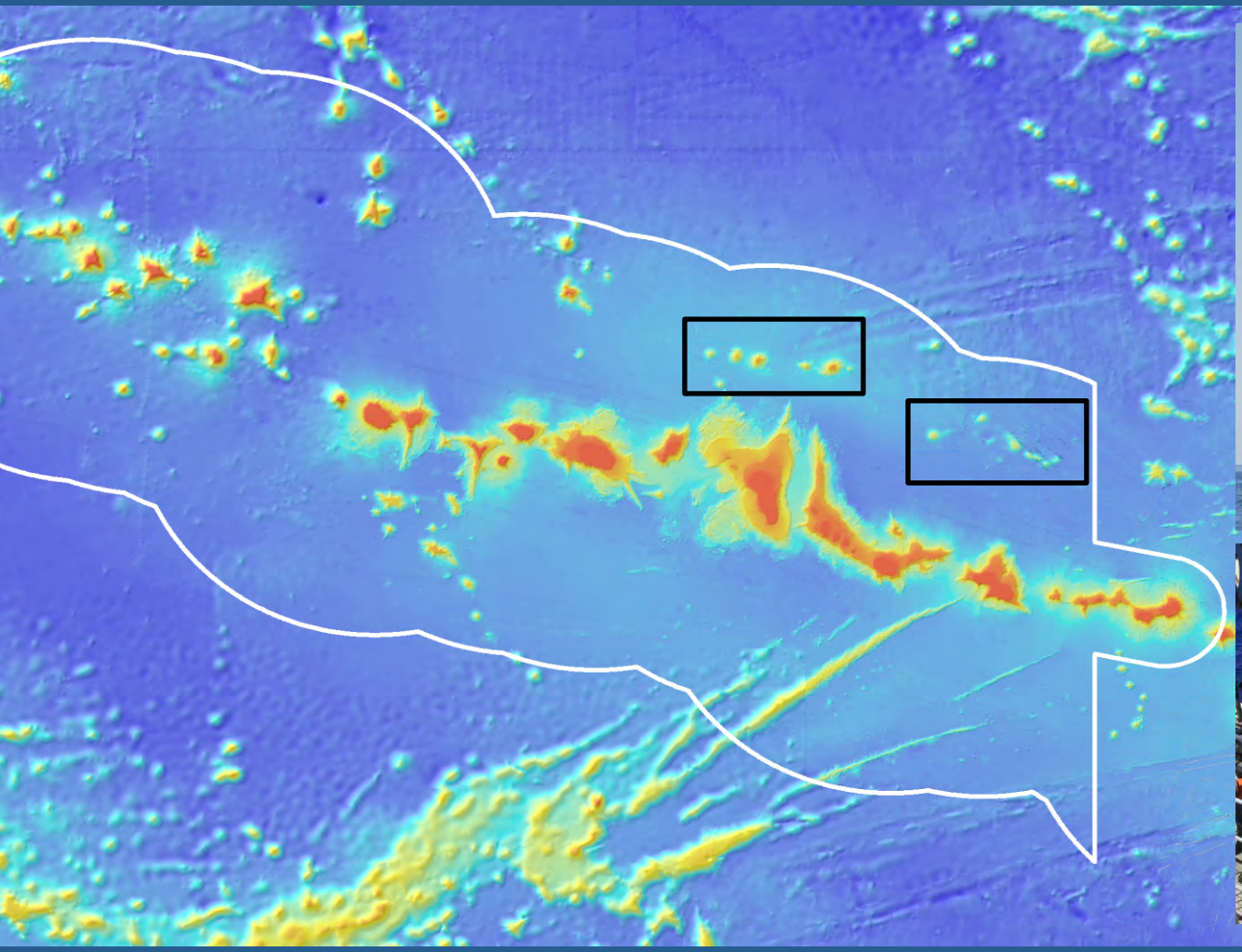
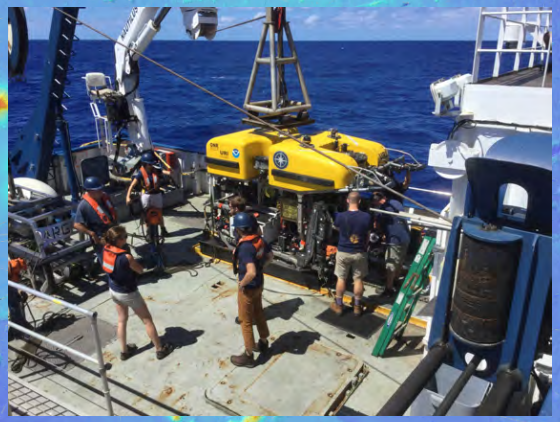
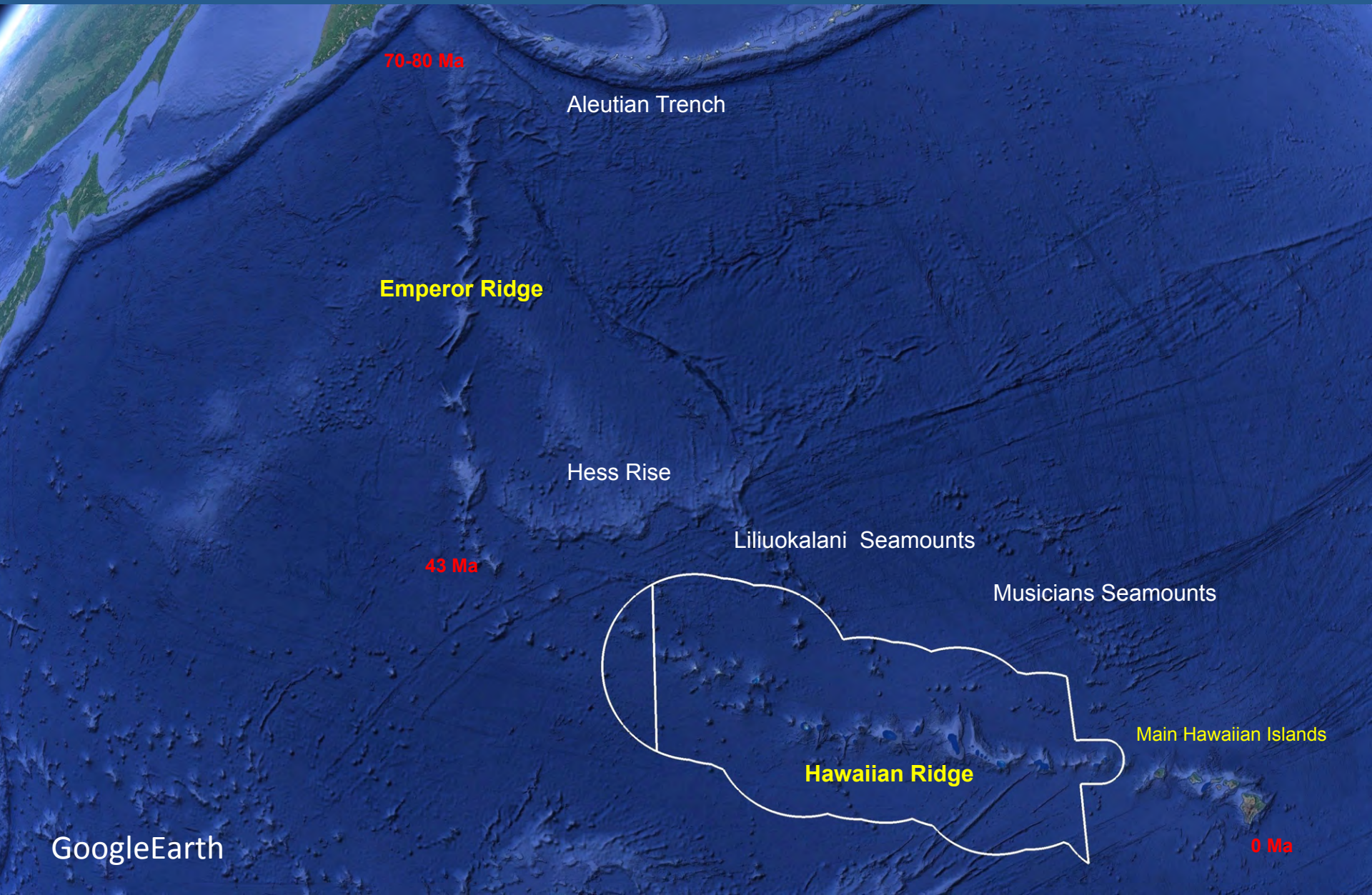
Exploration of Strange "Off-Ridge" Seamounts in the Expansion Area of the Papahānaumokuākea Marine National Monument



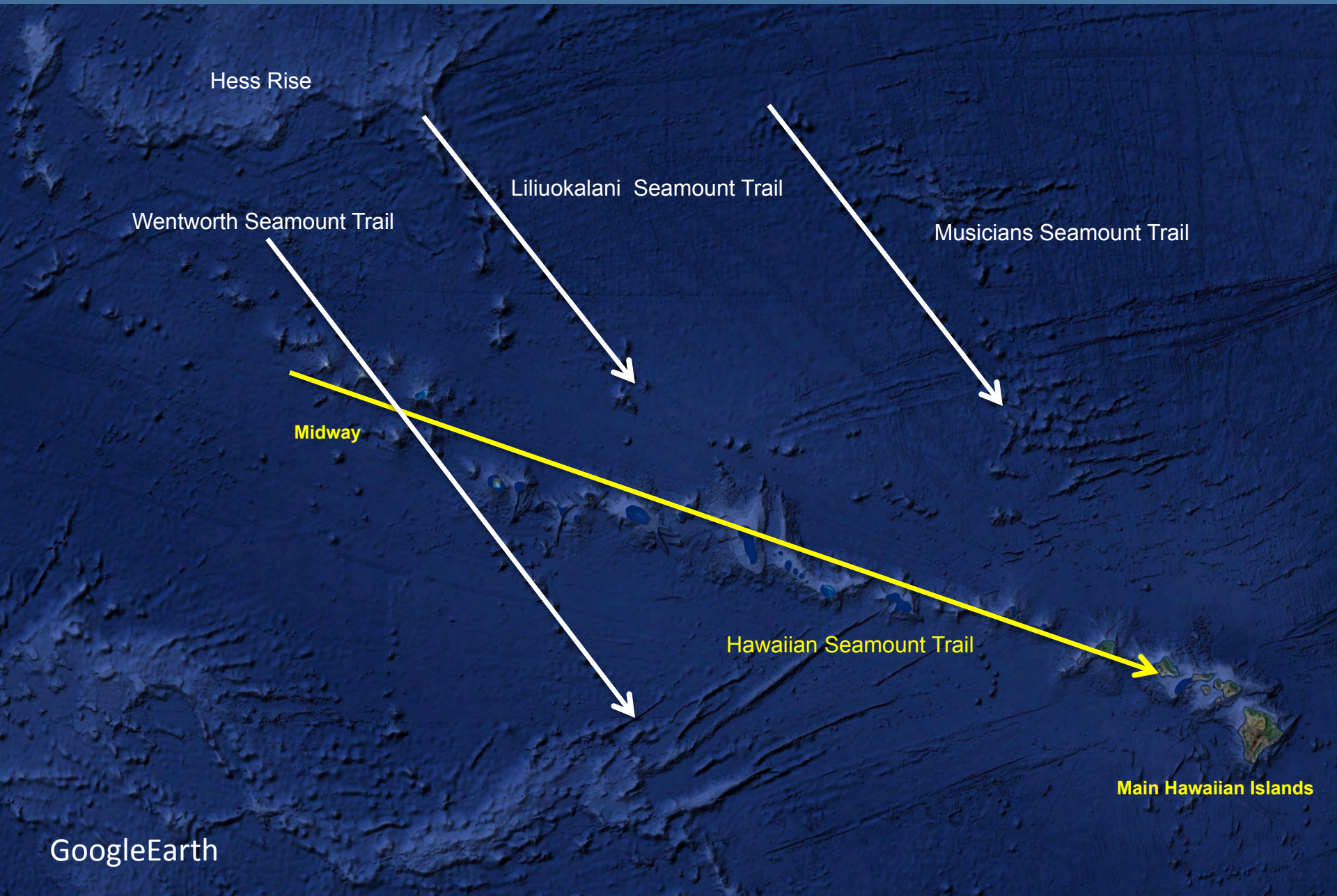


Christopher Kelley, UH, Thomas Hourigan, NOAA DSCRTP
Nicole Raineault, OET, Allison Fundis, OET, Renato Kane, OET
Andrea Balbas, OSU, Jasper Konter, UH, Dorsey Wanless, BS, Justin Umboltz, PMNM

Introduction to the Seafloor in the North Central Pacific

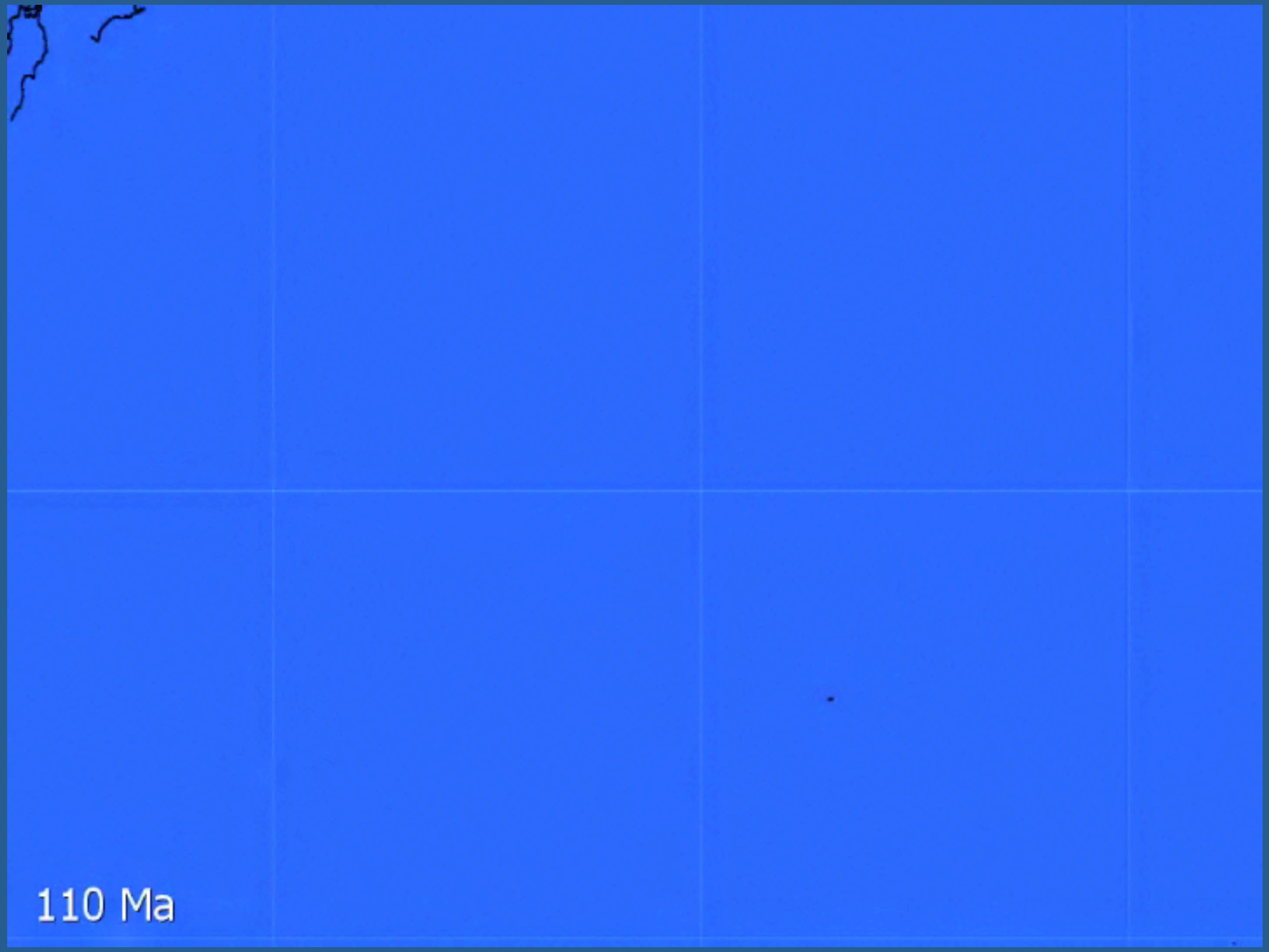


Known and Dated Seamount Trails in and Around PMNM

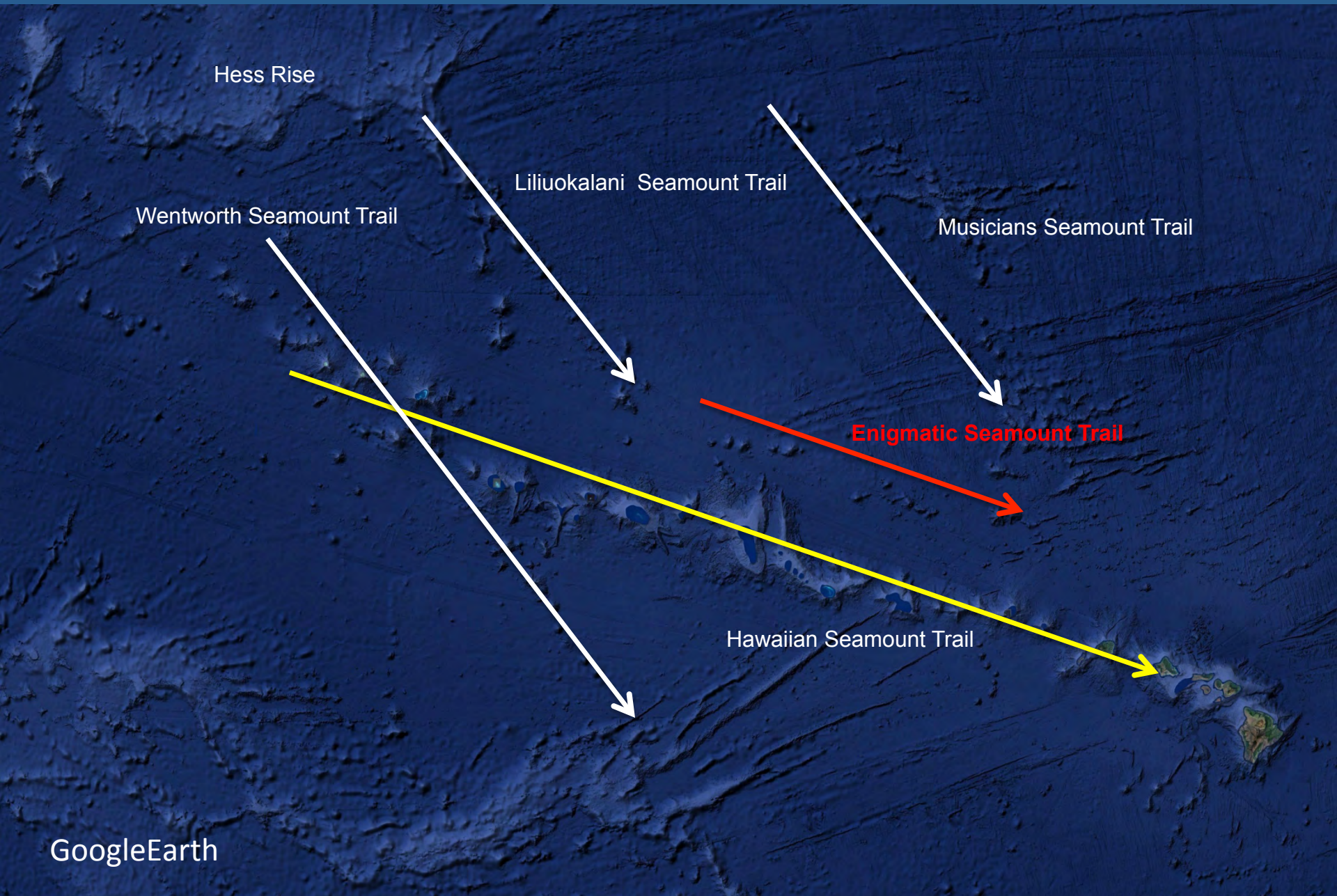


How It's Believed to Have Happened

How It's Believed to Have Happened

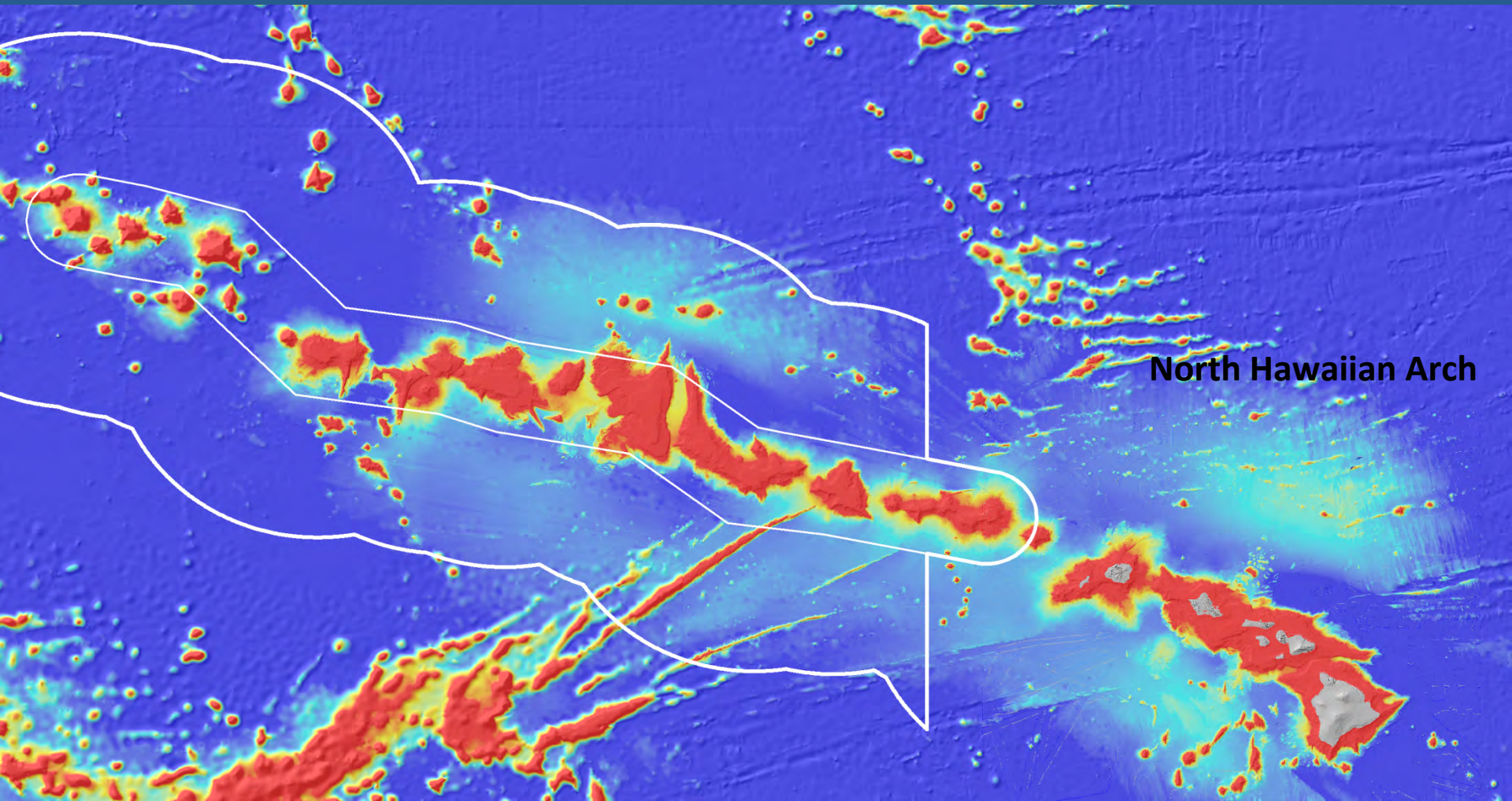


An Enigmatic Seamount Trail is Also Present in PMNM

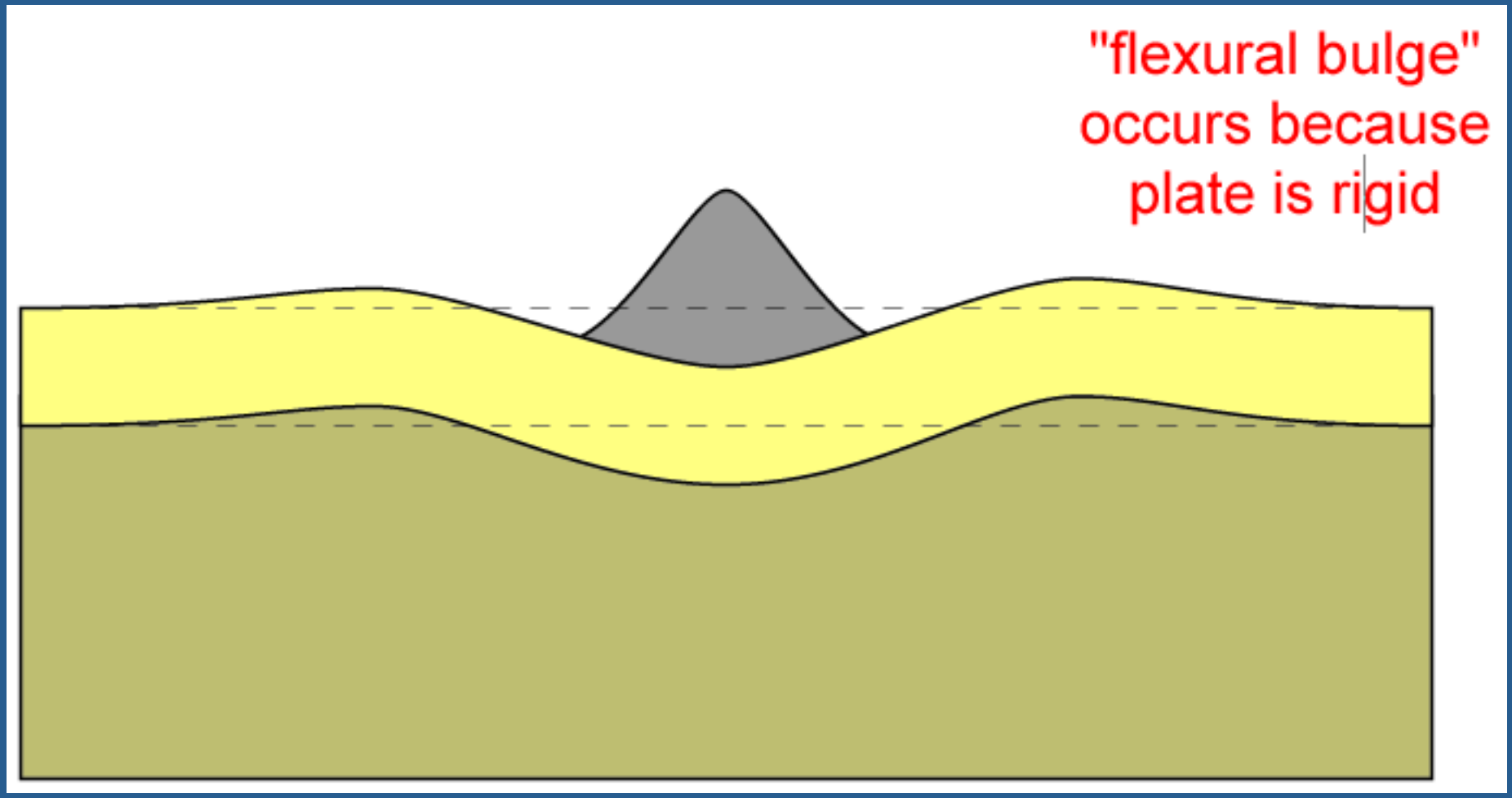


“These Enigmatic seamounts, particularly the western cluster, are located on the Hawaiian Arch.”

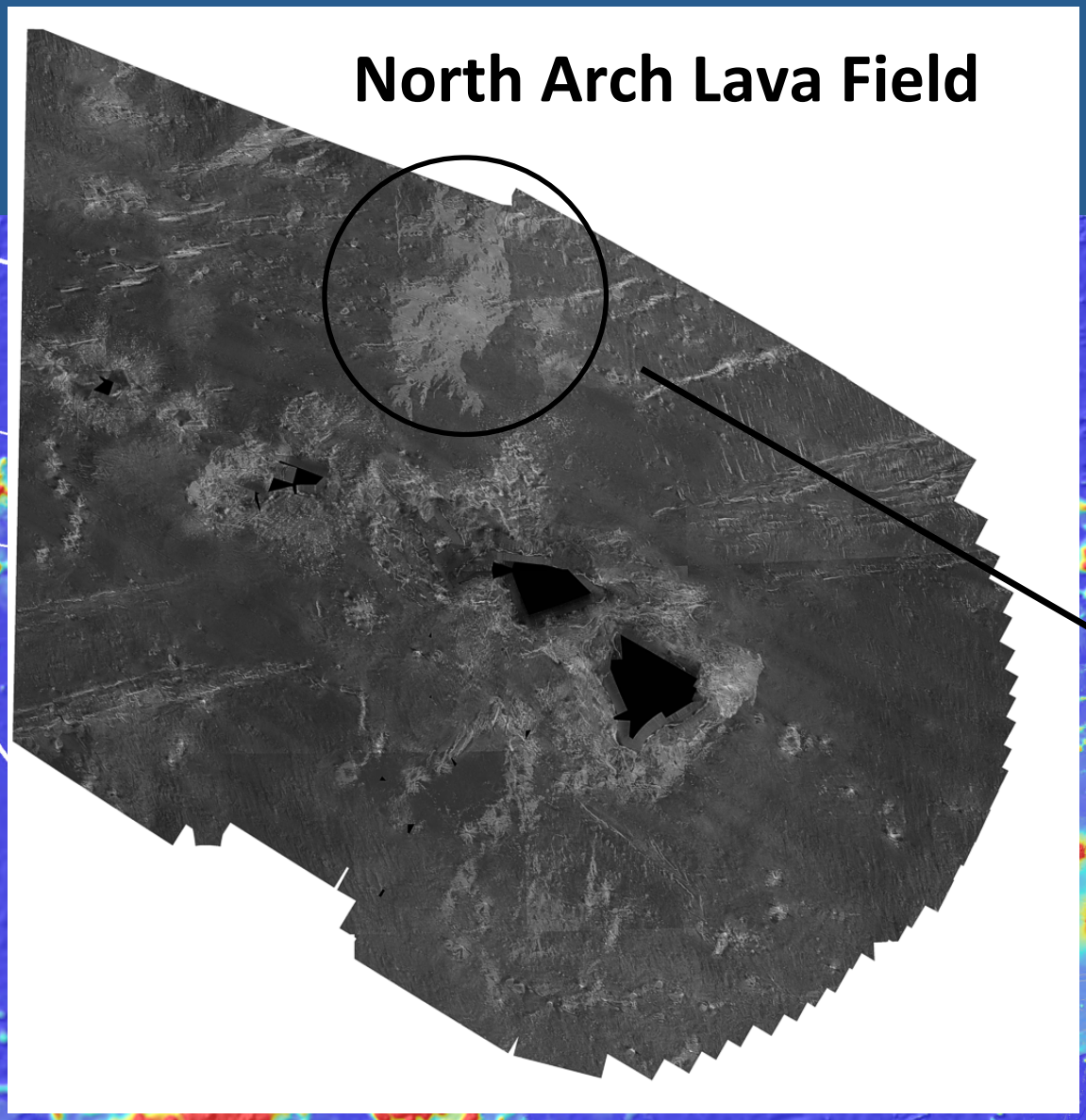
Jasper Konter, pers comm



Formation of the Hawaiian Trough and Arch

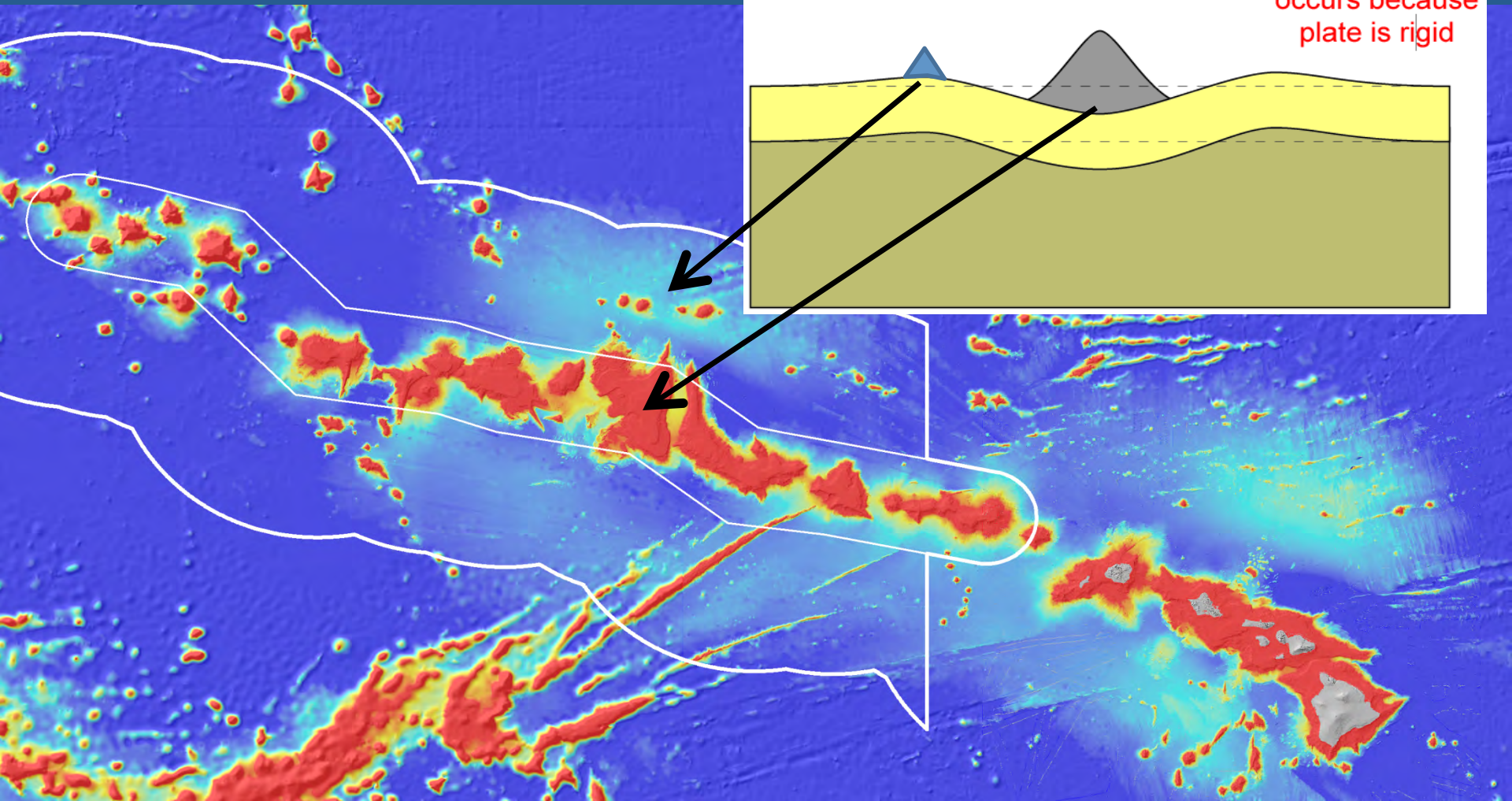


Gloria Sidescan Surveys 1980-90s



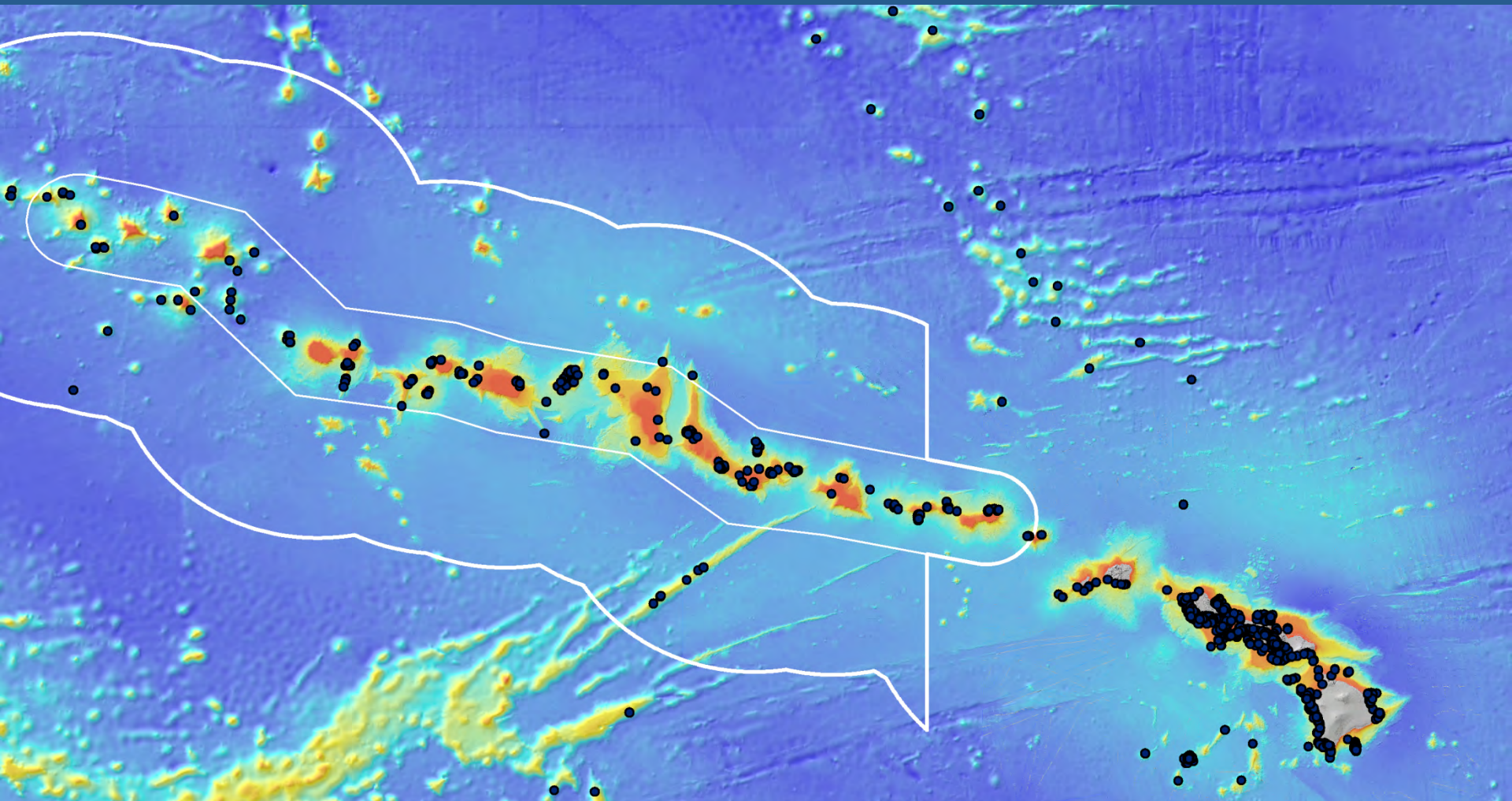
“These seamounts could have been formed by flexural arch secondary volcanism”

Jasper Konter, pers comm

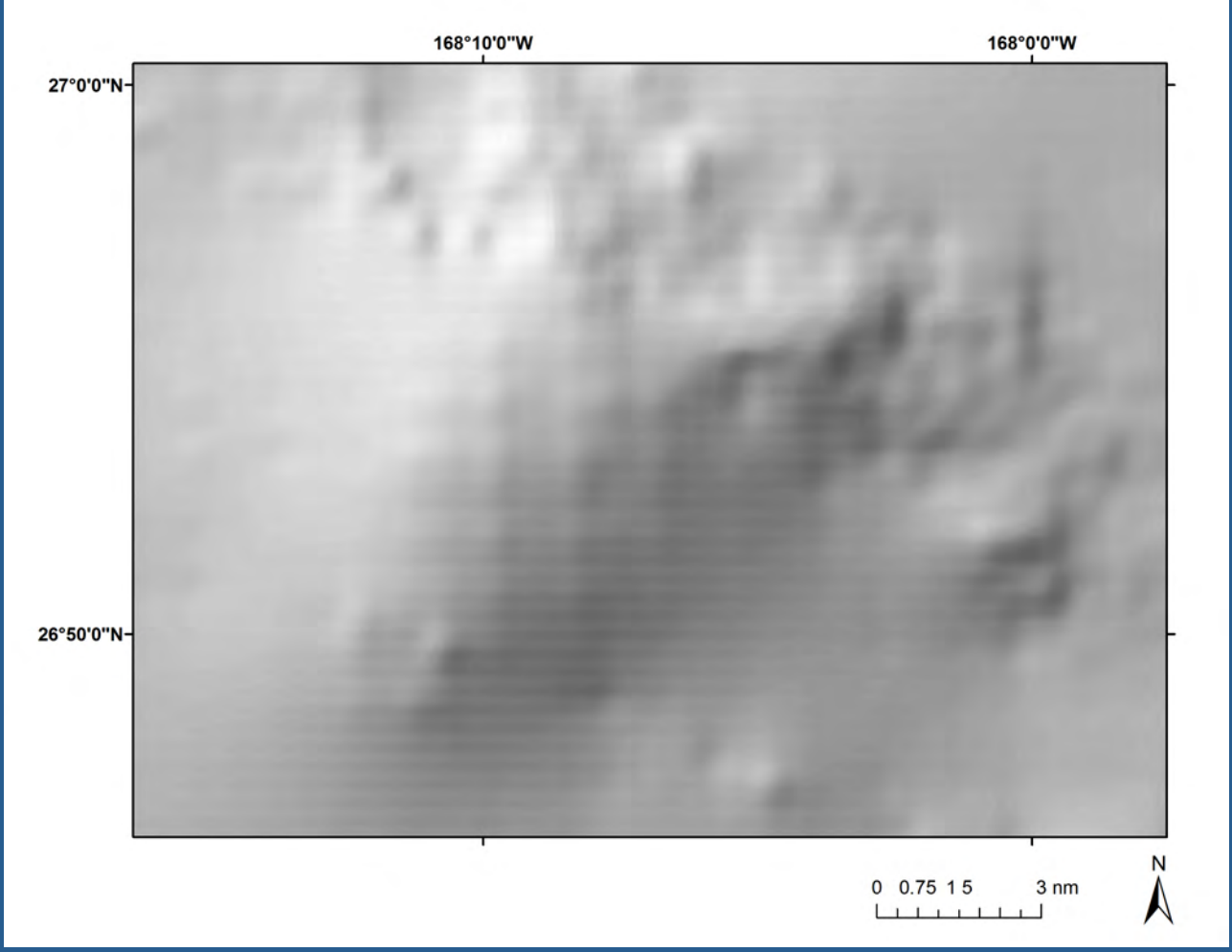


No one Had Ever Been to These Seamounts

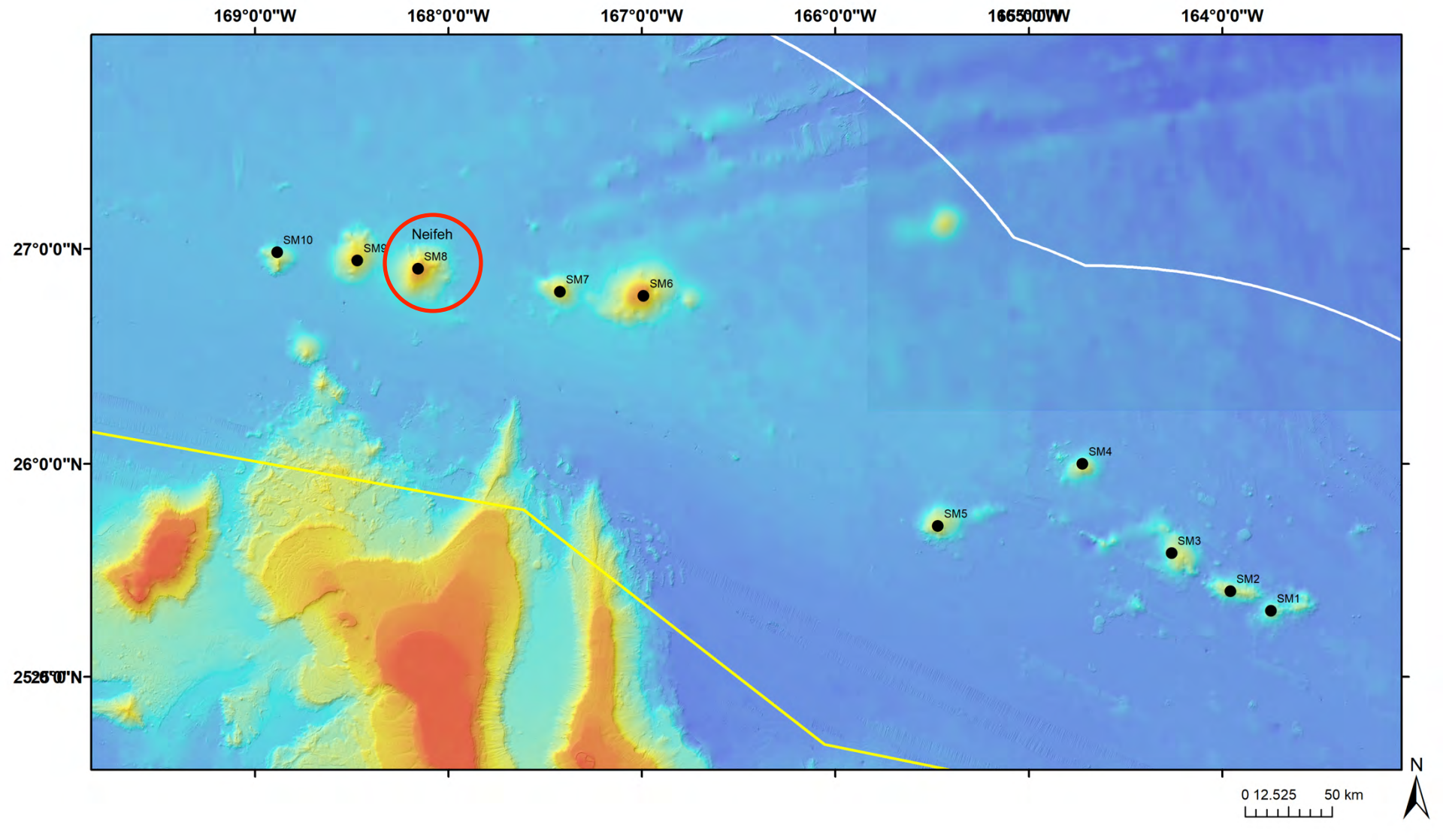
Previous Deepwater Exploration of PMNM



We Really Didn't Even Know What They Looked Like From Existing Satellite Data



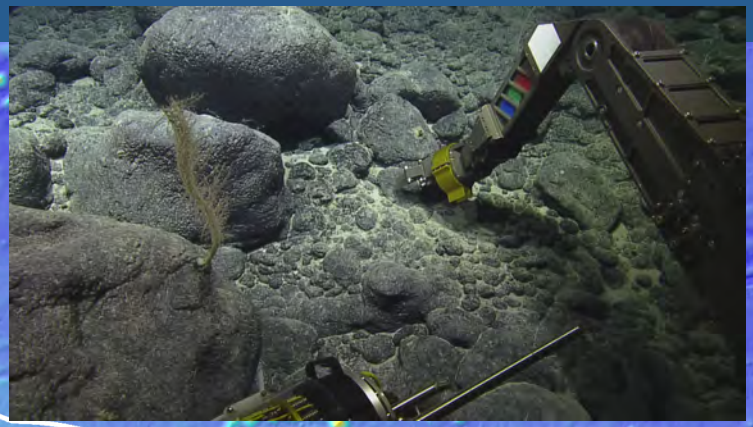
Only One of These Seamounts Even Had a Name



So What Did We Need to Do?

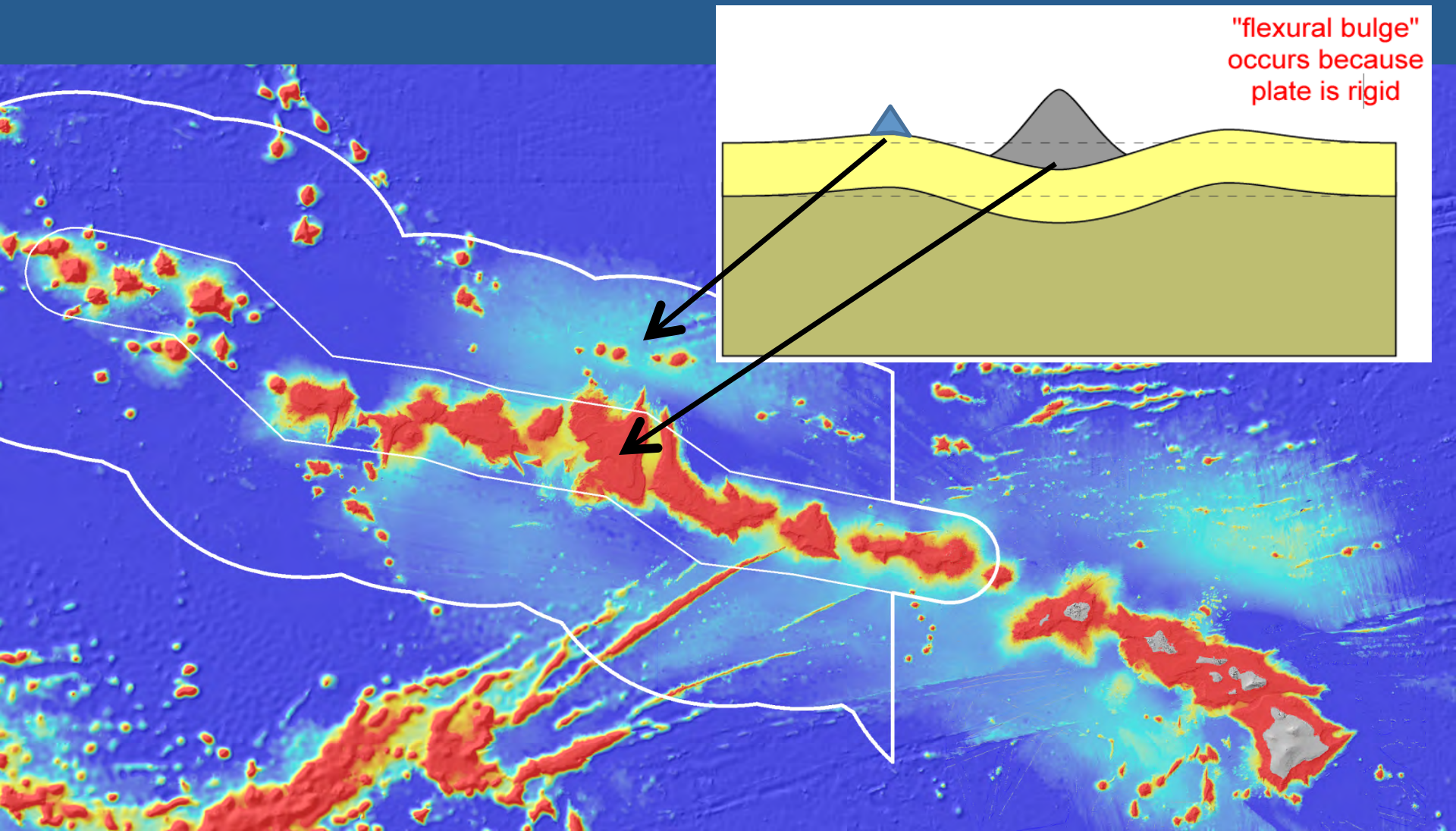
First, We Needed to Map Using Multibeam Sonar (Primary Objective 1)

Second, We Needed to Collect Rock Samples (Primary Objective 2)



If These Seamounts Were Formed by Arch Volcanism, They Should Have the Same Age as Gardner Pinnacles, ~ 12-14 Ma.

The Only Way to Determine That Was to Collect Rocks That Could be Dated



We Needed to Survey their Biological Resources (Primary Objective 3)

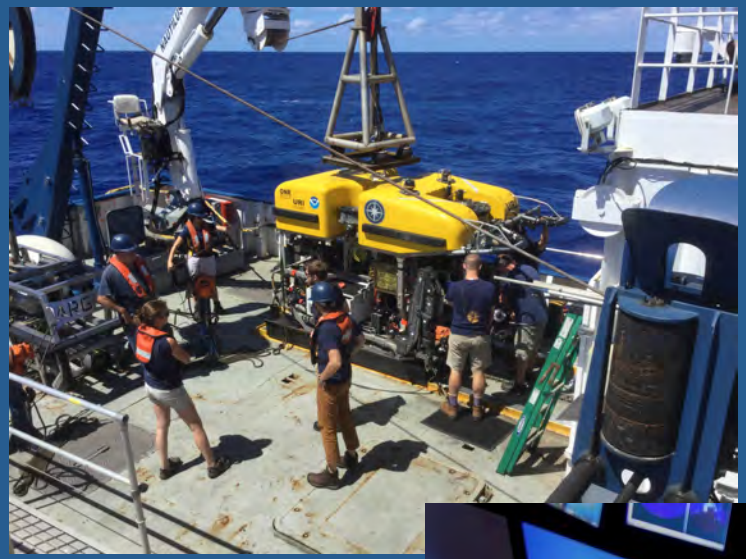
We Were Hoping to Find More Spectacular Deep Sea Coral & Sponge Communities Similar to Those We Had Found on Either Sides of These Seamounts During Earlier Dives Conducted off NOAA's *Okeanos Explorer* and UH's Ship *KOK*.

Naifeh Cluster

Un-named Cluster 1

This Time, We Had Their Sister Ship, R/V *Nautilus*, to do the Exploring

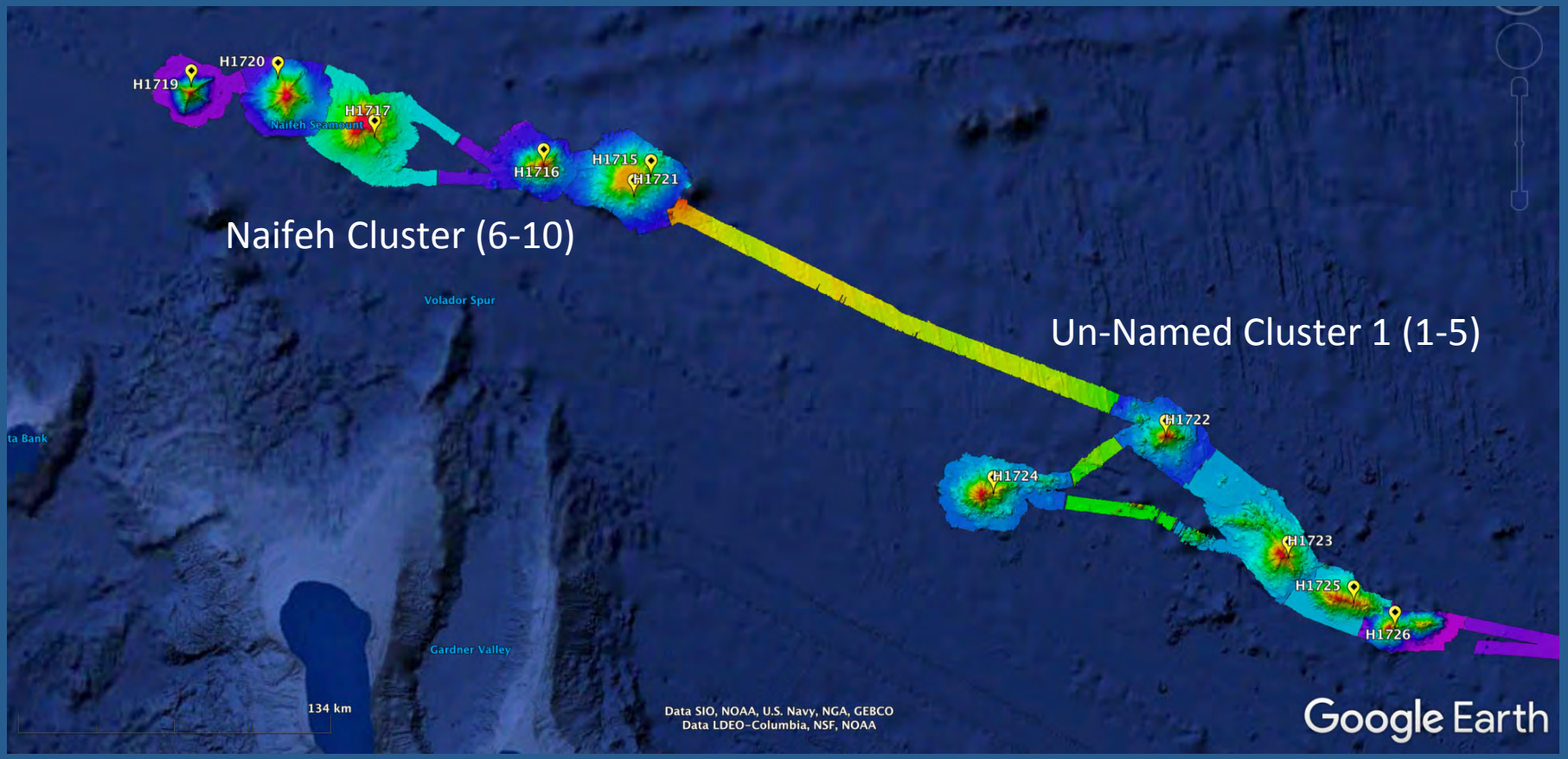
Operated by the Ocean Exploration Trust (OET), This Cruise, Designated NA101, Took Place September 15 to October 2, 2018



http://www.nautiluslive.org

Cruise Summary

Mapping and ROV Dives Conducted By the R/V *Nautilus* During NA101

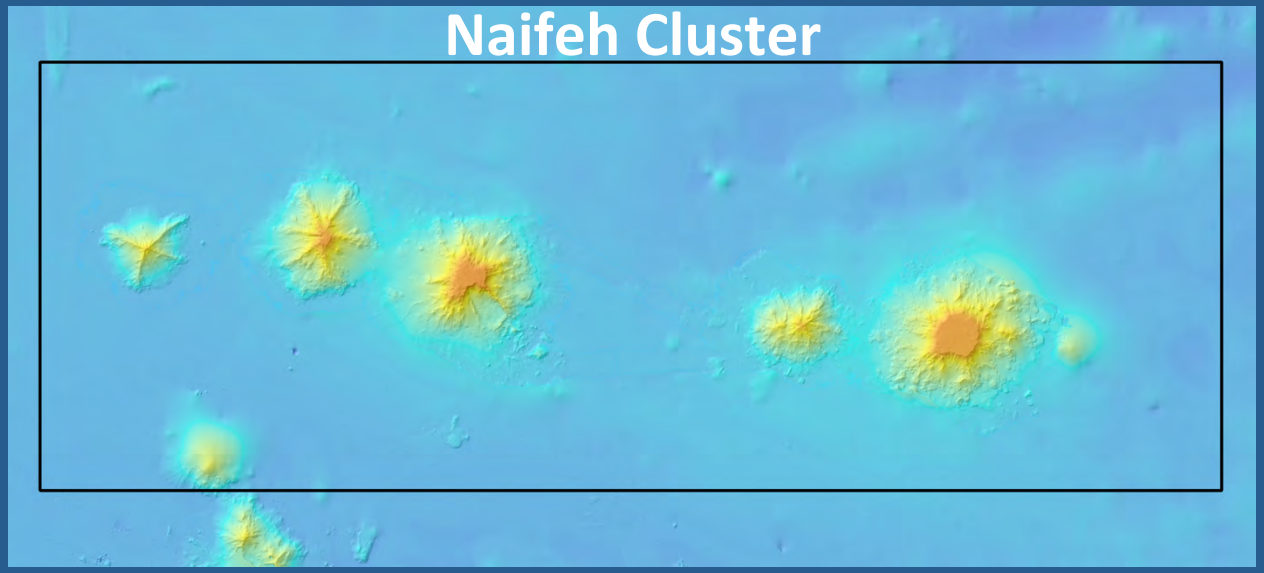


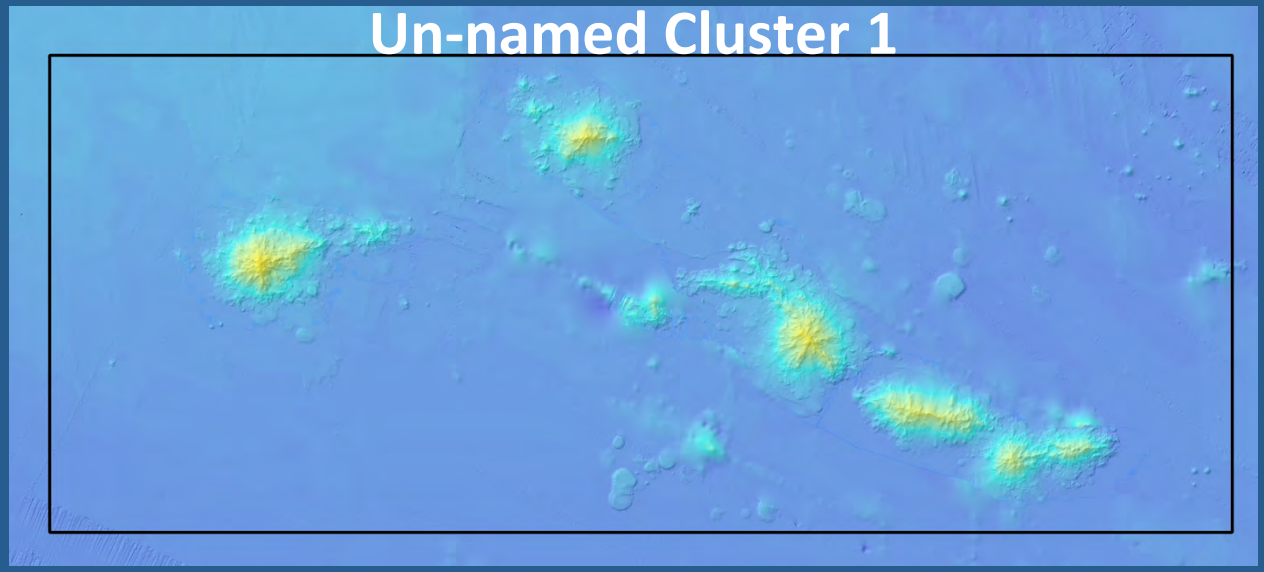
(Nicole Raineault, OET)

Primary Objective 1: Mapping During NA101

All 10 Seamounts Were Completely Mapped

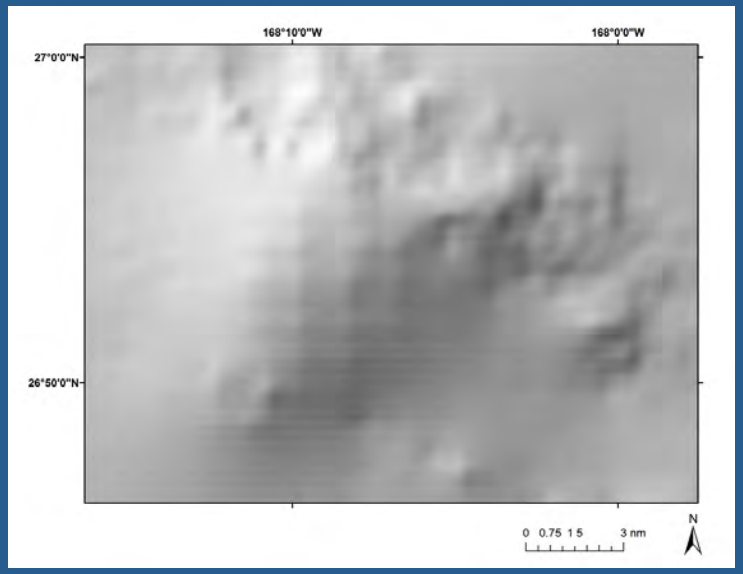
(Unknown Source)

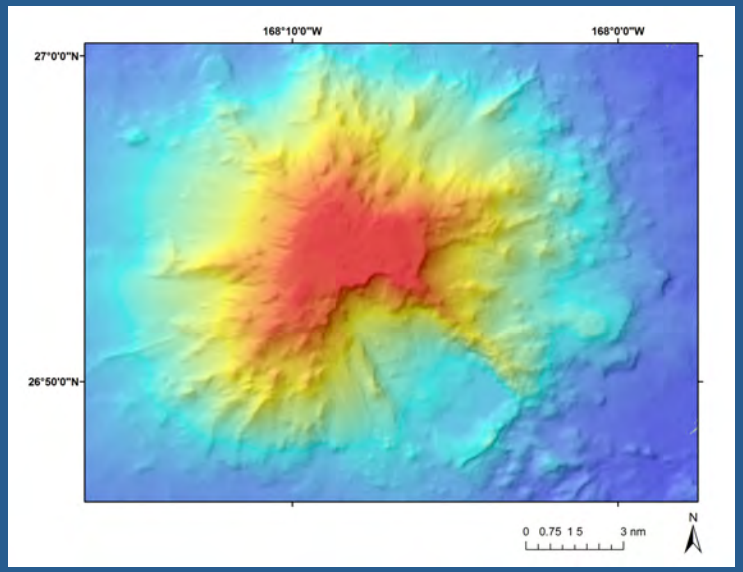




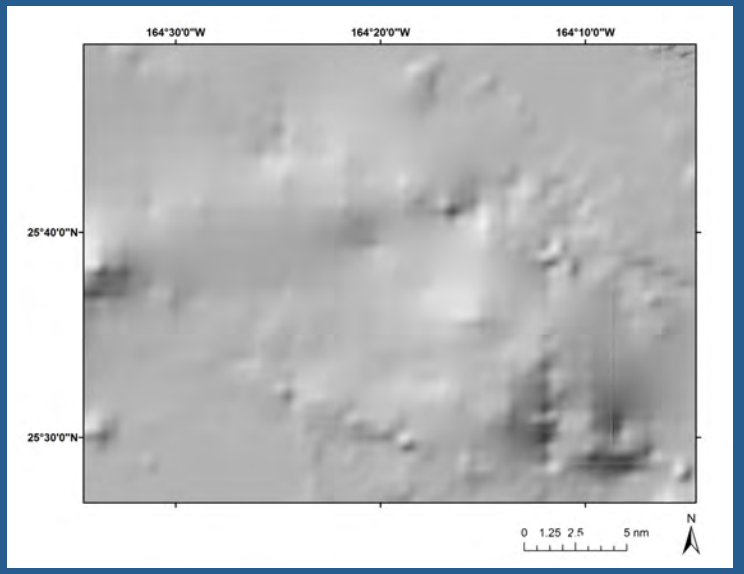
Before and After Mapping

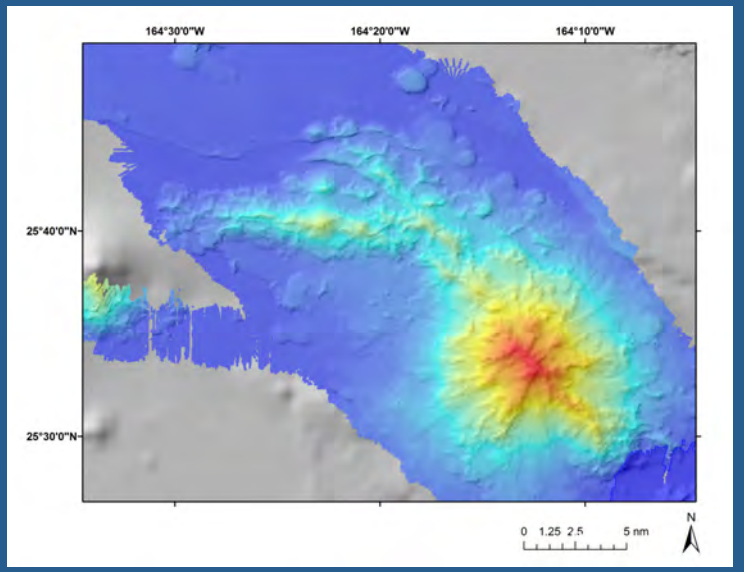
Naifeh Seamount (Summit at 723 m)





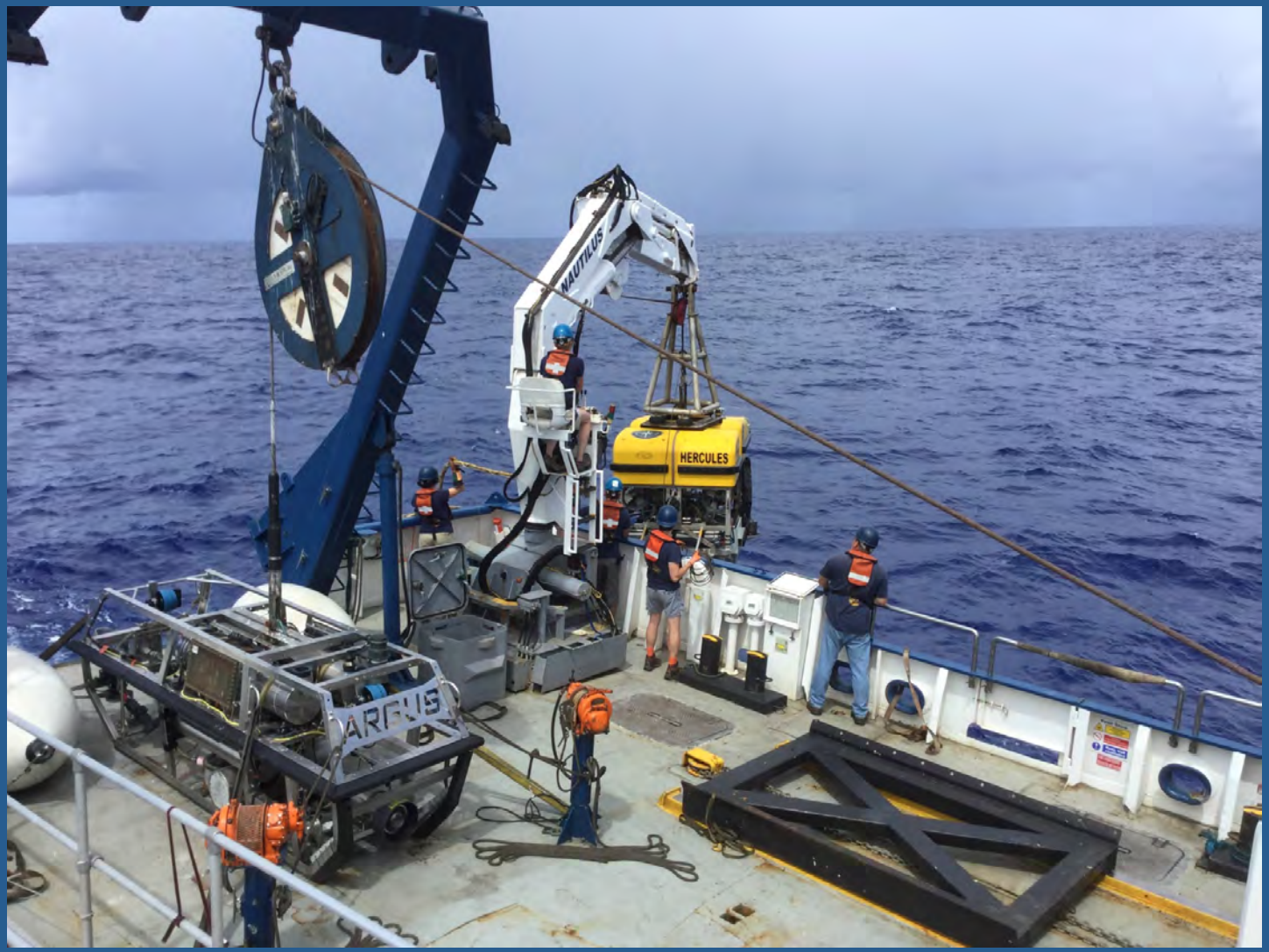
Seamount 3 (Summit at 1,676 m)





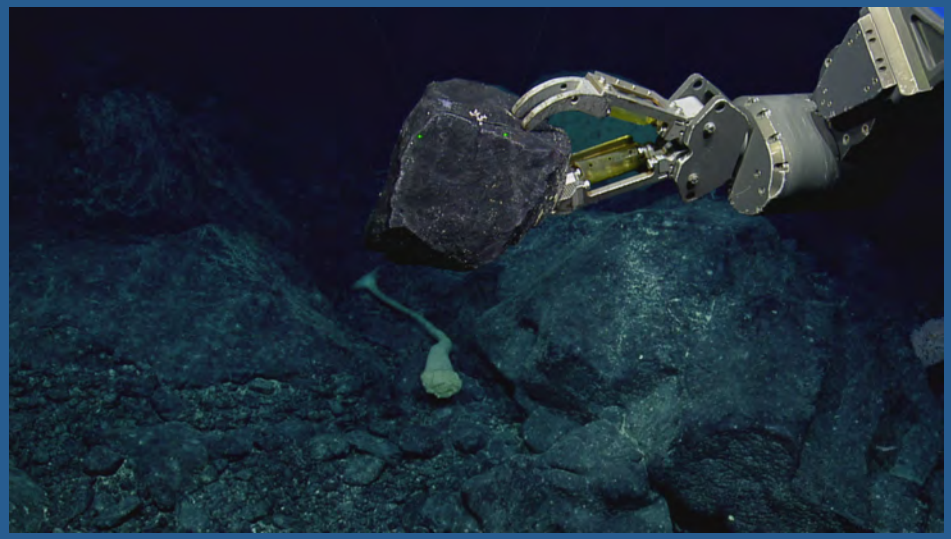
Eleven ROV Dives Completed During NA101

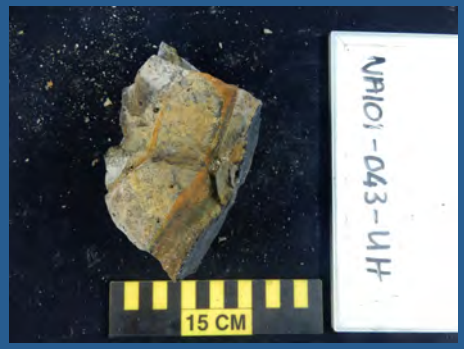
Dives Were Conducted on All 10 Seamounts at Depths of 1,243-2,844 m



Primary Objective 2: Geological Samples

A Total of 56 Rock Samples Were Collected From All 10 Seamounts

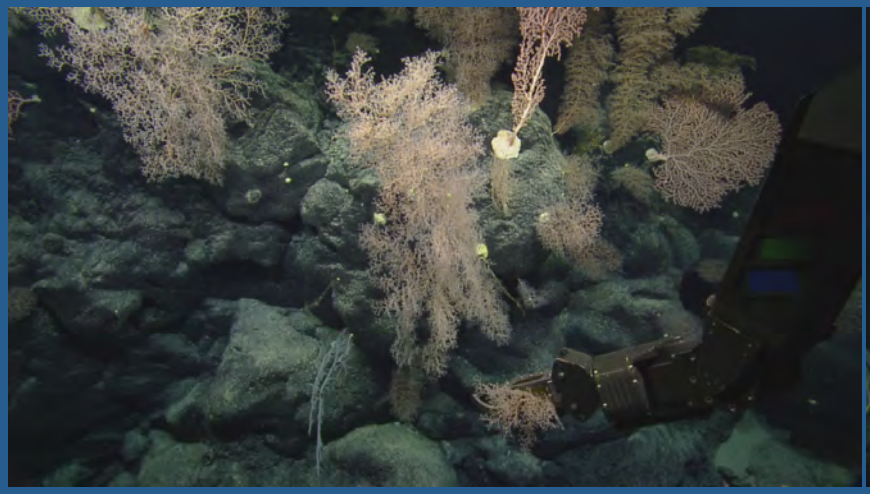


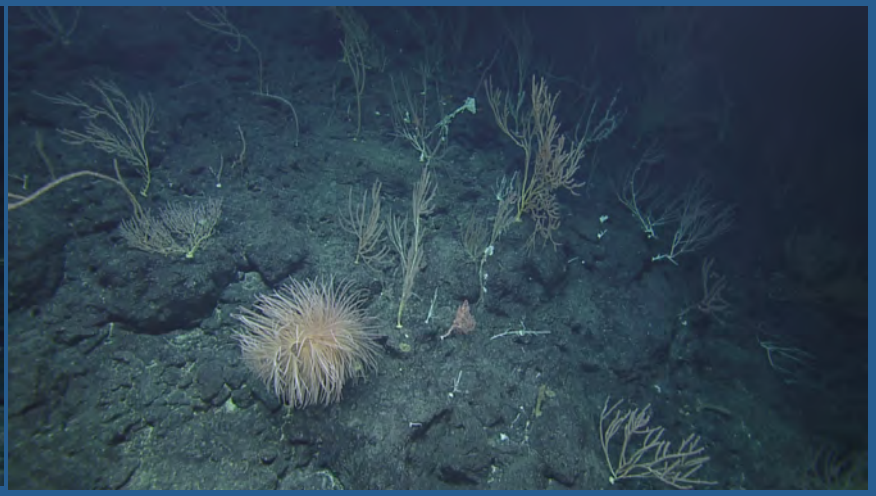


Rocks From 8 of the 10 Seamounts Appear to be Dateable Using Ar/Ar
All Rocks Were Split for Distribution to 4 Labs/Repositories

Primary Objective 3: Survey of Biological Resources

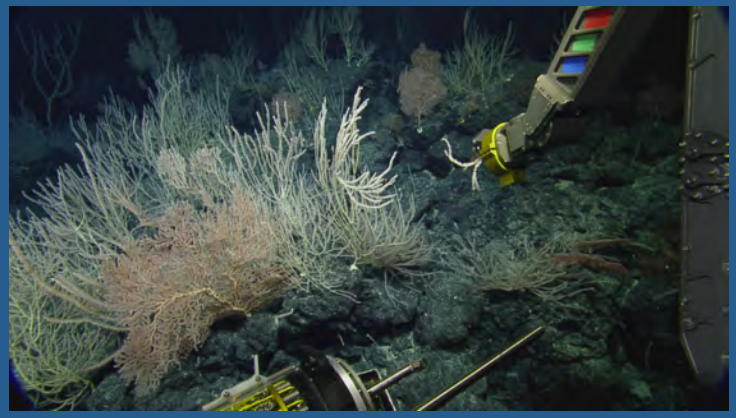
Five High Density Coral and Sponge Communities Were Discovered on Seamounts 4, 5, 6, Naifeh, and 9 With Densities of 3021-8064/km

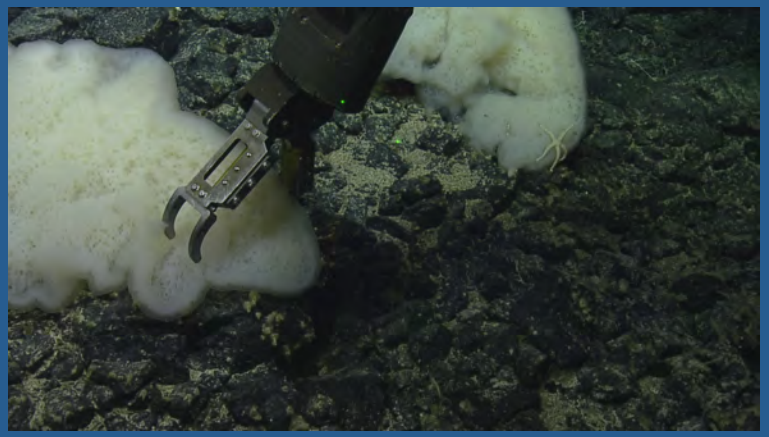




Primary Objective 3: Survey of Biological Resources

Forty-six biological specimens were collected that potentially including several new species of hexacorals and octocorals, 1 new glass sponge species, 2 new species of arthropods, 6 potential new species of holothuroideans, 1 new tunicate species, 2 new species of mollusks, 3 potential new species of seastars.

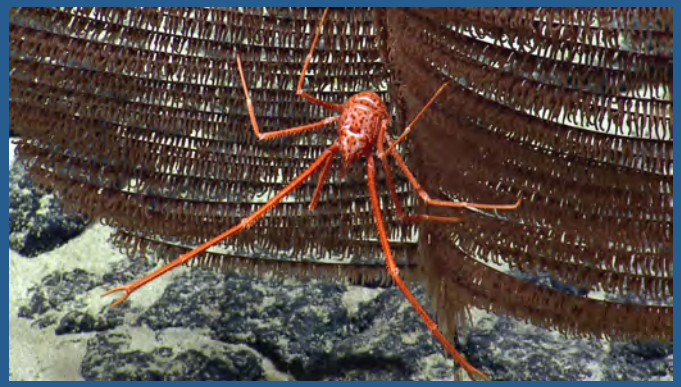




All specimens are being archived at the Museum of Comparative Zoology

117 Hrs of High Definition Video and 1000's of Image Captures

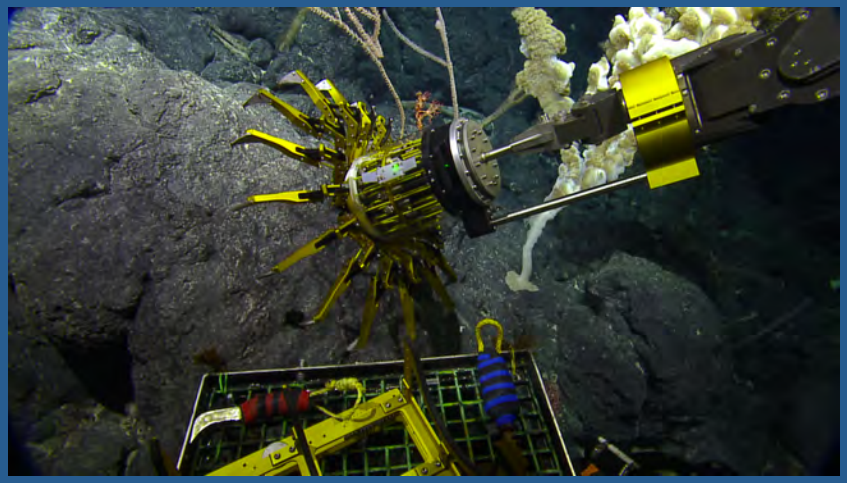
Many Different Types of Animals Were Documented



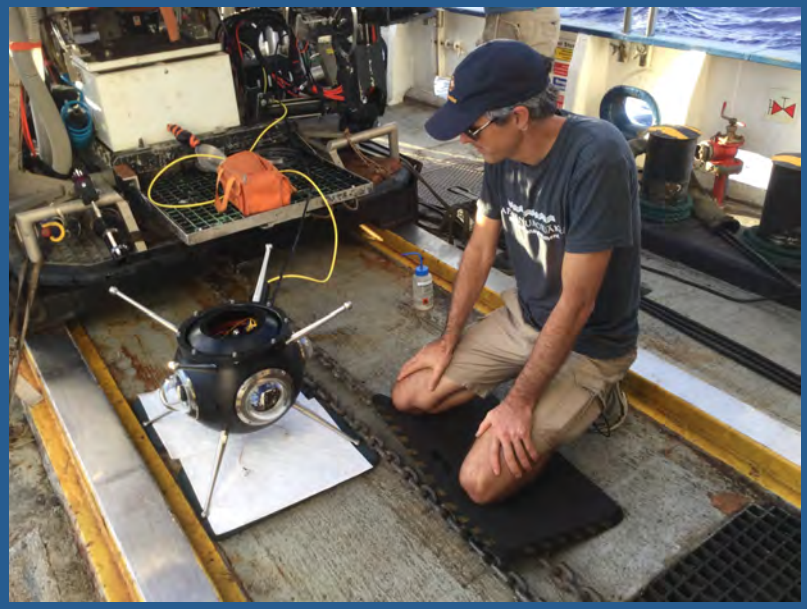
Gulper Eel Video

Secondary Objectives

Testing of A New JPL Gripper During the Dives



Testing of A New 3D Camera During the Dives



Collecting Water Samples for eDNA Analysis

Post Cruise Update

Enigmatic Seamounts Exploring the Geologic Origins and Biological Communities in Papahānaumokuākea Marine National Monument

By Christopher Kelley, Thomas Hourigan, Nicole A. Raineault, Andrea Balbas, Dorsey Wanless, Leigh Marsh, Rebecca Wipfler, Lila Ardor Bellucci, and Renato Kane

The Papahānaumokuākea Marine National Monument (PMNM) was established in 2006 to protect all emergent land (i.e., islands, atolls, pinnacles) in the Northwestern Hawaiian Islands (NWHI) as well as the seas extending 50 nautical miles (nm) out from these features. In 2016, the boundary was expanded to the full 200 nm US Exclusive Economic Zone, making PMNM the largest contiguous marine protected area in the country. Since the expansion occurred only two years ago, previous deepwater research in the monument was focused almost entirely within the original 50 nm boundaries. Submersible and ROV dives had only been conducted on five of the 88 seamounts in the "expansion area." Providing PMNM's management with more information on the resources in this part of the monument was the main driver for E/V *Nautilus* cruise NA101, conducted from September 15 through October 2, 2018.

The NA101 dives focused on two clusters of enigmatic seamounts located north of Gardner Pinnacles (Naifeh cluster) and Necker Island (unnamed cluster) (Figure 1) that had not previously been mapped or explored. Their location north of the NWHI chain and lineation may indicate they formed by "arch volcanism." This type of volcanism occurs along a flexural bulge that forms due to loading of the oceanic plate by an adjacent large volcanic edifice, in this case Gardner. This poorly understood process has been linked to the formation of a large lava field north of the Big Island of Hawai'i. If they were formed by arch volcanism, then Gardner and the seamount chains should have formed contemporaneously. Thus, the primary geologic objectives of the cruise were to determine the age of the seamount lavas using $^{40}Ar/^{39}Ar$ dating methodologies and analyze the geochemical constituents to better understand volcanic dynamics and origins.

The primary biological objectives were to determine if high-density, filter-feeding communities were present on these seamounts and to survey for new species or new records of species for this area of the Pacific. Prior to this cruise, 14 spectacular communities of deep-sea corals, sponges, and their associates had been found in PMNM at depths of over 1,500 m. Only one of these is located within the expansion area, although many more are believed to exist. Such communities represent hotspots of biological diversity in the deep sea and are thus principal targets for conservation. The primary mapping objectives were to

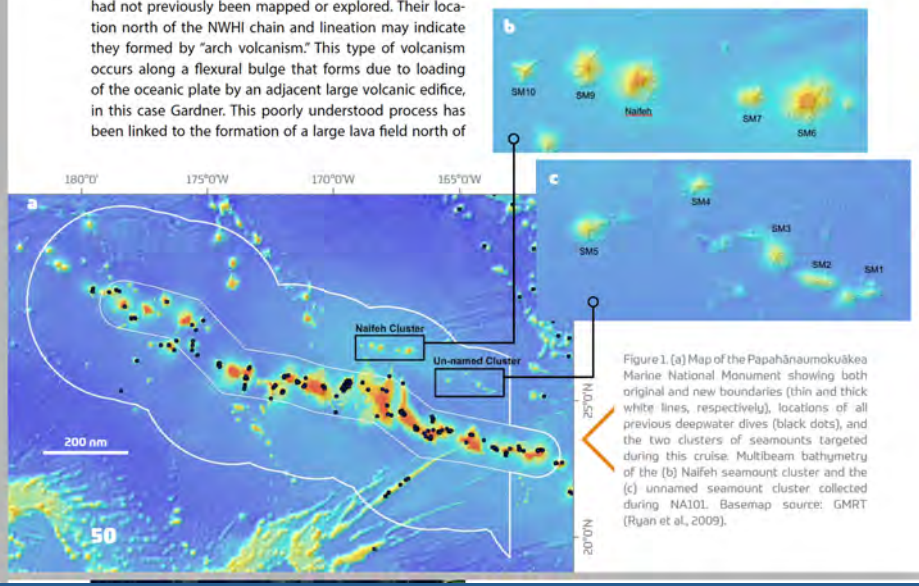
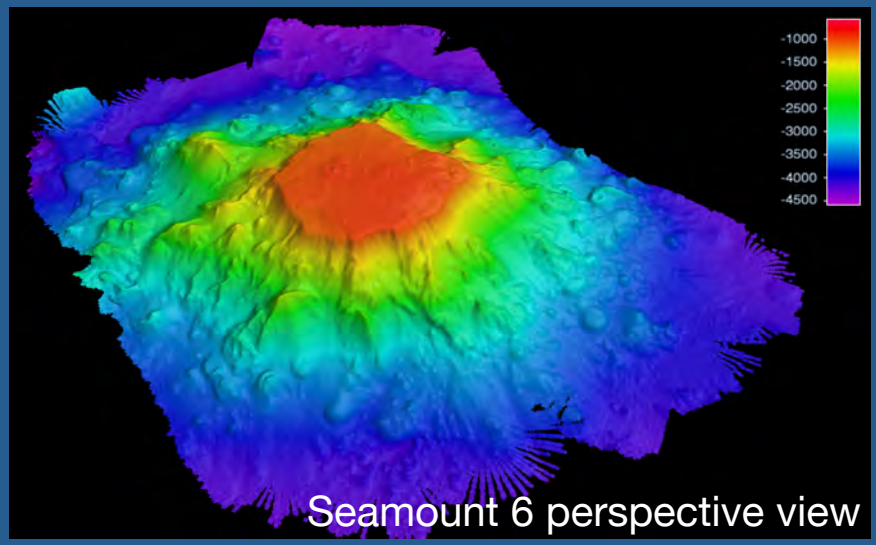


Figure 1. (a) Map of the Papahānaumokuākea Marine National Monument showing both original and new boundaries (thin and thick white lines, respectively), locations of all previous deepwater dives (black dots), and the two clusters of seamounts targeted during this cruise. Multibeam bathymetry of the (b) Naifeh seamount cluster and the (c) unnamed seamount cluster collected during NA101. Basemap source: GMRT (Ryan et al., 2009).

Kelley, C., T. Hourigan, N. Raineault, A. Balbas, D. Wanless, L. Marsh, R. Wipfler, L. Bellucci, R. Kane. 2019. Exploring the Geologic Origins and Biological Communities of Enigmatic Seamounts in the Papahānaumokuākea Marine National Monument. *Journal of Oceanography.* 32-1, p. 50-51.

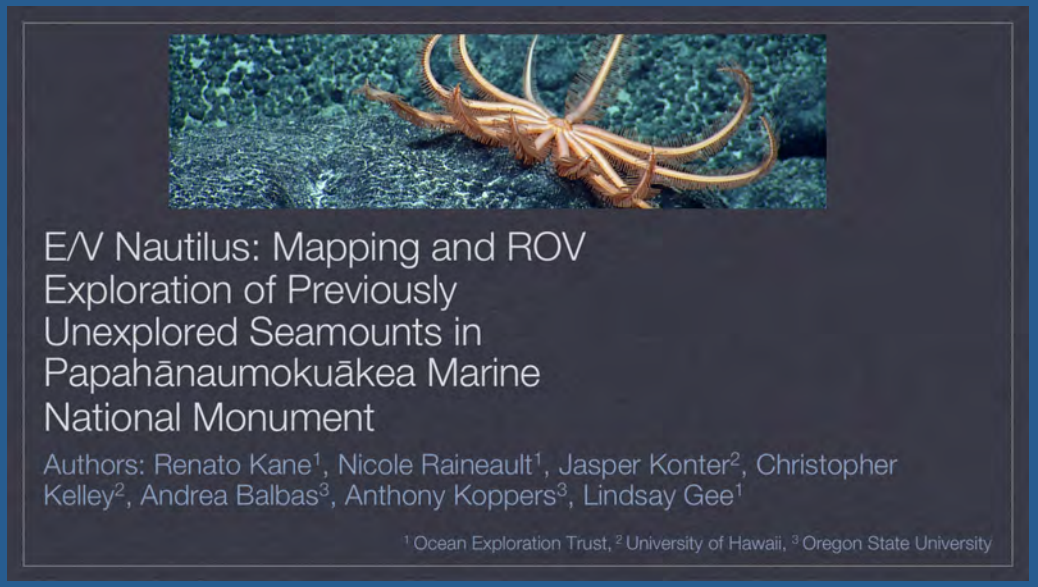
Post Cruise Update on Primary Objective 1: Mapping

- 16,594 km^2
- Three of five seamounts in the Naifeh cluster were revealed to be guyots, indicating they had once reached the ocean surface



Data Have All Been Submitted to NCEI and Are Publicly Available

(Renato Kane OET presented at OceanObs 2019)



Post Cruise Update on Primary Objective 2: Geology

Enigmatic Seamounts:
Investigating Pacific intraplate volcanism with lead isotopes

Molly J. Cunningham[1*], Jasper G.|Konter[2], V. Dorsey Wanless[3], Andrea Balbas[4]

[1] **Rensselaer Polytechnic Institute**, Department of Earth and Environmental Science, *cunnim4@rpi.edu | [2] **University of Hawaii at Mānoa**, School of Ocean and Earth Science and Technology
[3] **Boise State University**, Department of Geosciences | [4] **Oregon State University**, College of Earth, Ocean and Atmospheric Sciences

INTRODUCTION

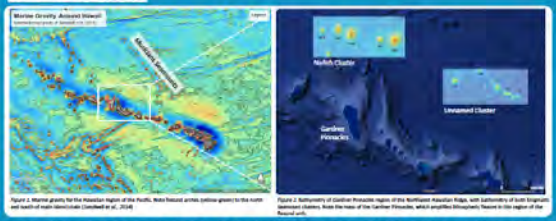
The Enigmatic Seamounts are two clusters of submarine volcanoes notable for their unusual volume: some of them once breached the ocean surface, evidenced by their guyot structure.

The isotopic composition of igneous rocks is indicative of their source in the mantle and the magmatic processes that caused them to erupt.

This study compares the lead isotopic composition of the Enigmatic Seamounts to established values for three varieties of Pacific intraplate volcanism.

Overlap in isotopic space will indicate the Seamounts' magmatic origin and advance scientific understanding of the development of Pacific volcanoes.

STUDY LOCATION



SAMPLES AND METHODS

Samples are **alkali basalts** based on petrography.

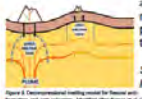
Secondary minerals include: **FeMn crust, zeolitic vesicle fill, $CaCO_3$ vesicle fill**.

Secondary minerals removed by cutting, manual separation, acid leaching. Samples were passed through two **resin columns** to isolate Pb isotopes. Isotopic analysis was conducted on a Multi-Collector Inductively Coupled Plasma Mass Spectrometer (**MC-ICPMS**) relative to NBS 981.

VOLCANIC ORIGIN THEORIES

Many varieties of intraplate volcanism occur in the Hawaiian region of the Pacific Plate. There are three mechanisms by which the Enigmatic Seamounts may have been erupted:

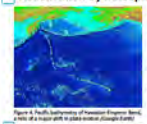
1 Arch volcanism *(Bianco et al., 2005)*



On-chain loading causes up-flexure of the adjacent lithosphere; decompressional melting underneath these flexural arches produces eruptions, which may be related to on-chain rejuvenated volcanism.

Supported by location along flexural arch, linear shape of clusters

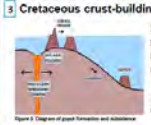
2 Reactivation by lithospheric extension *(O'Connor et al., 2015)*



The ~50 Ma shift in Pacific Plate motion may have caused extensional fracturing, allowing MORB-like melts to erupt through a system of normal faults.

Supported by proximity to Musicians Seamounts and Murray Fracture Zone

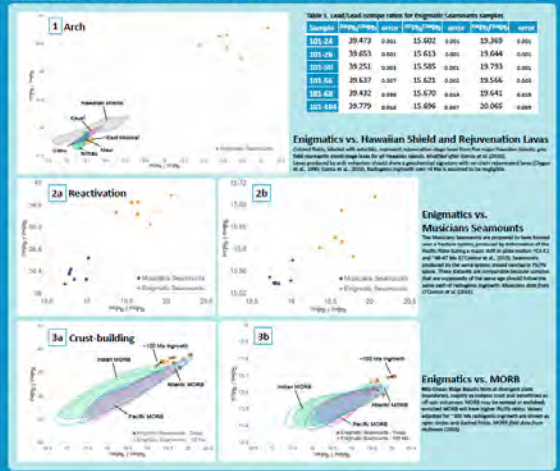
3 Cretaceous crust-building



Seamounts formed off-axis of a mid-ocean ridge, so that increasing subsidence with increasing distance from spreading center may explain the presence of guyots

Supported by large degree of subsidence evident from guyots

RESULTS: A COMPARISON TO ESTABLISHED ISOTOPIC SIGNATURES



DISCUSSION

Lead isotopes are highly constrained indicators of mantle sources. If lavas share a reservoir, their geochemical indicators should overlap in isotopic space.

When compared to other Pacific intraplate lavas:

1. **Arch volcanism**
   Enigmatic signatures are high in ^{206}Pb, ^{207}Pb and ^{208}Pb relative to rejuvenated lavas, eliminating arch volcanism as a source. Enigmatic signatures are distinct from all Hawaiian lavas, suggesting they are not associated with the Hawaiian hotspot.
2. **Reactivation by lithospheric extension**
   Enigmatic Pb signatures are too radiogenic to overlap with Musicians Seamounts MORBs; they are not a product of Pacific extension.
3. **Cretaceous crust-building**
   Enigmatic Pb signatures overlap most with MORB reservoirs. Enigmatic Pb is most likely derived from the radiogenic end-member of Pacific MORB.

CONCLUSION

These samples have very radiogenic ^{208}Pb, ^{207}Pb, and ^{206}Pb values that distinguish them from Hawaiian lavas and Musicians Seamount lavas.

In a comparison with fields of established values for other volcanism types, samples from the Enigmatic Seamounts are most similar to E-MORB and may be representative of the radiogenic end-member of MORB lavas.

Ongoing research will determine age and bulk geochemistry of the Enigmatic Seamounts. Further isotopic investigations should produce Hf, Nd, Sr, and/or Os ratios to better constrain their mantle source and eruptive mechanism.

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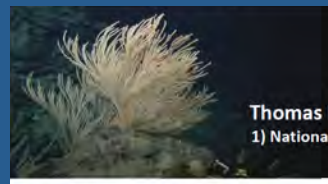
ACKNOWLEDGEMENTS

Infinite thanks to Jasper Konter for serving as my mentor and guiding me through this project! Thanks also to Bridget Smith-Konter, Diamond Tachera, Lauren Ward, and Blythe Okuhata for coordinating this research experience, and to Andrea Balbas and Dorsey Wanless for serving as geologists on the expedition that collected these samples. This research was supported by sampling by CIET's EV Nautilus, and NSF Grant No. 1558108.

(Molly Cunningham & Jasper Konter, University of Hawaii, presented at AGU 2019)

Post Cruise Update on Primary Objective 3: Biology



Exploring Deep-Sea Coral and Sponge Communities on Enigmatic Seamounts North of the Central Hawaiian Ridge

Thomas Hourigan[1], Christopher Kelley[2], Nicole Raineault[3], Leigh Marsh[4], Lila Ardor Bellucci[5], Rebecca Wipfler[6]
1) National Oceanic and Atmospheric Administration; 2) University of Hawai`i; 3) Ocean Exploration Trust; 4) University of Southampton; 5) Eckert College; 6) University of Illinois at Urbana-Champaign

Exploration – First Look:

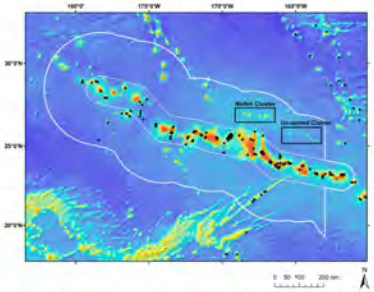
We present initial results from the Ocean Exploration Trust's *E/V Nautilus*, which mapped and conducted 11 remotely-operated vehicle (ROV) surveys on 10 previously unexplored seamounts in Sept. 2018.

Cruise Highlights:

- *Mapping:* 16,594 km² mapped
- *Biology:* High-density coral & sponge communities were documented on 4 seamounts. 46 biological samples and 14 e-DNA samples collected.
- *Geology:* 65 rock samples collected for 40Ar/39Ar dating to determine the age of the seamounts and to analyze geochemistry to better understand volcanic dynamics and origins.
- Instrument testing: Successful tests of a 360° camera (Massachusetts Inst. Tech.) and ROV-deployed "gripper" tool.

An Expanded Monument

In 2016, Papahānaumokuākea Marine National Monument was expanded to create the nation's the largest contiguous marine protected area. There have been few surveys The unexplored seamounts are among 80 seamounts in the expansion area – only five of which have been visited.

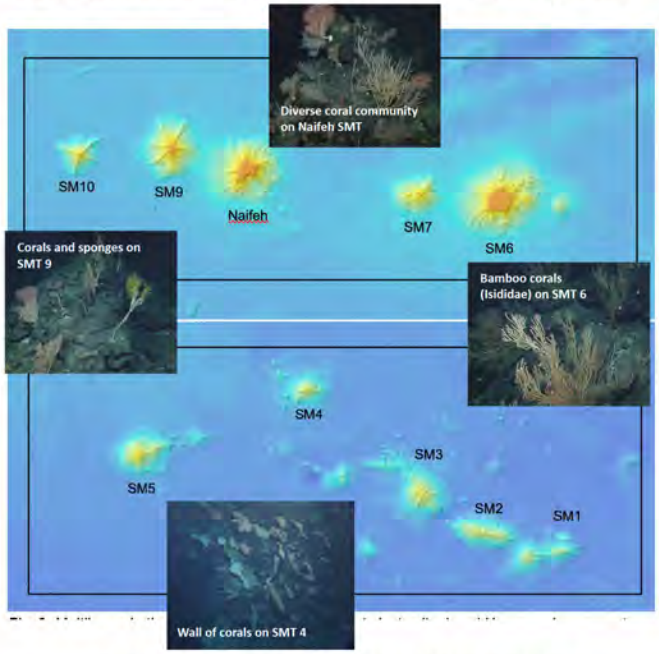


Papahānaumokuākea Marine National Monument showing the two clusters of previously unmapped and unexplored seamounts targeted during this cruise. Black dots are the location of all previous deep water dives around the Northwestern Hawaiian Islands.

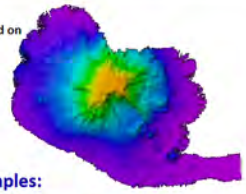
Coral and Sponge Communities – Hot-spots of Biodiversity in the Deep Sea

Discovering habitats with high-density deep-sea corals and sponges and understanding their distribution is a priority for conservation planning. On Pacific seamounts, such communities can be damaged by human activities, such as bottom-contact fishing or deep-sea mining.

Gorgonians, black corals and glass sponges (Class Hexactinellida) were observed on all dives, with high-density communities on four seamounts at depths between 1548-2420 m. Corals were the dominant taxa in most high-density communities, but species composition varied from those dominated by bamboo corals (Fam. Isididae) to others with a diversity of taxa (esp. Fam. Chrysogorgiidae, Coralliidae, Primnoidae). A variety of glass sponges also occurred in high densities.



OCEAN EXPLORATION TRUST



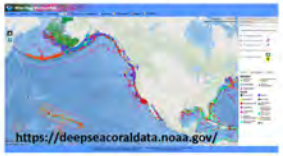
High density coral/sponge communities were observed on ridge features (Naifeh Seamount)

Biological Samples:

Biological Samples – 46 primary biological samples were collected, including a number of probable new species. Collections included 6 glass sponges, 13 octocorals, 3 black corals, 4 galatheoid squat lobsters, 1 sea urchin, 6 sea cucumbers, 2 ophiuroids, 3 sea star, 2 mollusks, & 2 stalked tunicates. Vouchers from all samples are housed at Harvard's Museum of Comparative Zoology

Next Steps:

- Coral and sponge observations will be annotated by the U. Hawaii Undersea Research Laboratory and made available by NOAA's Deep Sea Coral Research & Technology Program



- Corals will be DNA barcoded & eDNA will be analyzed for octocoral signatures
- Rock samples – geochemistry and 40Ar/39Ar dating

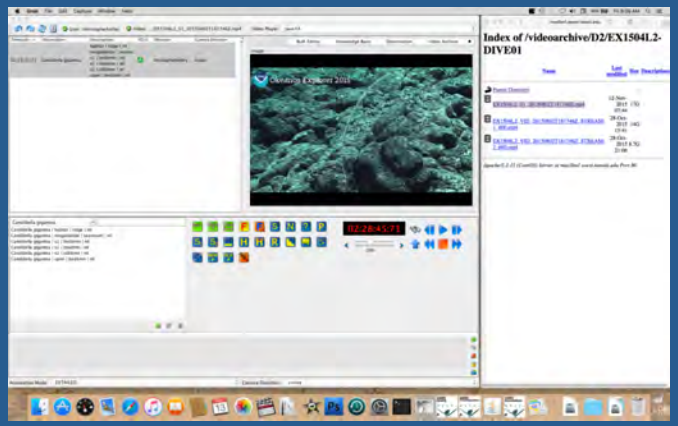
Acknowledgments

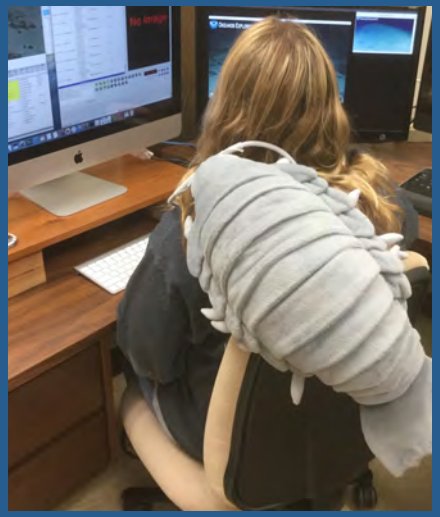
We wish to thank the OET Corps of Exploration aboard the E/V Nautilus, as well as the many shore-based scientist who contributed to the success of this exploration,

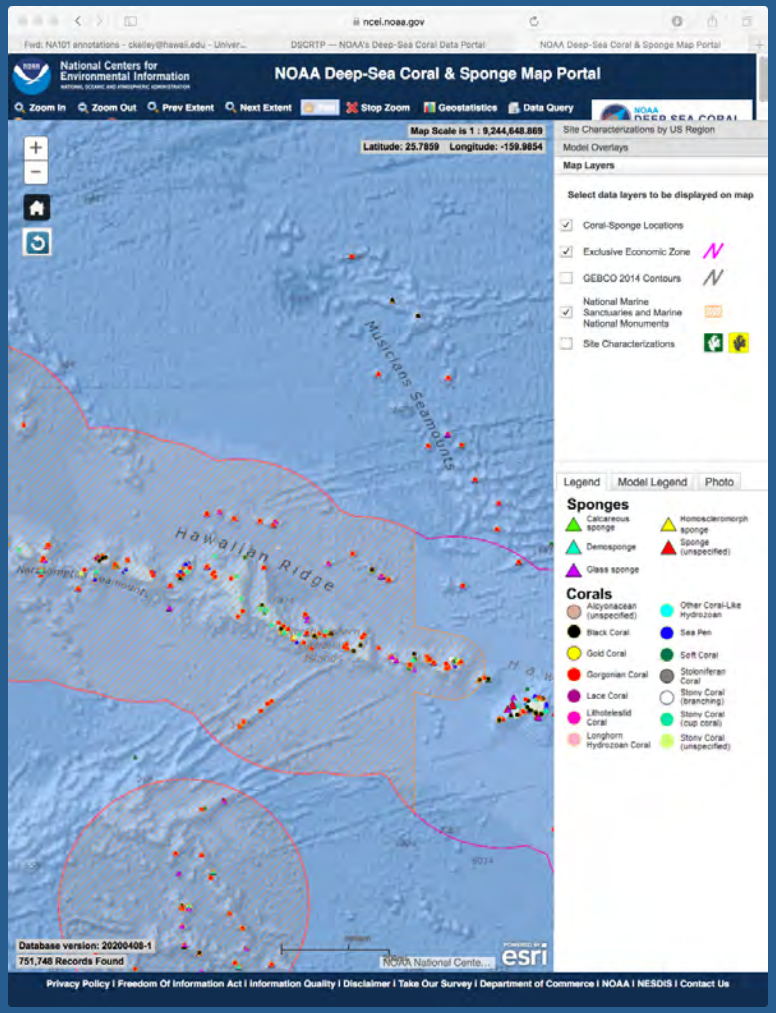
(Tom Hourigan, NOAA DSCRTP, presented at Ocean Sciences 2020)

Post Cruise Update: Primary Objective 3: Biology

All Video was Annotated and the 15,905 Records Were Submitted to NOAA DSCRTP Documenting Over 45,000 Corals and Sponges along with 4,839 Associated Animals





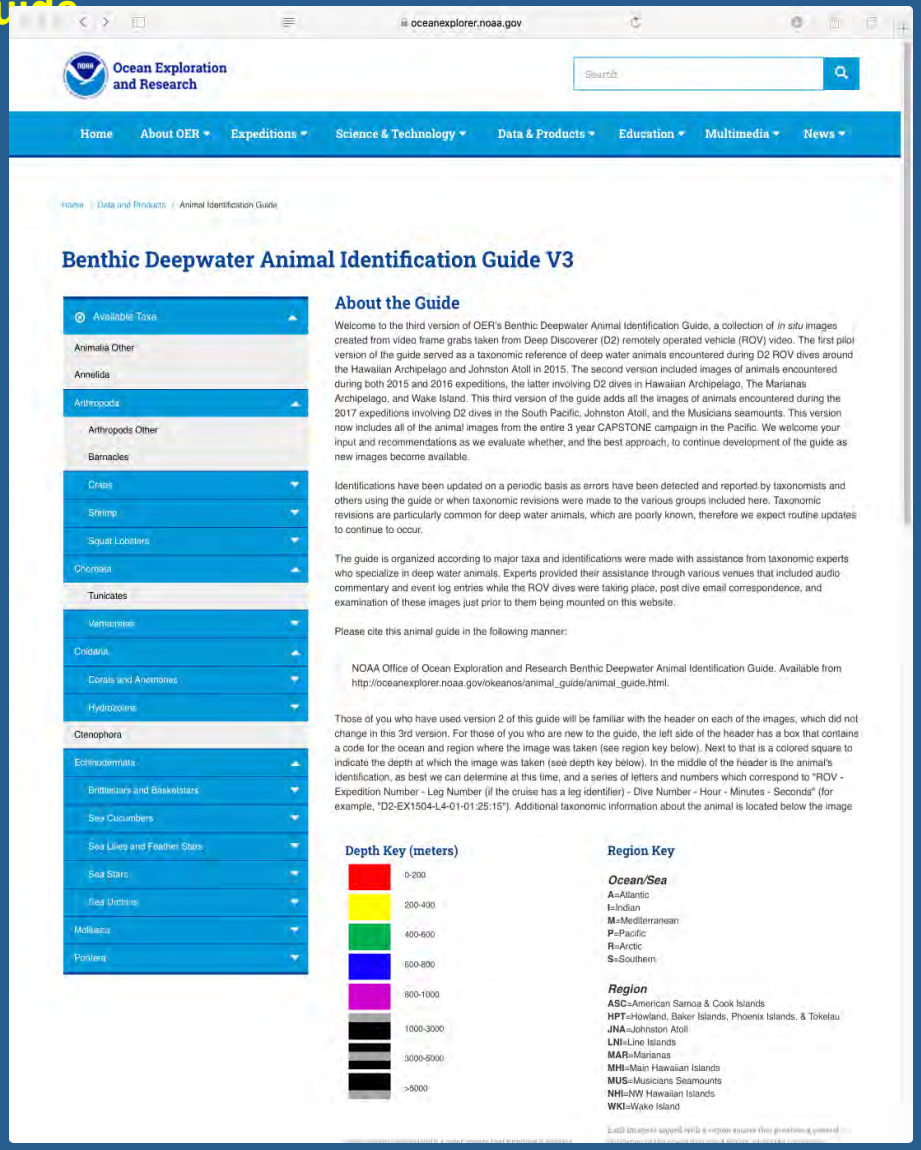


(Deep-Sea Animal Research Center (DARC) at the University of Hawaii)

https://deepseacoraldata.noaa.gov

Post Cruise Update: Primary Objective 3

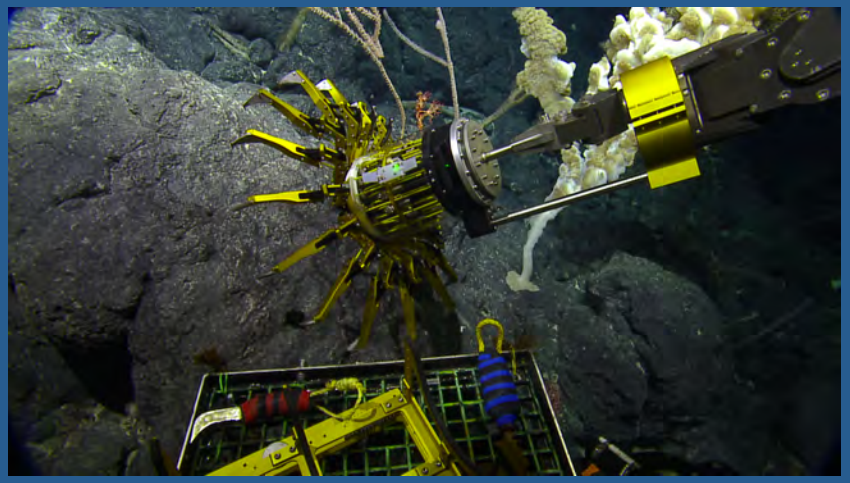
Over 5000 Images Formatted For Incorporation into the NOAA OER Online Animal Guide



(DARC at the University of Hawaii)

Post Cruise Update: Secondary Objectives

A New JPL Gripper Was Also Tested During the Dives



(Spencer Backus, JPL)

DOI: 10.1002/rob.21934

SYSTEMS ARTICLE

WILEY

Design and testing of the JPL-Nautilus Gripper for deep-ocean geological sampling

Spencer B. Backus[1] | Rina Onishi[2] | Andrew Bocklund[3] | Andrew Berg[1] | Eric D. Contreras[1] | Aaron Parness[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California
[2]Stanford University, Stanford, California
[3]Virginia Tech, Blacksburg, Virginia

Correspondence
Spencer B. Backus, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109.
Email: spencer.backus@jpl.nasa.gov

Funding information
Ocean Exploration Trust; Jet Propulsion Laboratory, California Institute of Technology; National Aeronautics and Space Administration; National Oceanic and Atmospheric Administration, Office for Exploration and Research, Grant/Award Number: NA17OAR0110336; URI/GSO Marine Geological Samples Laboratory and National Science Foundation, Grant/Award Number: OCE-1555523

Abstract

We present the design and experimental results for the JPL-Nautilus Gripper, a 16-finger highly underactuated microspine gripper for use in the deep ocean. The gripper can grasp objects from 10 to 30 cm in size and anchor to flat and curved rocky surfaces (i.e., cliff faces and seamounts). Laboratory results demonstrated an anchoring capability of greater than 450 N on rough rocks in both shear and normal loading directions. Deployment on the Hercules ROV (remotely operated vehicle) aboard the E/V Nautilus on three deep-ocean dives verified performance at depths up to to 2,100 m with approximately 100 N loads applied through the ROV's thrusters, including moment loads. The gripper also serves as a development unit for future robotic tools that will include a coring drill in the center of the gripper, as previously demonstrated in non-ocean environments with microspine grippers. Such a tool will facilitate the collection of geologic samples from the deep ocean using more agile and cost-effective systems.

KEYWORDS
exploration, manipulators, marine robotics, mechanisms, underwater robotics

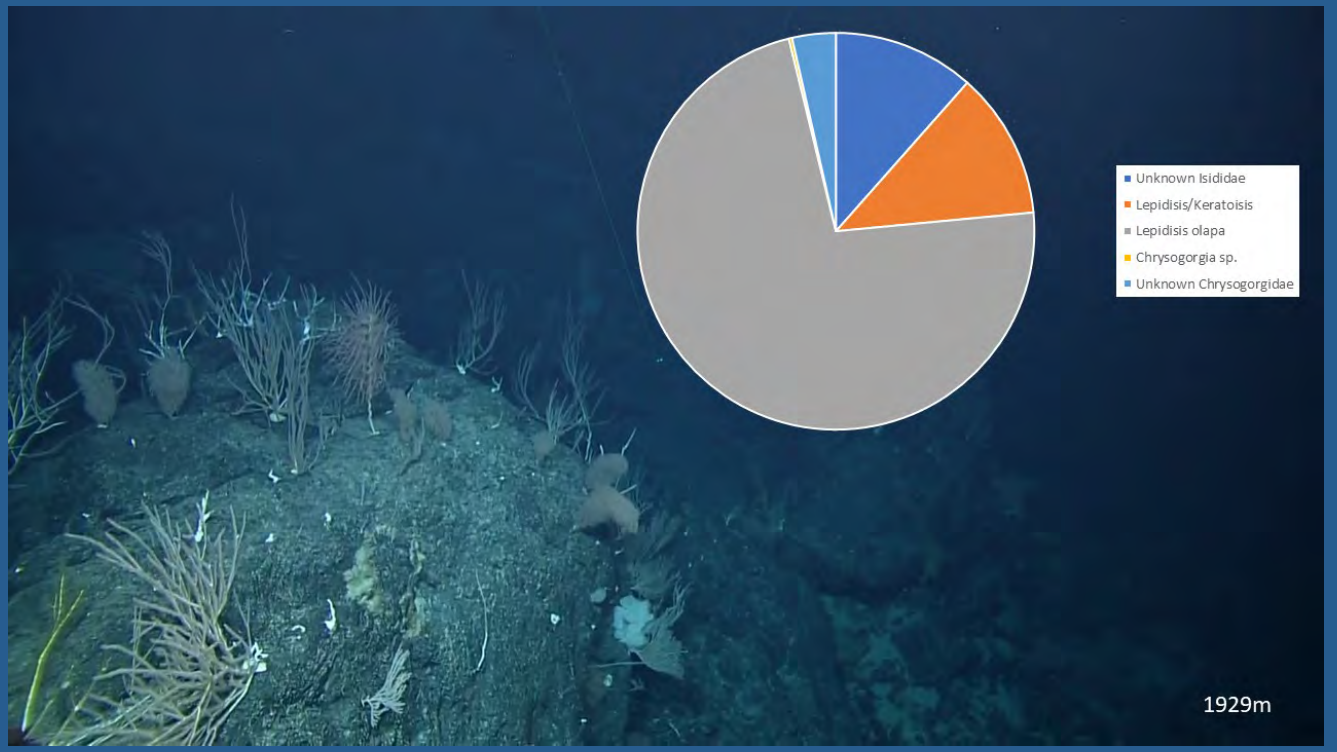
1 | INTRODUCTION

Collecting representative rock samples is central to any geological expedition but the lack of appropriate sampling tools limits the collection of seafloor samples to specimens that can be picked up off the seafloor or broken off from outcrops. Currently, most marine drill-based sampling systems consist of dedicated drill ships or large multi-ton dedicated robotic drills capable of taking core samples that are 10–100 s of meters long (Sager, Dick, Fryer, & Johnson, 2003). There are a few remotely operated underwater vehicle (ROV) operated drill systems but these systems still take relatively large cores and can only operate when the ROV has parked on the seafloor or thrusts against a cliff face (Ludvigsen et al., 2017; Murton, 2016; Stakes et al., 1997). Therefore the marine geology community has repeatedly expressed a desire for a small, vehicle agnostic drill that can be handled by a robotic manipulator and collect oriented cores in a wide range of terrains and rock types from a free-floating vehicle (Emerson & Shank, 2016; German & Tominaga, 2016; Hayman & Perfit, 2016; "ROV Manipulator-Based Drilling," 2015; Sager et al., 2003). Anchoring the drill to the target rock may be necessary to hold the vehicle in position and counteract drilling loads.

Here we present the design and evaluation of a microspine-based rock anchor (shown in operation in Figure 1) that may be combined with a coring drill in the future to facilitate the collection of small rock cores from a free-floating ROV. This design leverages prior work combining microspine grasping with rock drilling that has been conducted for microgravity sampling but adapts it to the marine environment (Parness, 2011; Parness & Frost, 2012; Parness et al., 2013; Parness, Willig, et al., 2017). In the remainder of this paper, we present a brief overview of existing ROV mounted drills and the work to date on microspine anchors developed for sampling, describe the design and fabrication of the JPL-Nautilus Gripper, the methods and results of lab-based characterization of its capabilities, and its performance on a field trial conducted aboard the E/V Nautilus on cruise NA101 to the Papahānaumokuākea Marine National Monument.

Post Cruise Update: Secondary Objectives

Water Samples Were Collected For an eDNA Study



Twenty-five water samples were collected from nine seamounts for the eDNA study. Sampling targeted dense coral and sponge communities where representative coral and sponge specimens, HD video and still images were also collected. Whole community diversity around these seamounts was explored by combining high throughput amplicon sequencing of the eDNA samples, including markers developed for octocorals, black corals, sponges, and fish, with traditional video and DNA barcode analysis.

(Meredith Everett, NOAA, presented at the 7th International Symposium on Deep-Sea Corals)

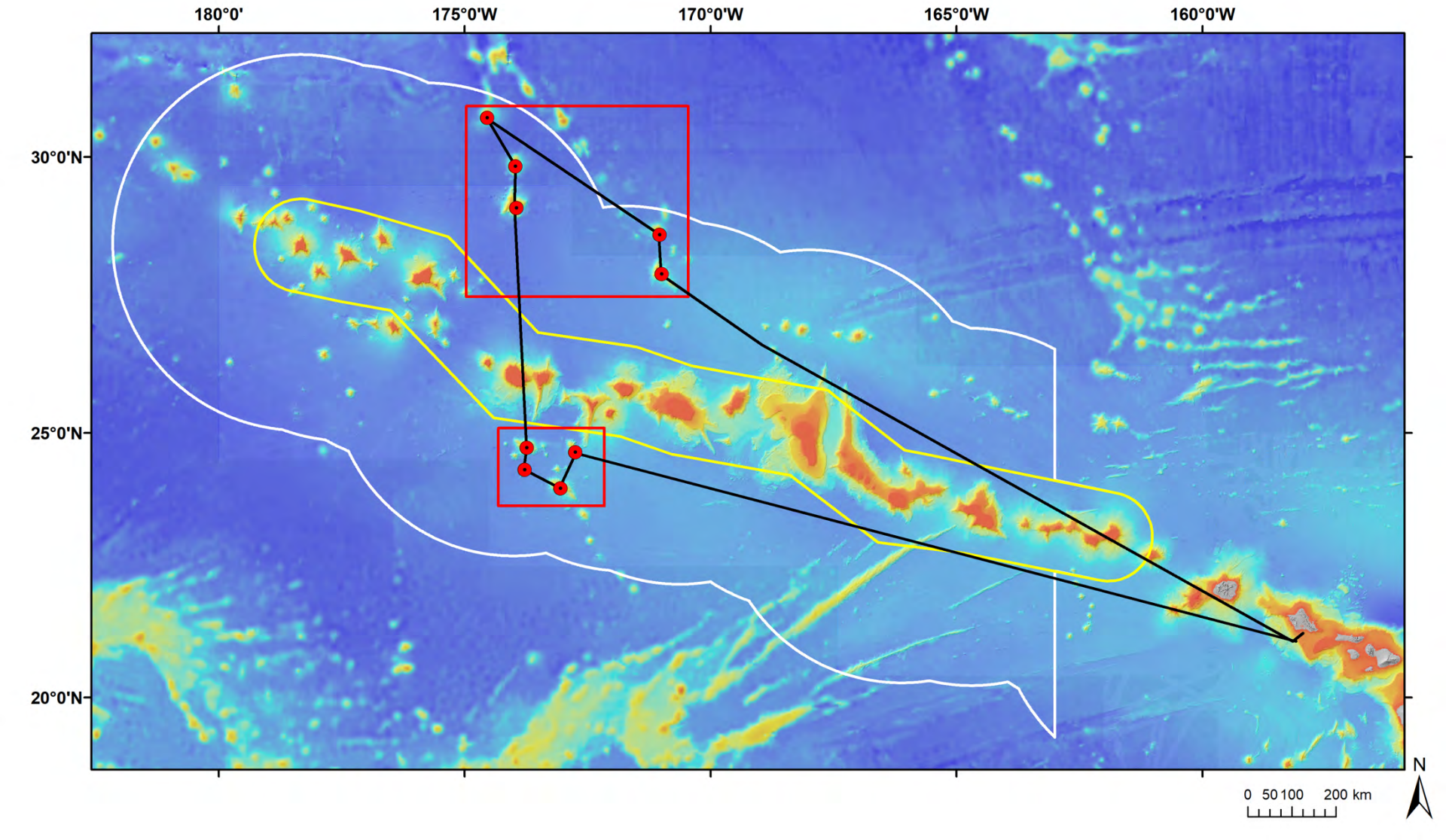
Post Cruise Update: Secondary Objectives

A New 360° camera Was Successfully Deployed During the Dives

(Allan Adams, MIT)

But Wait, That's Not All!

The E/V Nautilus is Heading Back Up to PMNM in 2021 to Map and Dive on More Unexplored Seamounts!



There Are Thousands of Seamounts in the Pacific

These Cruises Will Help to Clarify Their Complex Origins and Remarkable Communities

Many Thanks to Those Who Helped Make This Cruise Possible at:
PMNM, OET, UH, OER, and DSCRTP, as well as:
The onboard participants of Nautilus cruise NA101 including the co-scientists from OSU, Boise State, MIT, JPL, the ROV pilots, videographers, crew, communication interns, and many others.