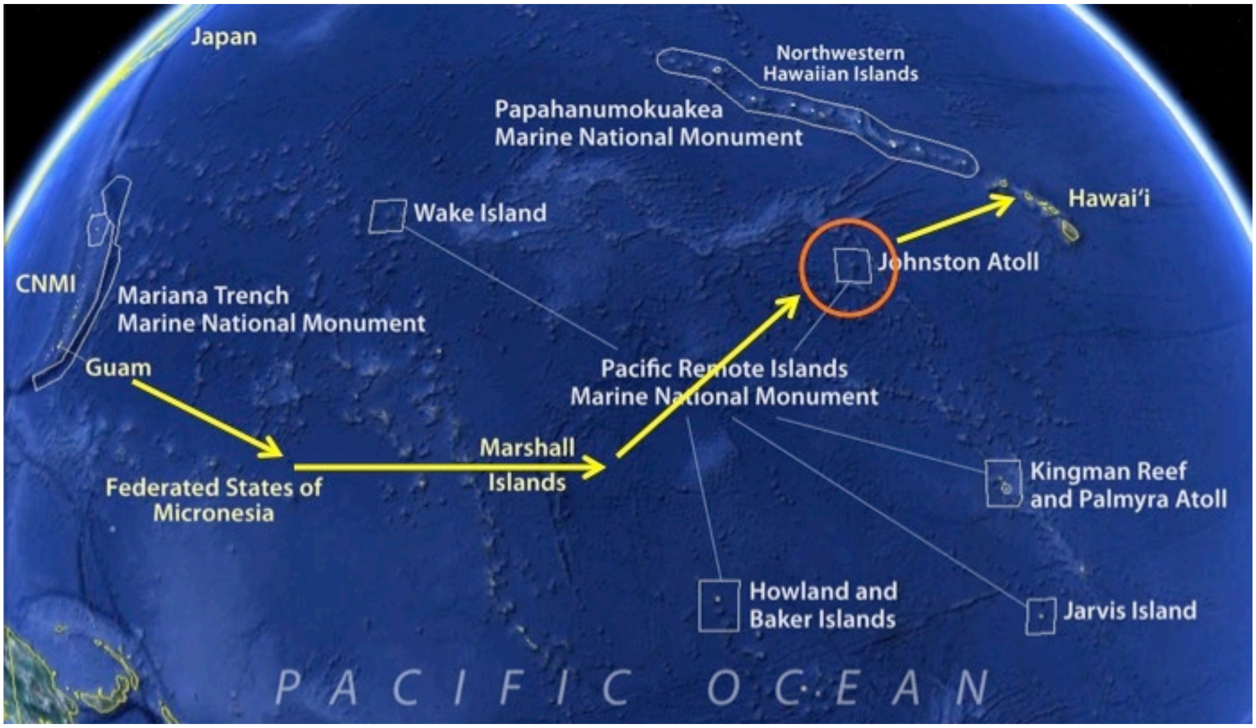


Fig. 3. Transit plan (arrows) for cruise FK161229 and location of other marine monuments and PRIMNM units prior to expansion. Orange circle shows the JAU. Modified from Google Earth, 2012.

Project Objectives

Multibeam surveying within the Johnston Atoll Unit (JAU) of the Pacific Remote Islands Marine National Monument (PRIMNM), was the focus of this project. The objectives were to carry out multibeam mapping, sub-bottom, and magnetics surveys, provide the fully processed data to the research community and public, synthesize it with pre-existing data in the region, and produce derived products including interpretative geologic maps and substrate analyses necessary for habitat characterization and mineral resource evaluation. The plan was to map as many seamounts in the southwestern portion of the JAU, known as the Johnston Seamount

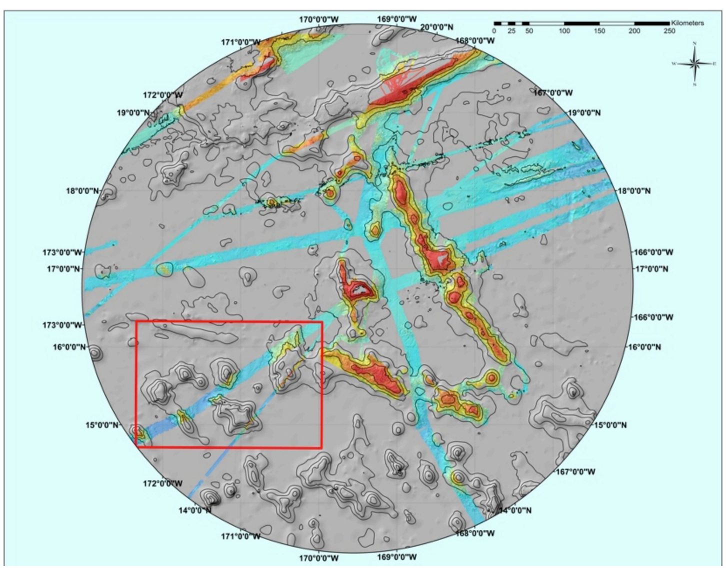


Fig. 4. The JAU with FK161229 primary survey box in red. Colorized swaths are preexisting multibeam coverage overlaid on the gray satellite-derived low-resolution contoured bathymetry.

Group, as the available time on site would allow. A third *EX* cruise to the JAU was carried out in July 2017, and our new mapping data allowed the science teams to get a jump on planning that next round of *D2* dives in unexplored locations within the JAU (Fig. 5).

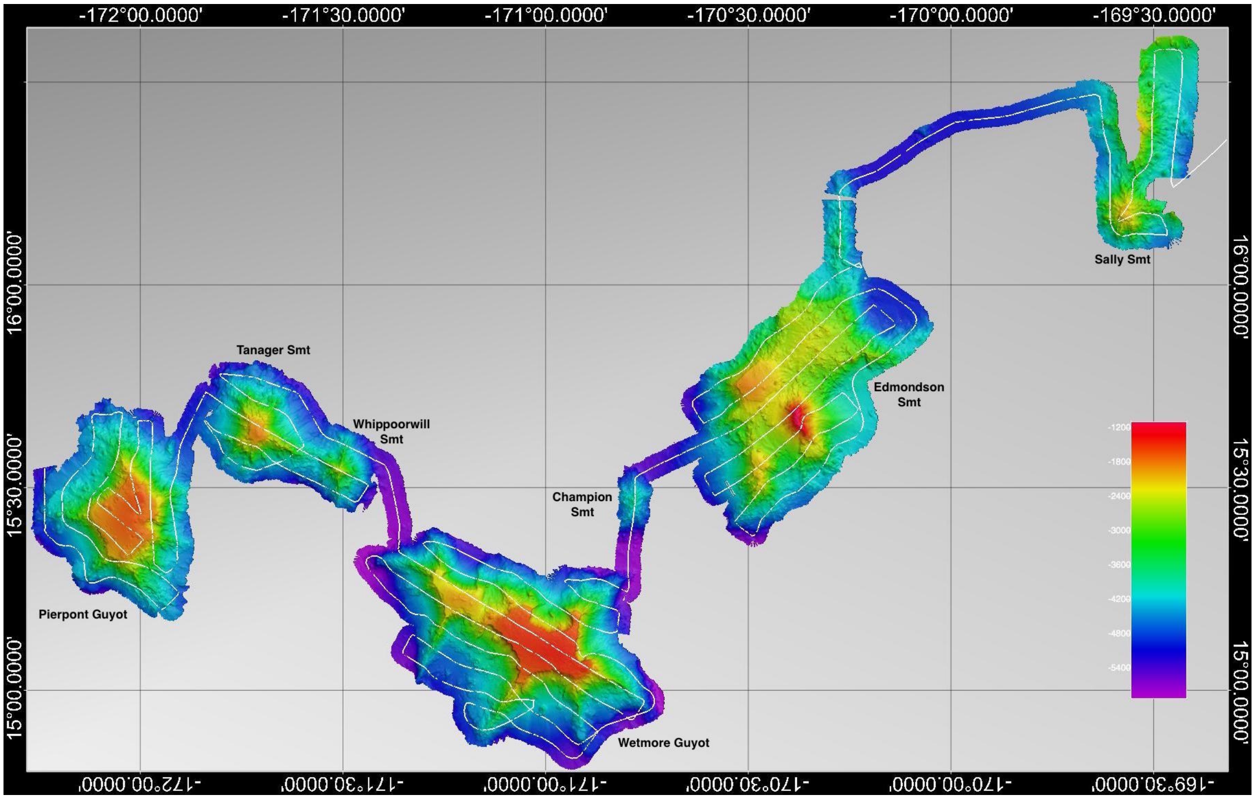


Fig. 5. EM 302 bathymetry for the seven seamounts surveyed within the red box of Fig. 4 plus an area just south of Johnston Atoll itself in the upper right (Sally Seamount). Names are proposed.

Geological Setting

General

- Johnston Atoll, approximately 700 miles west-southwest of Honolulu, marks the center of the circular U.S. EEZ
- Recent expansion of the Pacific Remote Islands Marine National Monuments increased JAU 12.5 times the original area to 431,000 km^2
- Seamounts within the JAU comprise the northern portion of the Line Islands Seamount chain
- The Line Islands are a complex, NW-trending chain of atolls, submarine ridges, and seamounts in the central Pacific Ocean, southwest of Hawaii (Fig. 6, left)
- The >4000 km long chain extends from the Mid-Pacific Mountains (20°N, 170°W), southeast to the north end of the Tuamotu Islands (13°S, 150°W) [Davis *et al.*, 2002]
- The Line Islands chain is located on ocean floor that was formed during the "Cretaceous Normal Superchron" [Atwater *et al.*, 1993], a magnetically quiet period in the late Cretaceous, lasting from 119 Ma to 83 Ma [Harland *et al.*, 1982]

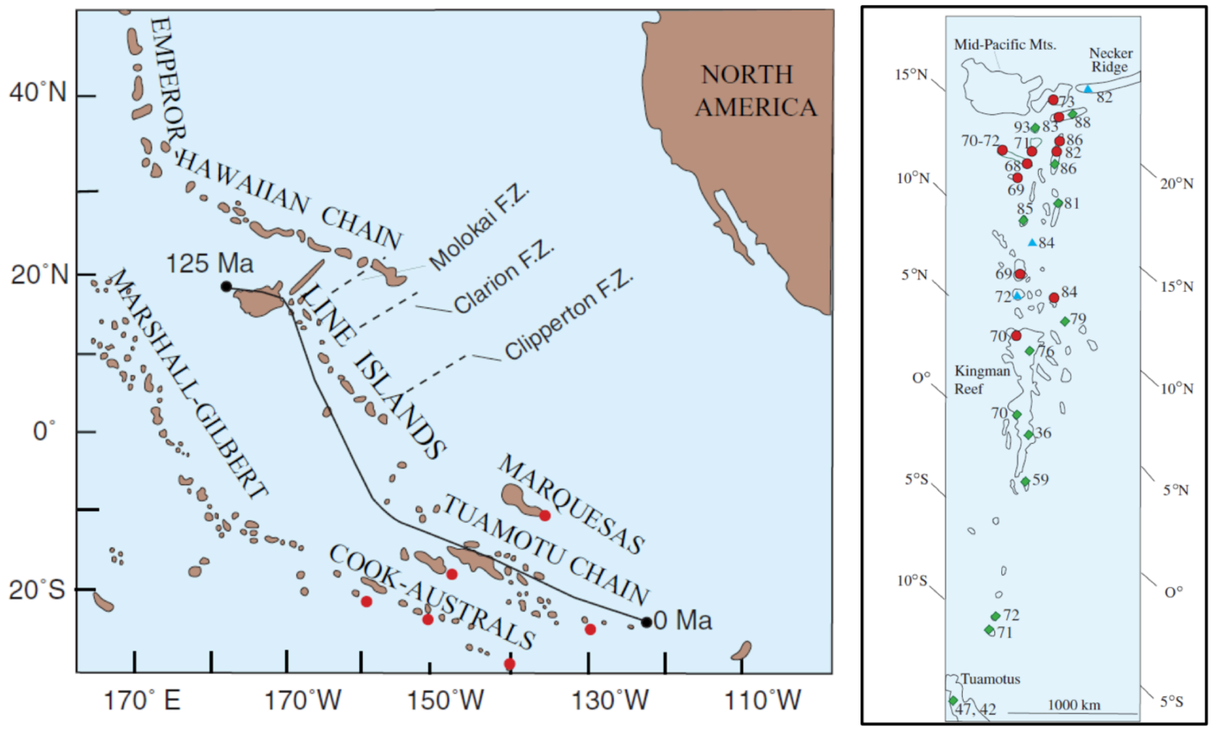


Fig. 6. Map on left shows location of Line Islands relative to other island chains and fracture zones. Black line is hypothetical trace of a hot spot according to Duncan and Clague (1985). Red dots are positions of presently active hot spots. Map on right shows the spatial distribution of rock ages in Ma along the Line Islands chain from four studies (red dots, Davis *et al*., 2002; green, Schlanger *et al*., 1984; blue, Saito and Ozima 1976, 1977). Both figures are from Davis *et al*., 2002.

Geochronology

- Winterer [1976] divided the Line Island chain into three geomorphic provinces (Northern = big ridges, Central = variable sized scattered seamounts, Southern = a massive structure supporting the coral island foundations)
- Two major episodes of volcanism, at ~81–86 Ma (east) and 68–73 Ma (west), occurred synchronously over distances of >1200 km and >4000 km, respectively (Fig. 6, right) [Davis *et al*. 2002]
- Ages are incompatible with single or multiple hot spot models
- Orientations of various features and edifices suggest that volcanism may have been controlled by pre-existing weaknesses in the lithosphere

Geochemistry

- Volcanic rocks erupted during the younger episode of volcanism include strongly alkalic basanite, nephelinite, alkalic basalt & differentiates ranging from hawaiite to trachyte [Davis *et al*., 2002]
- Volcanic rocks erupted during the older period of volcanism span a smaller compositional range than the younger rocks

- Extensive coeval volcanism along major segments of the chain is compatible with decompressional melting of heterogeneous mantle due to diffuse lithospheric extension along faults, fractures, and fissures
- Related to broad upwarping of the Superswell region in the eastern South Pacific, where these lavas originated

Materials and Methods

R/V *Falkor* cruise FK161229 took place from December 29, 2016 to January 16, 2017, from Guam to Hawaiʻi. We used the Kongsberg EM 302 multibeam sonar system, the Marine Magnetics SeaSPY2 towed magnetometer, and the XBT system. No additional scientist provided instrumentation was employed.

What data types did we use?

- Multibeam bathymetry and backscatter for geology and structure
- Marine magnetics to help delineate volcanic centers, rift zones, and age relationships
- GLORIA sidescan backscatter to extend interpretation (USGS, 1990-91)
- Satellite derived global topography to extend interpretation (Ongoing updates)

What were the methods?

- Editing multibeam bathymetry data in Qimera software
- Processing multibeam backscatter data in FMGT and MB-System software
- Gridding of bathymetry and backscatter data in MB-System and the Generic Mapping Tools (GMT) software (Open Source) at 20-meter resolution
- Building an ArcGIS project with all the data layers
- Digitize the geologic unit and structural feature interpretations in ArcGIS using geomorphological observations so that all polygons and lineations are georeferenced and can be statistically queried
- Construct 3D models allowing further analysis and visualization in Fledermaus

What was accomplished?

- All multibeam bathymetry regridded and synthesized to 20 m
- All 16 GLORIA 50-m quads reprojected, trimmed, mosaicked
- All magnetic data corrected and processed
- 8 Geological Units defined, 6 Structural/Geomorphological Symbols determined
- All geology and structure maps completed for JAU

What were the factors adversely affecting the data collection?

- A problem with the K-sync system did not allow us to run the CHIRP sub-bottom profiler (SBP) because it conflicted with the EM302
- There was a source of noise affecting the EM302, and we could not determine its origin
- The magnetometer logging software was also a serious issue which led to corrupted time-stamping, extensive science team time lost to recovering it, and lack of confidence with the results
- Carrying the ROV back to Hawaiʻi did limit the speed we could achieve on the transit because of the amount of fuel being burned as we motored into the trade seas, winds, and currents, thus reducing the amount of science time available on site

Results

Interpretative geologic maps were completed following the conclusion of the cruise, along with preliminary interpretation of the magnetics data. A manuscript for publication is also planned.

- Mapped a 11,250 km^2 area with multibeam (not including transits)
- Surveyed seven seamounts
- Determined edifice sizes ranging from 15 to 90 km in length
- Depths ranging from 5500 to 1200 mbsl
- Defined eight Geological Units and six Structural/Geomorphological Symbols
- Identified eight to ten individual volcanoes based on geologic mapping
- Officially proposed names for seven seamounts after early explorers, ships, and scientists that worked in this area (Fig. 5)
    1. Pierpont Guyot: after Capt. Joseph Pierpont, the first documented discoverer, although he did not name or claim it in 1796.
    2. Sally Seamount: after Pierpont's American brig *Sally* that accidentally grounded on a shoal near the islands.
    3. Champion Seamount: after the vessel HMS *Champion*, which made a survey and map of the island in 1892 for possible use as a telegraph cable station.
    4. Tanager Seamount: after the Navy's USS *Tanager* minesweeper that led the first biological surveys in 1923, called the Tanager Expedition.
    5. Whippoorwill Seamount: after the companion vessel to *Tanager*, USS *Whippoorwill*.
    6. Wetmore Guyot: after Dr. Alexander Wetmore, biologist, directing the Tanager Expedition scientific team, and eventually of the Smithsonian Institution.
    7. Edmondson Seamount: after Dr. Charles Edmondson, marine biologist on the Tanager Expedition, also of University of Hawaiʻi at Mānoa and Bishop Museum.
- Synthesized all existing multibeam bathymetry data into a 60-meter grid, including that from NOAA Ship *Okeanos Explorer* and the U.S. State Dept. Extended Continental Shelf (ECS) program using R/V *Kilo Moana* (Fig. 7)

The geological and structural interpretative maps for five of the seven seamounts studied in this project are included in the following pages as an example of the derived products we have generated. To place our interpretations in context, we also include various other data layers in the maps, shown by allowing some level of transparency in the overlapping ones. Geological units and structural/geomorphological symbols used in the maps are presented in the legend (Fig. 8).

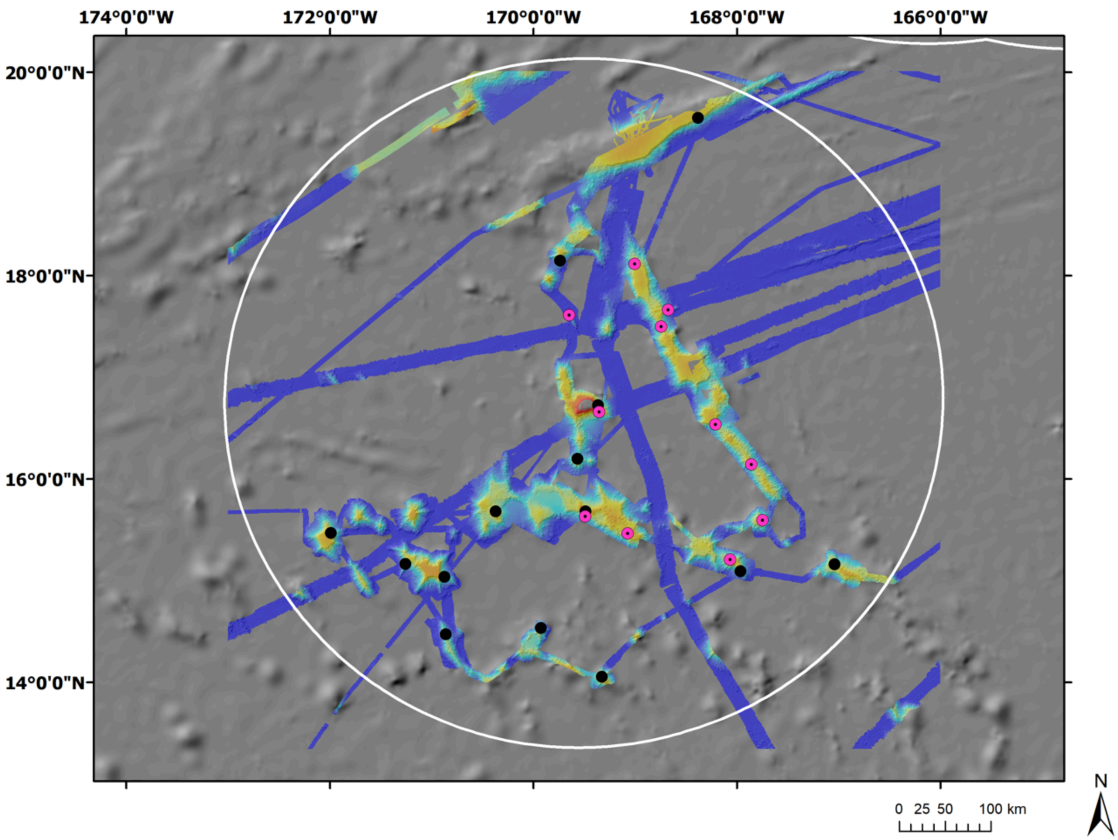


Fig. 7. All available multibeam data for the JAU synthesized into one grid at 60-meter resolution. Dots show positions of ROV *D2* dives from two different *EX* cruises, the second utilizing the *Falkor* data to plan and carry out dives on. Compare to coverage in Fig. 4. Some additional ECS data on the northern end of the JAU has just recently been made public. Still, many seamounts are unmapped.

In this case, the layers consist of shaded and contoured multibeam bathymetry and backscatter grids at 20-meter cell spacing. As an example, the first feature shown here is Pierpont Guyot or Tablemount (*proposed name*), located near the southwestern edge of the JAU boundary (Fig. 9). It exhibits a classic stellate shape of an ancient seamount, with five to six radiating rift zone ridges and landslides or debris flanks in between. Summit blow-ups were also prepared, showing the detail of the flat-topped feature, commonly referred to as a guyot or tablemount, with numerous secondary volcanic cones distributed around the top. As will become obvious, most of the seamounts mapped for this project display the same or a similar morphology and geological units, although some are far more complex with multiple major eruptive centers and a more varied distribution of units.

The detailed geological interpretative maps that were illustrated differentiate between volcanic, sedimentary, and erosional units of the seamounts. The unit contacts were drawn using morphological relationships observed from 20-meter bathymetric and 20-meter backscatter resolution grids. Structural relationships were mapped including individual volcano specific contacts, numerous landslide scarps, faults, and paleoshorelines. Along-track magnetic data show contrasting magnetic anomalies designating two main relative ages of emplacement for these seamounts. These new maps reveal additional complexities of a previously assumed simplistic model of volcanic growth. Nine or ten individual volcanoes built the five seamounts mapped in detail, a constructional evolution similar to that of the Hawaiian volcanoes. The high-quality data display the detailed nature of the contacts between these volcanoes and show multiple periods of subaerial growth. The subaerial regions with flat or gradually sloping carbonate and sediment-capped summits are present at three main depth ranges, indicative of three different subaerial growth durations.

Numerous post-erosional monogenetic cones that erupted through the carbonate caps are the most notable features of the summit morphology. Over 50 individual summit volcanic cones were identified. A post-subsidence, submarine emplacement of the summit cones is hypothesized due to the preservation of the cones' smaller size and location where subaerial erosion could have easily erased these features from the geologic record. These features are also observed on the summits of other seamounts within the JAU seamount group. The frequency of occurrence of summit cones on JAU volcanoes suggests that the eruptive mechanism generating the cones has been long-lived throughout the formation of these seamounts and differs from the equivalent rejuvenated stage of Hawaiian volcanoes.

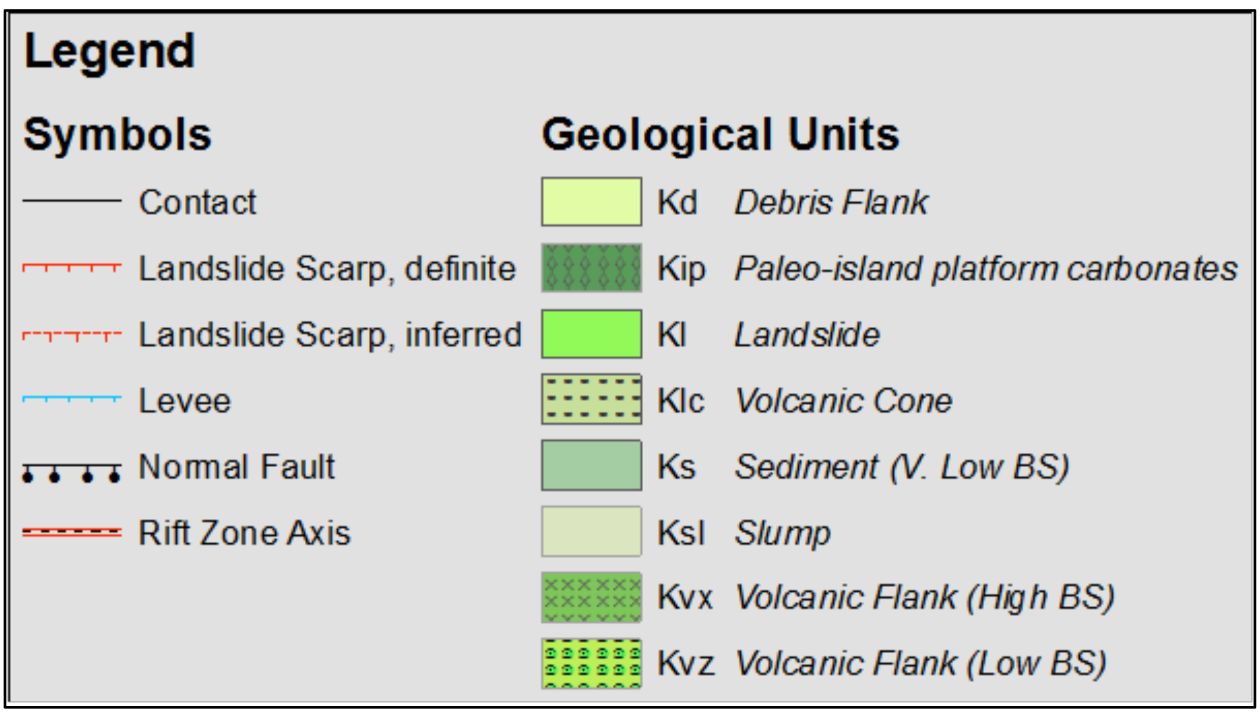


Fig. 8. The legend showing the structural/geomorphological symbols and the eight geological units of Cretaceous age, along with their abbreviations, that were developed for this study. BS = backscatter.

The following section presents the geological, structural, and geomorphological highlights of the five seamounts for which detailed interpretative mapping was carried out.

<u>Pierpont Guyot</u> (*name proposed*)

- The flat-topped seamount was formed by one singular volcano
- >40 individual volcanic cones that erupted through and on top of the carbonate platform
- Central platform dominated by low intensity backscatter sediments
- Upper edifice consists of debris flanks with variably eroded morphology and submarine volcanic rift zone ridges

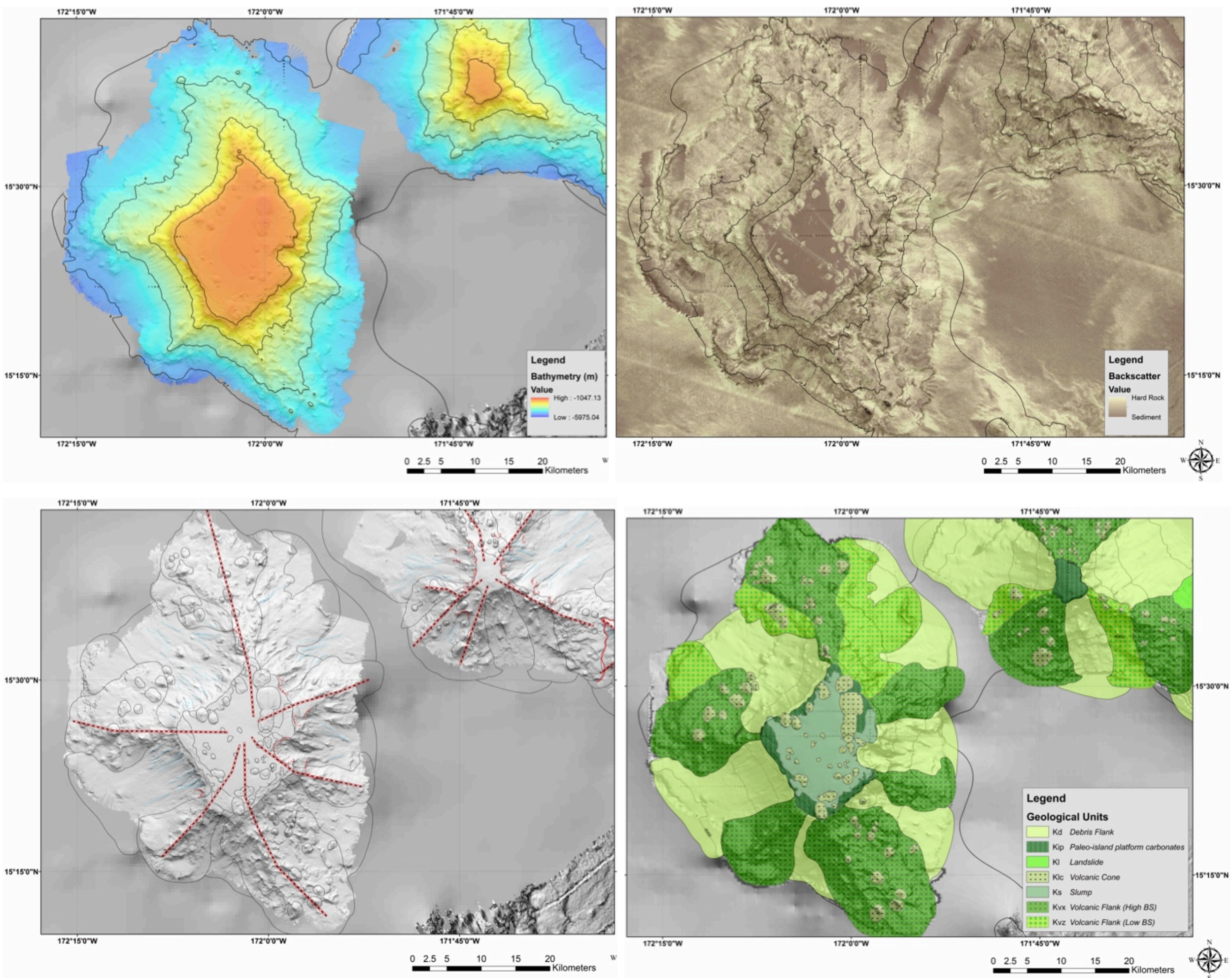


Fig. 9. Pierpont Guyot and a portion of Tanager Seamount in the upper right of figure (*names proposed*). Multibeam bathymetry overlain on synthesis of preexisting multibeam and low-resolution satellite-derived bathymetry with 1000 m contours (upper left). Multibeam backscatter overlain on GLORIA sidescan (upper right). Hard returns are light in color (rock), soft returns are dark (sediment). Structure and outlines of geological units overlain on hillshade bathymetry (lower left). See Fig. 8 for symbology. Geological map overlain on hillshade and 1000-m contoured bathymetry with units as defined in legend (lower right). This illustrates our mapping process.

<u>Tanager and Whippoorwill Seamounts</u> (*names proposed*)

- Represent two individual and conjoined seamounts (Fig. 10)
- Both are of classic Cretaceous era stellate shape with radiating rift zone ridges
- Tanager Seamount has a relatively small, rounded carbonate cap

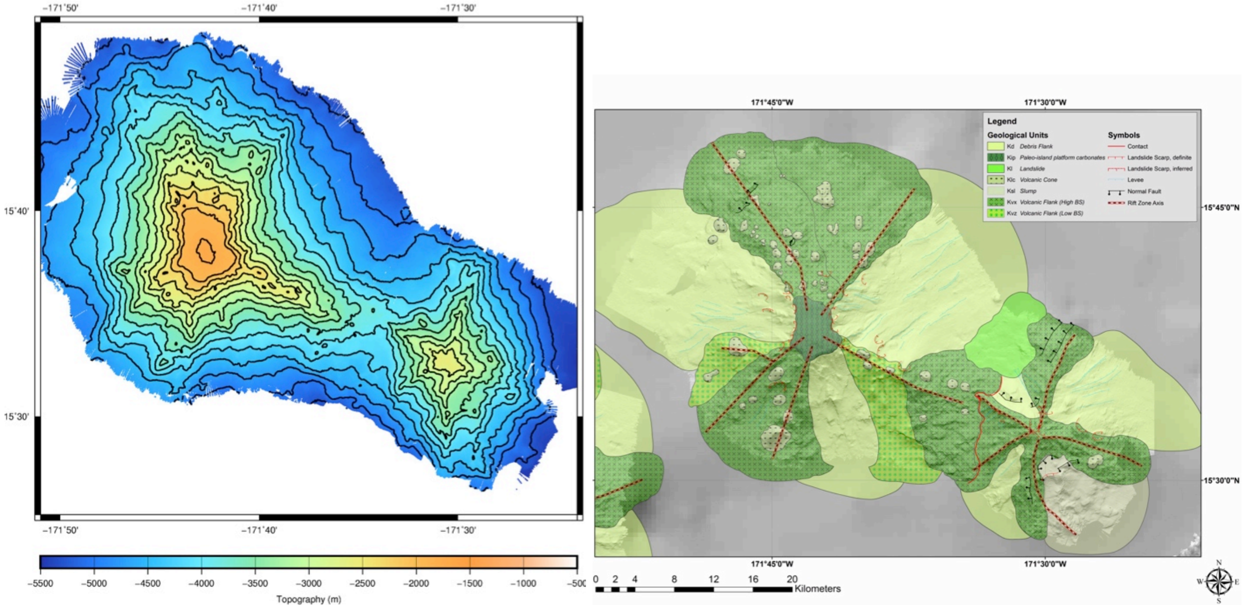


Fig. 10. Tanager (west) and Whippoorwill (east) Seamounts (*names proposed*). Multibeam bathymetry with 250 m contours (left). Geological and structural map overlain on bathymetry.

<u>Wetmore Guyot</u> (*name proposed*)

- Composed of at least two individual volcanoes based on rift zone axis orientations and three levels of carbonate platforms at various depths (Fig. 11)
- Largest and most shallow platform may be a veneer on top of two volcanic edifices
- Both summit platforms are devoid of volcanic cones

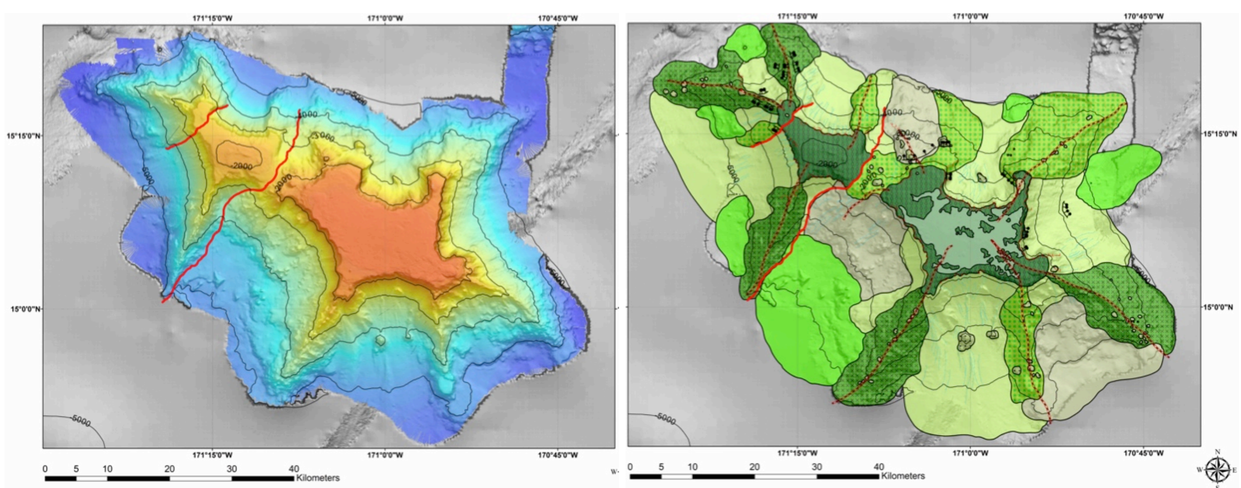


Fig. 11a. Wetmore Guyot (*name proposed*). Bathymetry (left) and Geo/Structural map (right).

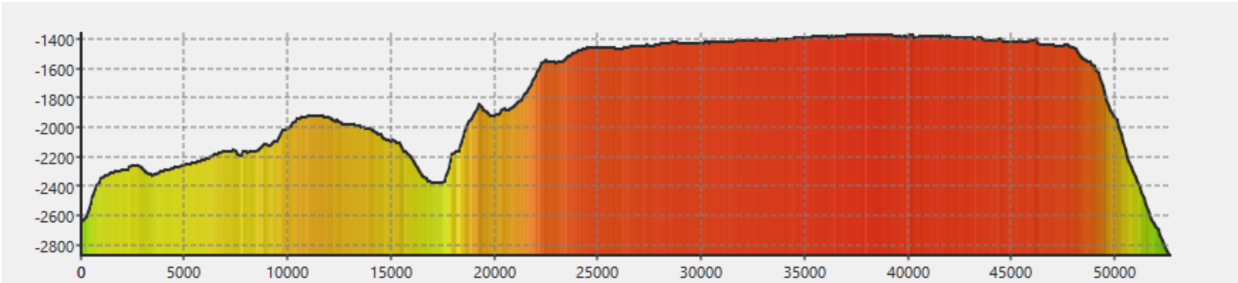


Fig. 11b. Profile across Wetmore Guyot from NW to SE showing the three carbonate platforms at different water depth levels. Water depth in meters on Y-axis, distance along profile in meters on X-axis. Colorization corresponds to false-colored bathymetry depicted in Fig. 11a, left.

<u>Edmondson Seamount</u> (*name proposed*)

- Composed of at least four individual volcanoes based on rift zone axis orientations, carbonate platform levels at various depths, and local bathymetric highs (Fig. 12)
- Largest and most shallow platform lacks flat topped morphology
- This tallest construct appears to be some kind of extremely large volcanic cone, dome, or other edifice that is highly unusual if it represents secondary volcanism

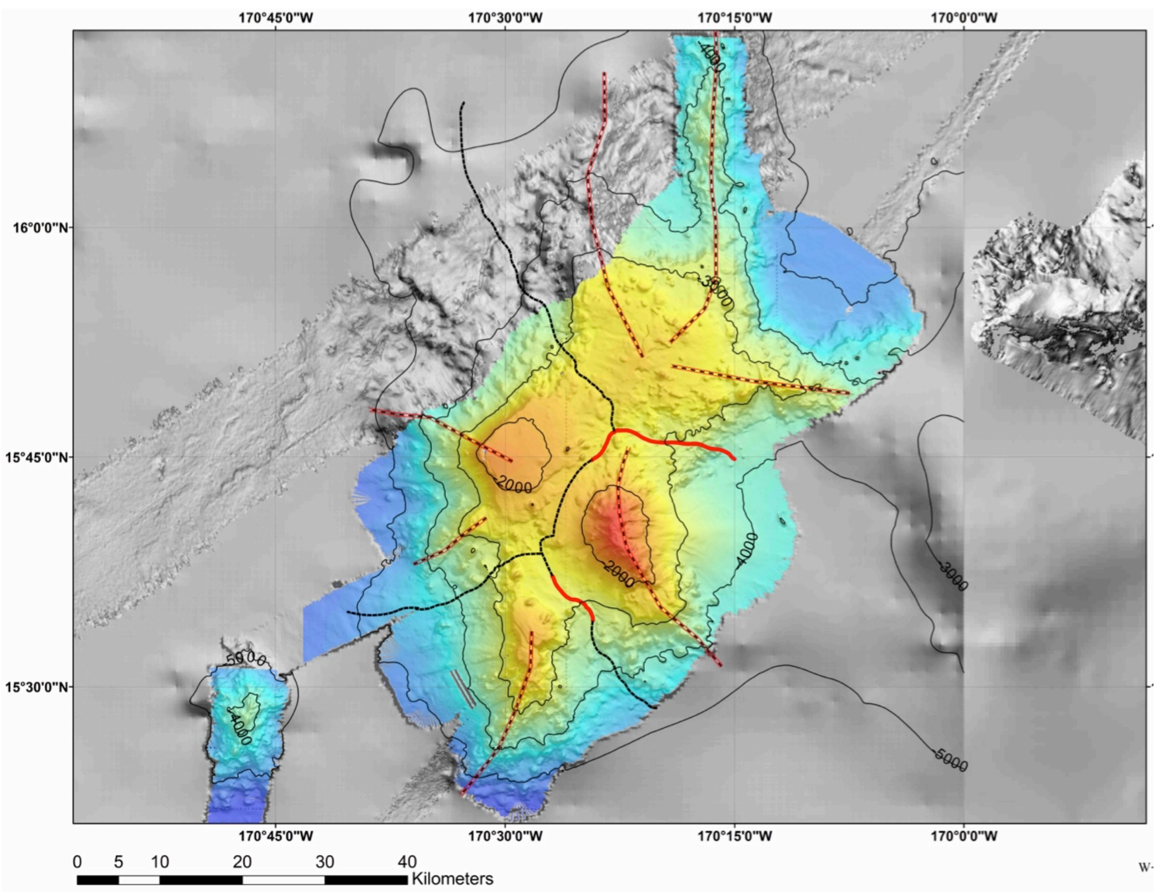


Fig. 12a. Edmondson Seamount (*name proposed*). Bathymetry presented as in Fig. 9, along with rift zones and volcano contacts (red where constrained by morphology, dashed otherwise) overlain.

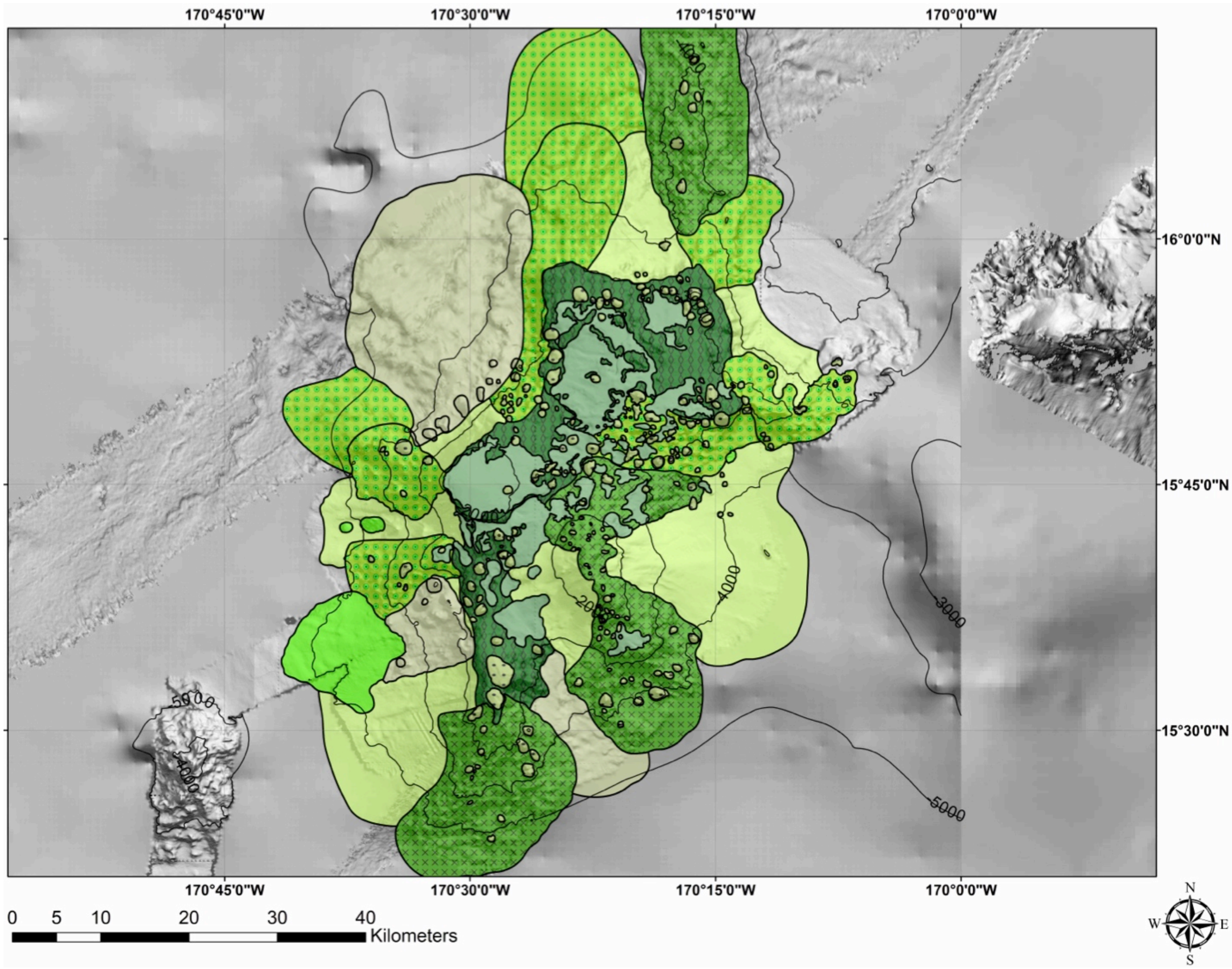


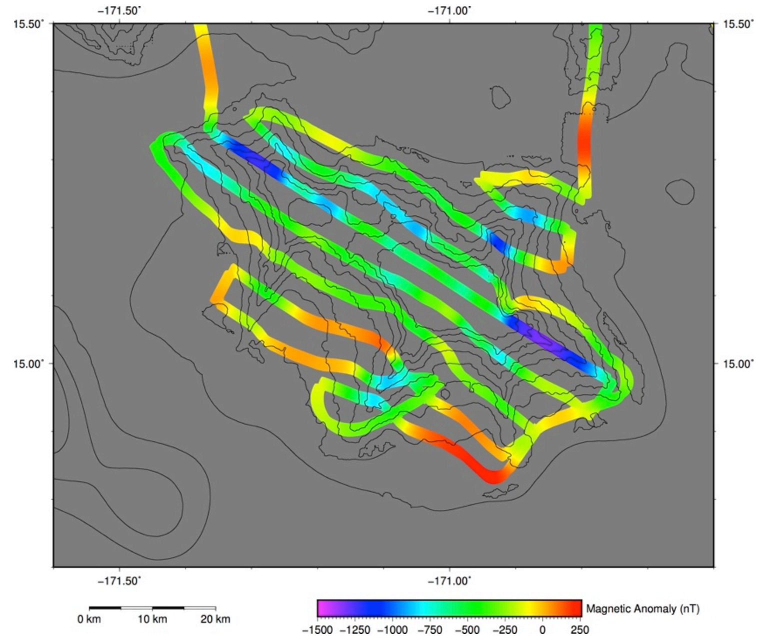
Fig. 12b. Geological map of Edmondson Seamount overlain on bathymetry as in Figs. 9 and 11a. Geological units as in Fig. 8.

Summary of FK161229 Geological and Structural Mapping Results

- Multiple subaerial periods of growth, with three main depth ranges
- >50 summit volcanic monogenetic cones, suggests delayed post-subsidence, submarine emplacement
- Eruptive mechanism generating the cones has been long-lived
- Complex eruptive histories formed these seamounts
- Further work requires systematic sampling and analysis

Marine Magnetics

Example plots resulting from the magnetic field survey that was carried out concurrently with the multibeam survey are presented in Figure 13.



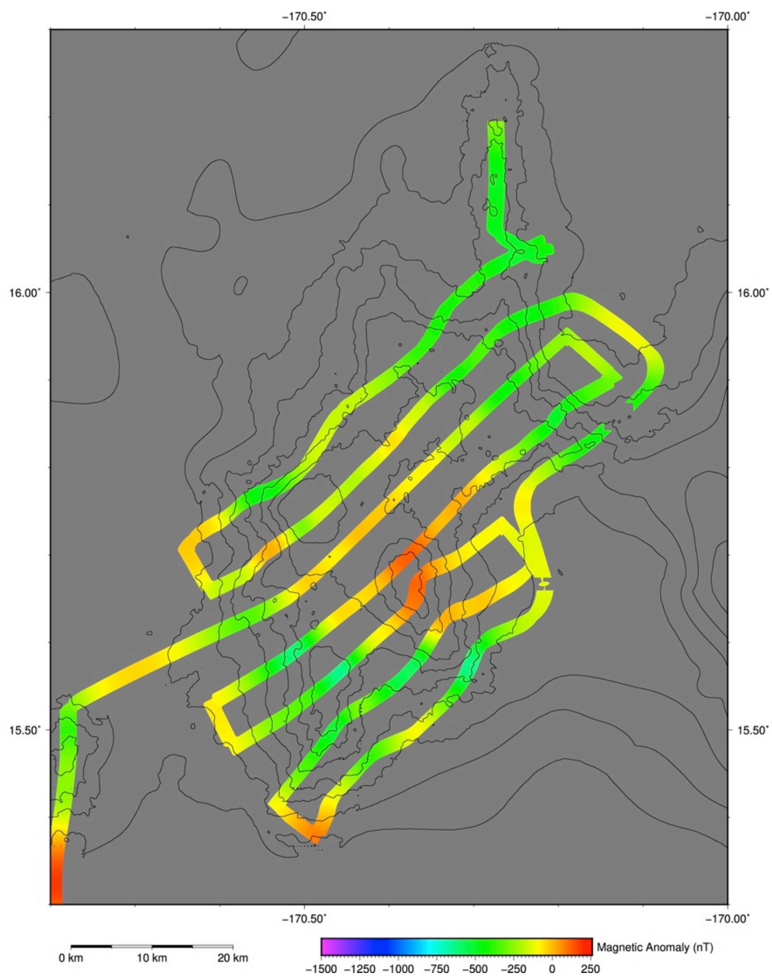


Fig. 13. Magnetic anomaly maps for Wetmore Guyot (top) and Edmondson Seamount (bottom). High magnetic intensity is shown by higher values and hot colors while lower intensity is represented by negative values and cooler colors overlain on 500-m contoured bathymetry.

Presentations and Publications

- Oral presentation for scientists and students at the Geological Society of America, Cordilleran Section meeting, Honolulu, May 2017 [Tree *et al*., 2017]
- Public Talk at Hanauma Bay in SOI sponsored series, Honolulu, Aug 2017
- Display table presentations for SOI sponsored event at the Waikiki Aquarium, Oct 2017
- Talk at the NOAA Inouye Regional Center for resource managers and scientists in their Distinguished Speakers Series, Ford Island, Pearl Harbor, Oʻahu, Jan 2018.
- Talk at UH Manoa for scientists and students, Oceanography Department weekly OCN780 series, Mar 2018
- Map imagery presented in Hawaiian Airlines in-flight magazine article about SOI and *Falkor*, Dec 2017
- Short article in the annual *Oceanography* magazine supplement, Mar 2018 [Raineault *et al*., 2018]

Datasets and Sharing

<u>Coordination with OER/*EX* and other NOAA programs</u>

- The July 2017 *EX* cruise originated in Hawaiʻi, thus it was more operationally efficient for them to map the northern and central areas and *Falkor* to survey features in the southwestern side of the JAU on the way in from the Western Pacific.
- Derived products and/or edited files were made available to the various interested NOAA groups including the PRIMNM office, the Coral Reef Ecosystem Program, and the Office of Ocean Exploration and Research for a following NOAA Ship *Okeanos Explorer* cruise. The *EX* cruise targeted some of the seamounts we mapped with ROV dives, along with additional mapping of neighboring seamounts.

<u>More Products in the Wild</u>

- All the raw and processed data have been delivered to the R2R and MGDS programs at Lamont-Doherty Earth Observatory to be made available for download by the public and the wider research community.
- Our interpretative map package has been made available from the SOI website under this cruise ID.
- We continued our efforts in merging the *Falkor* data with the pre-existing data, along with the new *Okeanos Explorer* data collected following our cruise. This grid was made available to the community and public in early 2018.

Outreach Efforts and Media Materials Generated

<u>Artist-at-Sea</u>

- Lucy Bellwood, Adventure Cartoonist, created the *Mappin' the Floor* adventure comic book that was later colorized and given out at the Honolulu port event in Oct 2017 as educational and outreach material (Fig. 14).

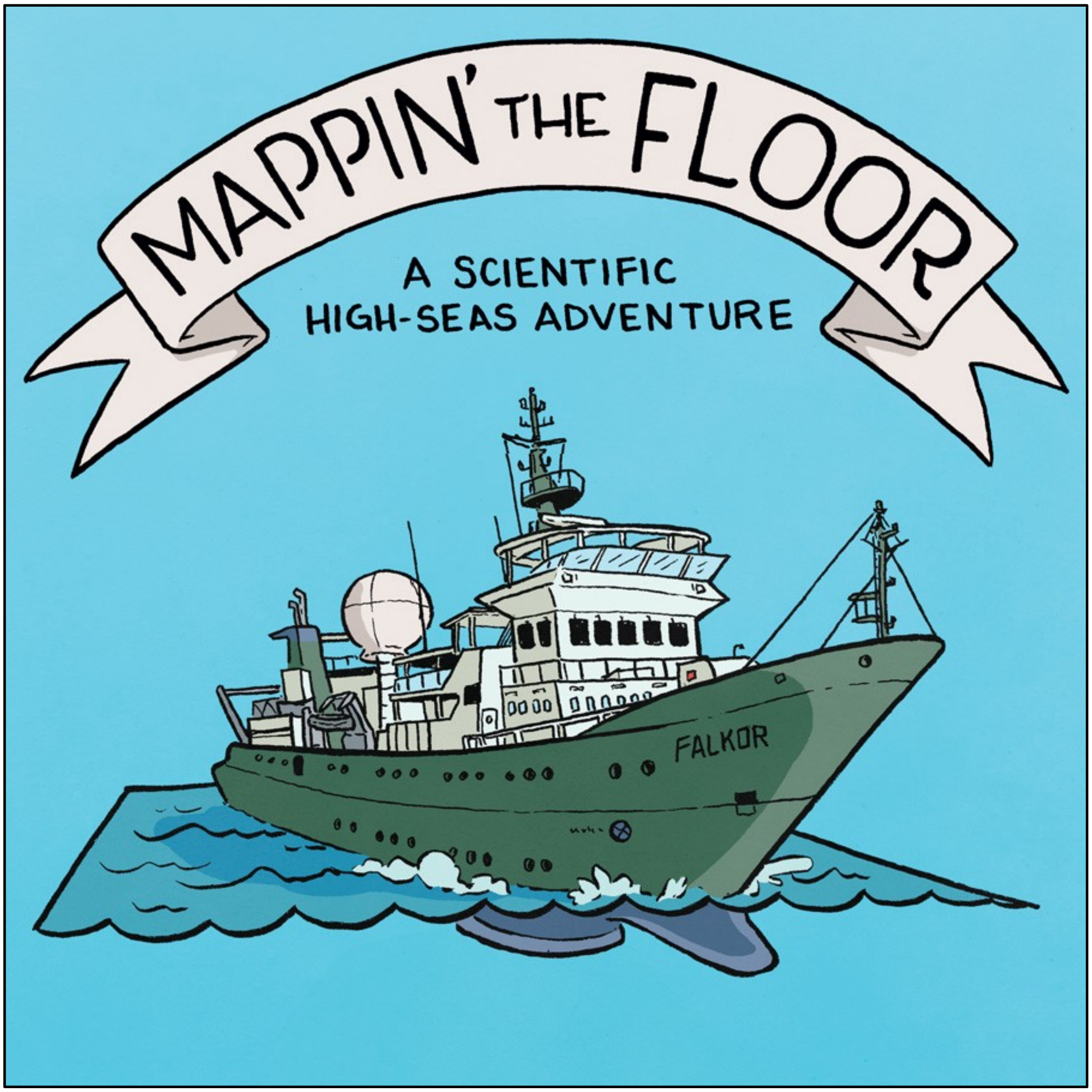


Fig. 14. Cover of the *Mappin' the Floor* comic book created by Artist-at-Sea Lucy Bellwood during this cruise. It presented many aspects of the technologies used, location visited, and science done.

Other Outreach and Educational Efforts

- Jena Kline, Iolani School math and science teacher, developed lesson plans, other educational materials, and participated in outreach events via satellite link
- Brock Callen, Sr. & Jr., Sail Martha's Vineyard and 11th Hour Racing, participated in outreach events via satellite link
- Andrew Kang, University of Guam graduate student (and Guam native), SOI Student Opportunities Program representative, assisted with all cruise activities
- Monika Gonzalez, SOI contract multimedia correspondent, developed web site content, videos, and setup the outreach events via satellite link

Science Support

- The NOAA Pacific Islands Regional Office (PIRO) provided a month of salary support and travel costs to Guam for PI Smith to attend the cruise and to complete the data post-processing and product development shoreside after the at-sea work
- Jonathan Tree was supported on another grant (NSF) to the PI to afford further development of his mapping skills and provide a comparison with a different geological setting and volcanic regime
- Joyce Miller is retired and volunteered her services at no cost
- The UH/SOEST Dean's office provided travel funds for Tree and Miller to join the ship in Guam

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