2014 WORKSHOP

TELEPRESENCE-ENABLED EXPLORATION OF THE EASTERN PACIFIC OCEAN

WHITE PAPER SUBMISSIONS

OCEAN EXPLORATION TRUST

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

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NORTHERN PACIFIC

Deep Hawaiian Slopes

Amy Baco-Taylor (Florida State University)

Collaborators

Stephen Cairns (Smithsonian Institution)
Henry Reiswig (Royal British Columbia Museum)

Region

Hawaii/Emperor Seamounts

Rationale for Exploration

Thanks to the assets and funding that have previously been available through the Hawaii Undersea Research Laboratory, many of the features of the Hawaiian Archipelago have been explored to depth of ~2000m. However the slopes of these features at depths >2000m remain a complete enigma. It has been shown in many studies that deep-sea coral and sponges communities are structure by depth, with corals known to depths of at least 6000m in other parts of the world. Therefore corals and sponges are likely to continue to be abundant well beyond 2000m. We propose exploration of any of the features of the Hawaiian Ridge at depths >2000m with the anticipation of finding many new species of deep-sea corals and sponges as well as other megafaunal invertebrates.

Overview of Target Area

The target area is the deep slopes (>2000m) of any of the features of the Hawaiian Archipelago and adjacent seamounts.

Brief Overview of What is Known About this Area

There has been extensive study of the deep-sea coral and fish communities of the Hawaiian Archipelago, but these have largely been focused in precious coral depths, to about 600m. Forays deeper have found equally rich and diverse deep-sea coral and sponge communities to depths of 2000m, with the distribution likely continuing on into the abyss. These studies have shown changeover in species composition of corals with increasing depth. Surveys over the last 3 decade have revealed an array of new species, even within the more well-explored areas, including 6 new genera and 21 new species of corals described in the last ~5 years. This high rate of species discovery suggests there is a plethora of undiscovered species new to science at all depths within the Archipelago.

Feasibility of Studying this Target Area

The advantage of this area for exploration over the more remote regions of the eastern Pacific is the short transit times. Honolulu provides a logistically easy port with deep water just a few hours offshore. Targets further to the northwest are also enticing but do require longer transit times. Easy, exciting exploration at a low cost compared to most parts of the Pacific is hard to pass up!

Education & Outreach Potential for Exploration at this Target Area

The advantage of this area for exploration over the more remote regions of the eastern Pacific is the short transit times. Honolulu provides a logistically easy port with deep water just a few hours offshore. Targets further to the northwest are also enticing but do require longer transit times. Easy, exciting exploration at a low cost compared to most parts of the Pacific is hard to pass up!

USS Stickleback (SS-415)

Alexis Catsambis (Naval History and Heritage Command's Underwater Archaeology Branch)

Region

Hawaii/Emperor Seamounts

Rationale for Exploration

USS Stickleback (SS-415), a Balao-class submarine, served briefly during WWII and supported United Nations Forces in Korea. After WWII, Stickleback was converted into a snorkel (Guppy IIA) type submarine. On 28 May 1958, while participating in an antisubmarine warfare exercise with USS Silverstein (DE-534), the submarine lost power and broached 200 yards ahead of the destroyer escort, colliding with Silverstein. The entire crew was saved, but Stickleback sank on 29 May in 1,800 fathoms of water. Beyond the historical and archaeological benefits of exploring the area, research conducted on the site will provide a better understanding of the effect of deep-water submergence on WWII-era submarines as well as the vessels effect on the surrounding environment.

Brief Overview of Target Area

USS Stickleback was lost while conducting training excercises off Oahu, Hawaii. An exact location is unknown at this time.

Brief Summary of What is Known of Target Area

The submarine was lost in 1,800 fathoms (about 3,300 m) off Pearl Harbor, Oahu, Hawaii.

Feasibility of Studying Target Area

Side-scan sonar survey will be feasible, possible ROV and multi-beam.

Educational and Outreach Potential for Exploration of Target Area

As the only remaining Balao-class submarine converted to a Guppy IIA that was not sold for scrap or transferred to another nation’s Navy, the site is unique and has potential for significant educational and outreach opportunities. Relocating and conducting research on this site will be an interest to the public, US Navy, WWII and Korean Veterans and their families, historians and researchers.

Sunken Battlefield of Midway

Alexis Catsambis (Naval History and Heritage Command's Underwater Archaeology Branch)

Region

Hawaii/Emperor Seamounts

Rationale for Exploration

The Battle of Midway (4-7 June 1942) took place in the waters surrounding Midway Atoll at the northwestern end of the Hawaiian archipelago. This target area represents an extremely significant event in world history and in underwater exploration. The major wrecksites located here are historically significant for their participation in the Battle of Midway and World War II. Little is known about the wrecksites themselves due to the extreme depth of the sea floor in this location. The opportunity to precisley locate, identify, document, and assess the wrecks surrounding Midway Atoll is important for world cultural, military and naval history as well as archaeology and hard sciences.

Brief Overview of Target Area

Midway Atoll is a small isolated atoll at the extreme end of the Northwest Hawaiian Islands. It is part of a chain of volcanic islands, atolls, and seamounts extending from Hawaii up to the tip of the Aleutian Islands.

Brief Summary of What is Known of Target Area

The wreck sites of Kaga and Yorktown are both located on the seafloor at depths exceeding 5000 meters. Yorktown sits upright under 16,650 ft of water in a remarkable state of preservation. Surveys were undertaken to locate Yorktown and Kaga in 1998 and 2000 respectively, but no followup investigations have been conducted since that time and these are the only significant wrecks associated with the Battle of Midway that have been, at least in part, located.

Feasibility of Studying Target Area

The primary difficulty with studying this target area involves the extreme depths where the wrecks are located, and the geographic isolation of the wrecks' locations. Earlier survey expeditions, however, have been conducted in the general area, indicating that both mapping and target investigations are feasible.

Educational and Outreach Potential for Exploration of Target Area

There is vast educational and outreach potential associated with these sites. The Battle of Midway was one of the most important naval battles of World War II and is considered by many historians to be the turning point in the war in the Pacific. Due to the high-profile nature of this event, the wrecks are of extreme interest to the public, especially survivors of World War II and the families of those who fought in the Pacific theater. Additionally, these site would provide the opportunity to learn about the effects of deep-water on shipwreck preservation and to study marine life and chemical processes (including corrosion rates) that exist in this environment.

Systematic Mapping of the California Continental Borderland from the Northern Channel Islands to Ensenada, Mexico

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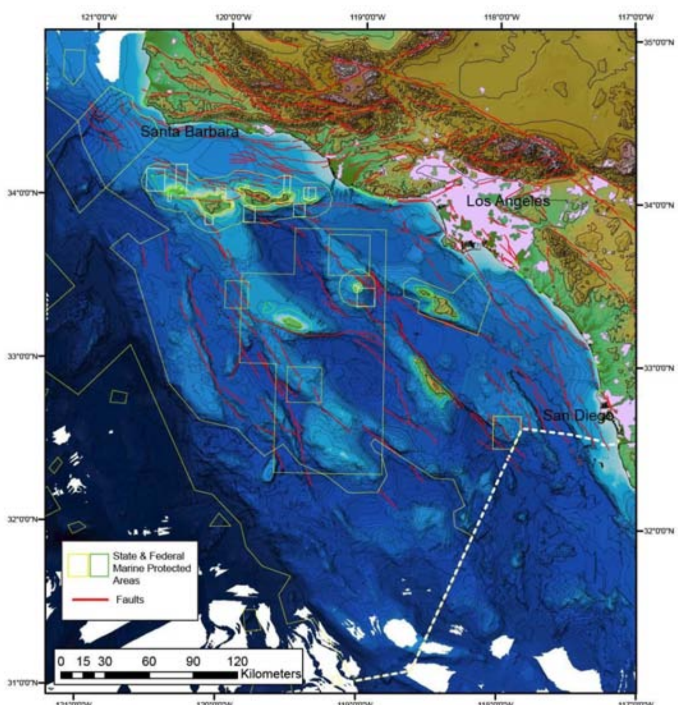
Region

NE Pacific Basin

Rationale for Exploration

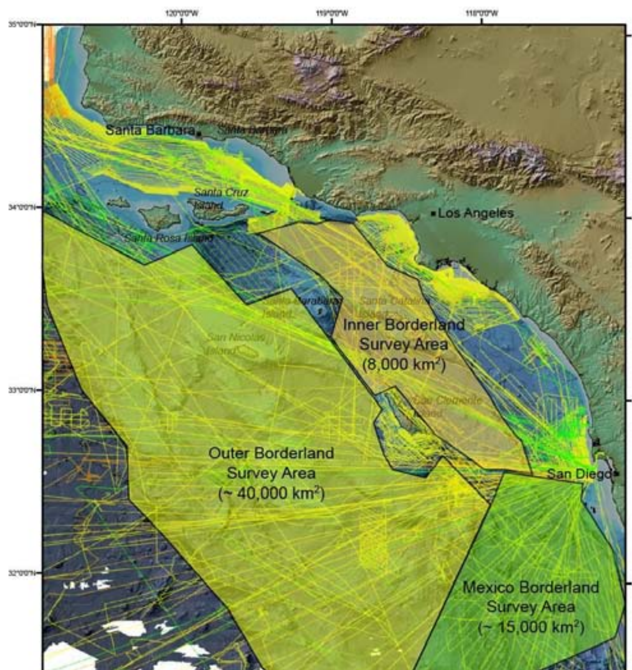
The California Continental Borderland ("Borderland") (Figure 1) is located offshore the densely-populated regions of southern California and northern Mexico (> 25 million people). The Borderland covers an area of over 65,000 km2, and is a geologically and physiographically complex region within an active plate boundary. The Borderland hosts an array of critical and poorly characterized biological habitats and associated assemblages of marine organisms that include both healthy and overfished rockfish populations, ESA-listed white abalone, and dense strands of deep-sea corals and sponges. The combination of active geologic processes (earthquakes, submarine landslides and sediment flows, and possibly tsunamis) coupled with complex oceanographic conditions (cold nutrient rich water from the California Current and warmer, oligotrophic water from the south), diverse habitats for fishes and invertebrates, and extensive anthropogenic influence from the coastal zone make the Borderland a prime location for exploration, scientific study, education, and outreach.



Systematic collection (Figure 2) of modern, quality controlled, high-resolution multibeam bathymetry, acoustic backscatter and water column data, plus co-acquired chirp sub-bottom profiles over the regions currently unmapped, or only poorly, mapped will open countless opportunities to study seismic and tsunamigenic hazards facing Southern California, geologic and tectonic processes, essential fish habitats, deep-sea coral and sponge communities, archeology, anthropogenic impacts and future resource use to name just a few. Mapping priority areas are separated into three regions to facilitate discussion and issues such as permitting: the Inner Borderland (~ 8,000 km^2 of mapping), Outer Borderland (~ 40,000 km^2 of mapping), and Mexico Borderland (~ 15,000 km^2 of mapping). Below, we expand on some of the questions and issues that could be addressed with complete multibeam bathymetry coverage (plus associated datasets).

Brief Overview of Target Area

Scientific investigation and resource exploration have been ongoing in the Borderland for over 50+ years, yet we still rely on soundings collected in the 1920's and 1930's for bathymetric information over large parts of the region. Efforts have been underway for many years to collect and combine bathymetry data collected for various reasons throughout the Borderland (e.g., Legg, 1991; Goldfinger et al., 2007; Dartnell et al., 2005; Dartnell and Gardner, 2009; Chaytor et al., 2008; Ryan et al., 2012; Paull et al., 2013) in order to understand both small and large scale geological processes and biological habitats. Substantial progress has been made in collecting quality, high-resolution bathymetry, sidescan/backscatter, and seismic reflection/sub-bottom data adjacent to the coast, on the shallow banks, and around the Channel Islands between Point Conception and San Diego (including the entire Santa Barbara Basin) (MBARI, 2001), but the extent and quality of data farther seaward and offshore Mexico is dramatically lower, often limited to data collected during transits of vessels in and out of San Diego (Figure 2).



Brief Overview of What is Known of Target Area

Tectonics & Earthquake-Landslide-Tsunami Hazards

The complex tectonic evolution of the Borderland is directly linked to the complicated transformation of the North America-Pacific plate boundary from subduction of the Farallon plate to the formation of today's transform margin. Since ~30 Ma the Borderlands have undergone episodes of plate fragmentation, large-scale block rotation, rifting, core complex exhumation, volcanism, and finally transtensional/transpressional deformation. Much of the transtensional/transpressional deformation occurs along a network of faults and fault-related structures, many of which remain active and are capable of generating large earthquakes, both onshore and offshore. At least 20% of the slip between the North American and Pacific plates occurs offshore in the Borderland (DeMets and Dixon, 1999). Most of the offshore slip is inferred to be occurring on faults that are closer to the metropolitan areas that the San Andreas Fault. While many, but not all, of the onshore faults are known and have been assessed for earthquake hazards, because of the limited availability of high-resolution bathymetry and sub-bottom profiles, the numerous major offshore fault systems are poorly mapped. Little is known about the paleoseismic history and future earthquake potential in part because the quality and coverage of existing bathymetry data is inadequate. Good regional bathymetry is the prerequisite for conducting marine neotectonic investigations (Ryan et al., 2012) and vital for the development of detailed visual surveys using ROV technology.

Detailed maps of offshore faults within the Borderland do not extend south of the US-Mexico border, primarily due to a paucity of modern swath bathymetry data. This lack of data prevents full characterization of their hazard and adds to the uncertainty of seismic hazard assessment. These faults not only pose an earthquake hazard to the urban and industrial centers in southern California and Mexico, but also a tsunami hazard along faults that generate vertical movement at the seafloor, and ground accelerations can trigger large tsunamigenic slope failures.

Evidence of submarine landsliding is pervasive throughout the Borderland (Lee et al., 2009), but few of these features have been mapped in detail. High-resolution bathymetry data collected in the Santa Barbara (MBARI, 2001; Greene et al., 2006) and Santa Monica basins (Gardner et al., 1999; Normark et al., 2004) provided the first opportunity to accurately define the surficial extent and morphology of the potentially tsunamigenic Goleta/Gaviota landslides and Palos Verdes debris avalanche. Bathymetry data collected in 2011 by the NOAA Ship Okeanos Explorer in the Santa Cruz Basin revealed the presence of previously unknown submarine landslides. Until all possible submarine landslide sources have been identified, assessment of tsunami and slope-failure induced damage to offshore facilities cannot be confidently undertaken.

Sediment Input, Pollutants, and Hydrocarbons

The basins in the Borderland are the sink for sediments from urban areas extending from Santa Barbara to Tijuana. Rivers and coastal erosion have always provided a flux of sediment that is ultimately deposited on the basin floors of the Borderland. However; in the last few centuries, an increase in sediment load and altered composition has occurred. Historically most of the untreated sewage from these urban areas was discharged through outflows at shallow depth, and even as these discharges are prohibited, storm drain outflow is still discharged directly into the Borderland. These inputs have and continue to carry increased organic matter and pollutants (Lee and Wiberg, 2002), which progressively move via submarine channel systems (e.g., Romans et al., 2009), from the narrow continental shelf into the deeper basins. Unfortunately, existing bathymetry is inadequate to identify where these channel systems are located, preventing determination and characterization of the depocenters of these contaminant-laden sediments.

Numerous seafloor fluid seeps and vent sites have been discovered within the California Borderland. These include ones where warm fluids are escaping along faults (Lonsdale, 1979; Hien et al., 2007), where streams of methane gas are bubbling out of the seafloor (Paull et al., 2008), and at natural oil seeps (Liefer et al., 2005, Lorenson et al., 2009; Valentine et al., 2010). These sites are usually associated with anomalous morphological features observed in high-resolution bathymetry and are commonly associated with massive accumulations of authigenic minerals, and up-lifted seafloor. Methane, sulfide, and oil that are being rising through the sediment to the seafloor support local microbial communities which in turn result in a biological community structure that is endemic to these sites. These chemosyntetic biological communities are also area of great biodiversity and viewed as areas of special biological interest.

The coastal areas of southern California immediately adjacent to the Borderland contain some of the most productive oil fields in the world (Gautier et al., 2012). Further development of these hydrocarbon resources may be considered at some point in the future. Quality bathymetry is a prerequisite for making scientifically-supported, informed decisions on whether or not this could proceed in an environmentally acceptable fashion and provide the basis for monitoring of the region.

Corals, Essential Fish Habitat (EFH), and Benthic Communities

Deep-sea coral (DSC) ecosystems are now widely recognized as biodiversity hotspots, providing habitat and reproductive grounds for ecologically important organisms. For example, DSCs on the banks off southern California provide complexity and structure to benthic communities and diversity for continental shelf and slope ecosystems (Tissot et al., 2006; Huff et al., 2013). Deep-sea corals are some of the slowest growing, longest-lived skeletal accreting marine organisms (Roark et al., 2009; Prouty et al., 2011), and vulnerable to adverse effects from fishing, climate change, and other potential impacts. Many valuable fishes associate with various types of seafloor structure (such as rocks) and co-occur with DSC. Characterization of these habitats is severely limited by the paucity of high-quality seafloor mapping data across large sections of the Borderland.

Seafloor topography is an important factor influencing DSC distribution. Throughout the Pacific Coast region, high relief, bathymetric features have been found to support coral communities (Love et al., 2007; Tissot et al., 2006; Strom 2006; Whitmire and Clarke, 2007). For example, observations from the Davidson Seamount off California suggests that gorgonian and black corals concentrate on ridges where currents are accelerated (Andrews et al., 2005; deVogeleare et al., 2005), linked to localized upwelling conditions that support high level of biological productivity that characterize the major currents (e.g., California Current) in the US Pacific region. Visual surveys conducted near the Channel Islands of the Borderland demonstrated that rocky outcrops at depths to 900 m support high densities and diversity of corals and sponges relative to elsewhere on the west coast (Yoklavich et al. 2011). Given the unconditional necessity of rocky substrata for the presence of many species of demersal fishes and DSC, the acquisition of Borderland-wide high-resolution spatial data on seafloor substratum types (particularly in rocky high-relief areas) is required in order to (1) improve the predictive performance of habitat-based models; (2) understand the distribution and abundance of habitats and associated fishes and DSC; (3) evaluate fishing and non-fishing impacts to benthic communities; and (4) identify areas where additional habitat protection is needed, along with a diverse array of other spatial management issues.

Benthos within Borderland basins are extremely diverse, rivaling shallow water reef ecosystems (Snelgrove and Smith, 2002) and represent richer assemblages than more oligotrophic settings, such as the North Pacific central gyre (Smith and Demopoulos, 2003). The surface and shallow-subsurface sediments of basin floors within the Borderland are being constantly and heavily modified by biological activity, over timescales as short as hours (Smith et al., 1986). It is thought that seasonal high surface production fuels deep-sea communities within the Borderland, although the nature, rates and variability of the flux of particulate organic carbon to the sea floor in the region are still very poorly quantified (Smith and Demopoulos, 2003), in part due to the lack of detailed mapping of many of the basins.

Education and Outreach Potential of Target Area

Systematic mapping of the Borderland offers a multitude of opportunities to engage the public, as well as the scientific, management, and conservation communities in the exploration of one of the largest regions along the US coast yet to be mapped in detail. The Borderland is an excellent field laboratory for the study of submarine natural hazards (faults/earthquakes, landslides, tsunamis), fish and deep sea coral habitat, and the impact of anthropogenic inputs on the marine environment - all of which are of great interest to the public. The coastal waters of the Borderland are perhaps the most heavily used along the U.S. Pacific coast and as such the public has a keen interest in the health of the marine ecosystem. Revealing the complexity and scientific importance of the Borderland via real-time systematic mapping/exploration to both a large local school age population (their backyard), in addition to similar groups world-wide, will provide the opportunity to capture the imagination and desire for scientific inquiry of a future generation of marine scientists.

Southern California Borderland

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Region

NE Pacific Basin

Rationale for Exploration

The southern California borderland, a region that extends 100-200 km from the Californian coastline, displays an unusually rugged physiography for a continental margin. It consists of a series of deep (500 - 2,000 m) basins separated by shallow ridges - some of these ridges emerging as islands. It encompasses more than 60,000 km2 and stretches from Santa Maria to San Diego and further southward into Mexican territorial waters. These very dimensions may explain why the California borderland has been only sparsely investigated despite its proximity to metropolitan Los Angeles and San Diego. Geologically, the California borderland occupies the diffuse boundary between the North American and Pacific plates. Although most of the motion between these two tectonic plates is accommodated on land along the San Andreas Fault system, it is estimated that ~20% of the motion occurs in the offshore California borderland. Some of the offshore faults extend through the Los Angeles metropolitan area, and possibly through San Diego. Offshore structures thus represent a major earthquake and tsunami hazard for coastal California. The incomplete multibeam bathymetric coverage has revealed large marine slides, raising further concerns about tsunami hazards. A more thorough inventory of active faults and marine slides would have obvious benefits for the assessment of natural hazards.

This complex seafloor relief of the borderland translates into an equally complex ocean circulation, with each basin displaying distinct hydrographic characteristics. For example, the ~600 m-deep Santa Barbara Basin is anoxic, and thus preserves in its sedimentary stratigraphy a precise record of climate changes. Rapid sediment accumulation in these basins has also favored the formation of hydrocarbons. Gas hydrates have been detected in several basins, and hydrocarbon seeps are common. The complex seafloor relief also provides a diversity of habitats, and a diverse ecosystem is expected. The northern Channel Islands are a National Park. Their surrounding environment is pristine and has been designated a National Marine Sanctuary, thus protecting its unique marine ecosystem. Lastly, some of the oldest evidence for humans occupation in North American have been found on the northern Channel Islands. These have been dated to ~12,000 yr BP, at a time when sea level was ~100 m lower than present. It is thus quite possible that even older sites are preserved on the shelves surrounding the islands. A careful assessment of the vertical deformation that has affected the Channel islands since then should allow for the reconstruction of the paleo-landscape that existed on the shelves during sea-level lowstand. Such approach should highlight some sites where shell middens or other evidence of late Pleistocene human occupation may be preserved.

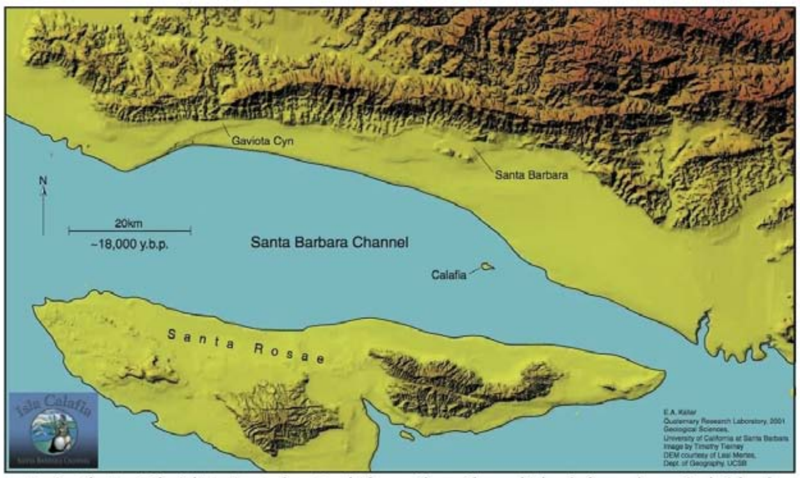
Brief Overview of Target

Subduction of the Farallon plate beneath North America proceeded steadily for 10's of millions years, until the Pacific-Farallon spreading center met with the North American continent at about 30 Ma. That time marks the initiation of the transition between Farallon-North America subduction to Pacific-North America transform motion - and the birth of the San Andreas fault. The series of complex events that accommodated this reconfiguration of the plate boundary account for the complex physiography of the California borderland. Hence, the Patton escarpment marks the paleo-subduction trench that became inactive at around 20 Ma, and the borderland's basins and ridges initiated their formation during a period of crustal extension which lasted until ~5 Ma.

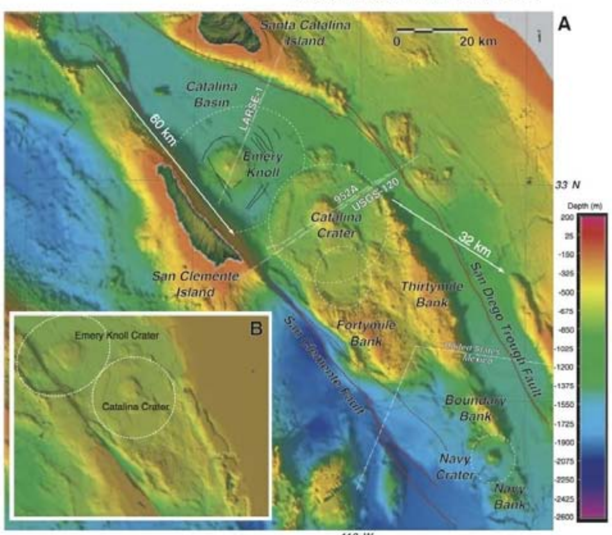
Most of the offshore borderland, with the exception of the crest of some of the ridges and the Channel Islands , is presently sinking. Tectonic activity is accommodated across a complex network of intersecting and subparallel faults. While none of these are precisely mapped, there exists a general consensus that some faults are buried and their slip absorbed by giant fold structures, while others reach to the seafloor, occasionally producing steep escarpments or furrows. Vintage seismic data indicate that ancient shorelines carved during previous lowstands of the sea level occur several hundred meters deeper than expected; these paleoshorelines are most likely warped and/or tilted by tectonic activity. Occasional ROV observations in the offshore Borderland and other tectonically controlled basins reveal areas of active fluid escape and some associated ecosystems; these features are expected to be mostly focused along major fault structures. Exploration targets might therefore include a diversity of features, as follows: 1) faults scarps and growth folds, along with the cold seeps expected to be associated with these; 2) deep submerged erosional terraces. dating their surfaces would constrain subsidence rates, and their rougher surfaces may provide a needed substrate for adapted ecosystems; 3) hydrate mounds, hydrocarbon seeps, mud volcanoes; 4) the ecosystems within the Channel Island National marine Sanctuary; 5) Possible evidence for human occupation on the shelves surrounding the Channel Islands that dates back to the Late Pleistocene; 6) the ~3,000 m-high Patton escarpment, which preserve the trench slope that existed prior to the initiation of the San Andreas Fault system; 7) some enigmatic craters west of san Diego, which have been interpreted as both impact craters or unusual volcanic constructs; 8) elongated seamounts sitting on the deep oceanic lithosphere west of the Patton escarpment, and smaller seamounts east of that escarpment, on thinned continental lithosphere.

Brief Summary of What is Known of Target Area

The offshore California borderland has been investigated for over 50 years, not only by the academic community and federal agencies, but also by the petroleum industry, at least until the 1970-80's. Yet, while the main bathymetric features are well delineated, mulitbeam bathymetric coverage is probably around 50% or less, leaving much to be discovered. In particular, marine slides, seeps, mud volcanoes, and subtle fault scarps can only be imaged with multibeam sonars. As described in the previous sections, the borderland region is known to be criss-crossed by seismically active faults -although how often these may be rupturing is subject to much debate. The lack of any seafloor observatory (including seafloor seismometers) and the very few seafloor investigations with deep submergence vehicles mean that much of our understanding of the California Borderland is based on shipboard surveys, remote sensing, and circumstantial evidence. The record of historical earthquake is too short to reliably assess the average recurrence interval of significant offshore earthquakes. In that sense, new, direct observation of fault scarps and sampling of adjacent sediments has the potential to provide much needed constraints on past earthquake activity.



During the Last Glacial Maximum lowstand, the northern Channel Islands formed one single island. Paleo-indian sites on the islands are dated at ~12,000 years BP *[Erlandson et al., Science, 2011]*.
Illustration from E. Keller, UCSB.



From M. Legg et al., Geophys. J. Int., 2004.

A. Enigmatic crater structures occur between San Clemente Island and San Diego. Active san Clemente Fault and San Diego Trough faults in red.

Inset B: reconstruction of craters after right-slip motion of both faults has been removed

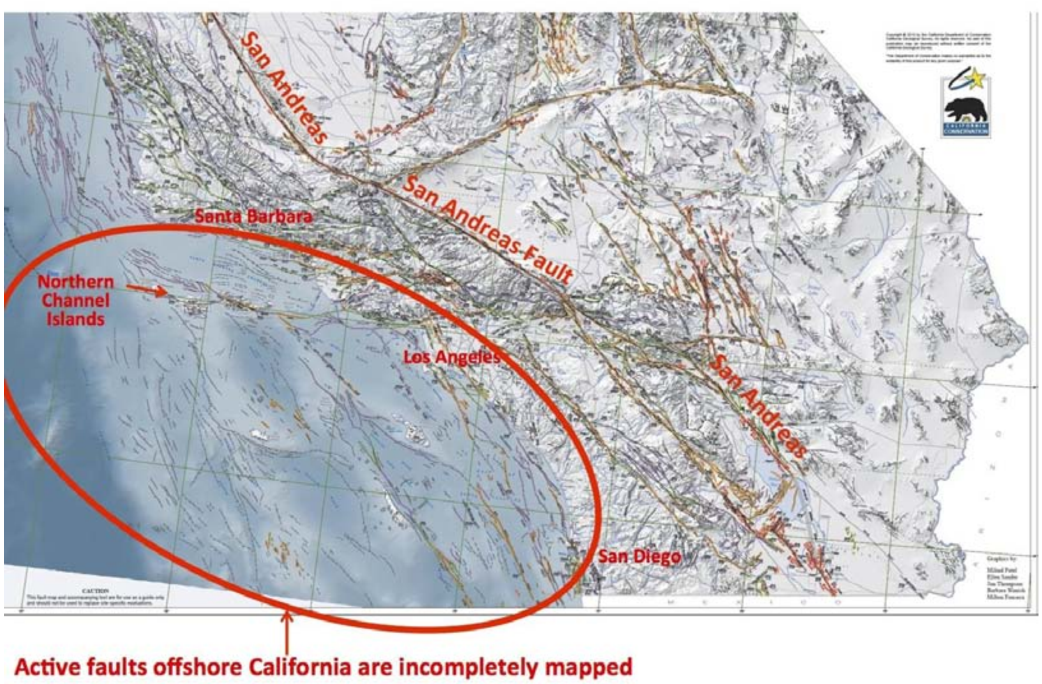
Feasibility of Studying Target Area

Because of its proximity to Los Angeles, San Diego, and Port Hueneme, the California borderland are easily accessible by oceanographic ship. In terms of ship scheduling, early fall is the optimal time window for a survey. December to May corresponds to Gray whale migration, and June to September corresponds to the peak in residency of endangered blue and humpback whales. Barring an unusual early storm, early fall should also have the calmest sea conditions.

Education and Outreach Potential of Target Area

The offshore California Borderland comprises the Channel Island National Park and the corresponding Channel Island National Marine Sanctuary, two obvious partners for public outreach. The Santa Barbara Museum of Natural History hosts many artifacts on the Channel Islands and is another possible partner. The local Native Americans, the Shumash, lived on the Channel Islands and would likely be most interested in partnering in the archeological investigation of the surrounding shelves. A large number of undergraduate students at the University of California - Santa Barbara typically enroll in introductory classes in oceanography, and any new discovery in the waters offshore Santa Barbara campus would integrate naturally with the content of these courses.

Fault Activity Map of California
California Geological Survey, 2010



Expanded Exploration of Approaches to Pearl Harbor and Seabed Impacts Off Oahu, Hawaii

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Region

Hawaii/Emperor Seamounts

Rationale for Exploration

Pearl Harbor was established as a US Navy base in 1899 and has been the nexus of Pacific naval activities for over a century, most famously during the attack in 1941 by the Japanese that caused the United States to enter World War II. As we approach the 75th anniversary of the attack in December 2016, there is a great potential to initiate public interest in the maritime heritage of World War II beginning here. Exploration around the approaches of the harbor can include deep water sites such as Japanese submarines, unexploded ordnance dumps, and downed aircraft. In addition to materials sunk during 1941, the extended use of the harbor since the nineteenth century yields a potential to explore other aspects of the maritime history of Hawaii. Two scuttled battleships from the Bikini atomic tests of 1946 - USS New York and USS Nevada, also lie further out - some 40 miles offshore. They are unlocated, unstudied and have great potential for yielding scientific data.

Brief Overview of Target Area

The region south and southeast of Pearl Harbor consists of a volcanic plateau at 1000 m depth, covering the area between the islands of Oahu and Molokai. West and southwest is a steep escarpment off the volcanic rise that plunges down to 3000 m and then farther to over 5000 m, which would be good areas to conduct ROV transects. The approaches to Pearl Harbor < 1000 m are the best areas for exploration targeting sunken craft from the 1941 attack. Deeper waters within the US EEZ, i.e. 40 miles off Oahu, have potential for discovery of wrecks and other features.

Brief Overview of Target Area

In addition to mapping, there has been some ROV exploration and manned submersible exploration by HURL (Kerby et. al.) around Oahu Mustard bombs and other ordnance were dumped in certain locations off Hawaii up until the 1950s and which have been explored to some extent for potential health hazards. Last year, the I-400 Japanese submarine aircraft carrier was found off the coast at 700 m depth, having been scuttled after the second world war by the United States. Despite recent discoveries and exploration, much more remains to be investigated along the approaches to Pearl

Harbor, remnants of one of the most infamous attacks in history. There is existing historic data to plot search areas for USS Nevada and USS New York.

Feasibility of Studying Target Area

Highly feasible. Facilities, high quality data, and a series of partners exist in the area. This is also a high priority area for survey by NOAA.

Education and Outreach Potential of Target Area

Media partnerships are also likely as well as outreach partners. The recent (December 2013) announcement of the discovery of I-400 generated international media interest and over 900,000,000 media impressions.

Gulf of the Farallones NMS Shipwrecks and Submerged Prehistoric Landscape

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Regions

Gulf of the Farallones
NE Pacific Basin

Rationale for Exploration

The area off the Golden Gate, near one of California's key cities and a major port, is the setting for Gulf of the Farallones NMS. Within the sanctuary's area lie an estimated 200 shipwrecks. While some are shallow, there are a range of deeper wrecks, some as shallow as 70 - 80 m which encapsulate 200 years of maritime history, some with incredible human stories. Very few have been precisely located or characterized. The setting outside the Gate in the sanctuary is also a submerged prehistoric landscape inundated after the most recent glacial maximum from 18,000 to 2,000 BP. This is a key area of public interest, under public stewardship, and with largely unknown and unquantified cultural resources.

Brief Overview of Target Area

The Gulf of the Farallones extends from the opening of San Francisco Bay to Drakes Bay on the northern California coast, encompassing the Farallon islands. The National Marine Sanctuary encompasses 3,200 square K. Depths range from intertidal to 1200 m. The geography is marked by a deep cut channel, and extensive sand bar, and a mud/ sand plain.

Brief Summary of What is Known of Target Area

A detailed assessment of historically documented wrecks has been accomplished (Delgado and Haller 1990); some survey work has been accomplished with large feature mapping by the NOAA Coast Survey and Okeanos Explorer. Some shipwrecks, i.e. SS City of Chester, and shallow sites have been archaeologically documented.

Feasibility of Studying Target Area

Highly feasible. The area is within easy reach of San Francisco and docking facilities - daily operations could even return to port with regular intervals.

Educational and Outreach Potential of Target Area

There are a number of potential partners beginning with NOAA ONMS, OER, the NPS, BOEM, BSEE, the Aquarium on the Bay, the Exploratorium, the SF Bay Model, the California Academy of Sciences, the Monterey Bay Aquarium, a number of universities including UC Berkeley, Stanford, SF State, SJ State, Sonoma State, community colleges, and a large media community. Recent (April 2014) media coverage of the rediscovery of an 1888 shipwreck inside the Golden Gate generated 1.4 billion media impressions.

USS Independence

James Delgado (NOAA ONMS Maritime Heritage Program)

Collaborators

Jerry Ostermiller (NOAA ONMS MHP)
Russ Matthews (TIGHAR)
Steve Gittings (NOAA)
Frank Cantelas (NOAA OER)
Robert Schwemmer (NOAA ONMS)

Regions

Gulf of the Farallones

Rationale for Exploration

The goal of the survey is to complete the first assessment of the U.S.S. Independence' s condition to help guide future NOAA resource management decisions. The goal can be achieved by completing several characterization objectives using acoustic, environmental and optical sensors best deployed on the Echo Ranger AUV. The AUV will provide NOAA with much higher resolution data than sensors mounted on a surface vessel. Acoustic sensors (side-scan sonar and multi-beam) provide a range of data at different resolutions that fulfill a number of archaeological and management needs. A comprehensive high resolution (~500kHz) side-scan sonar survey of the ship and surrounding seafloor will provide basic acoustic imaging to determine the physical condition of the vessel and associated material potentially scattered on the bottom near the ship from the Naval Radiological Decontamination School at Hunter's Point/Mare Island (1946-1953). Many of these are barrels; Department of Defense reports estimate a number close to 40,000. In addition, bathymetric data from a multibeam echo-sounder provides information about the vessels vertical relief and information on the ship's structural condition including areas of collapse and height above the seafloor. A sub-bottom profiler will indicate the type of substrate the hull is resting on and help interpret aspects of the site's present condition and future deterioration. A systematic photo mapping survey to create a photo mosaic will yield details on construction, artifacts, damage, and current condition. Environmental data collected by CTD and other available sensors in the area of the site will characterize ocean processes and conditions affecting the wreck.

Brief Overview of Target Area

The wreck of USS Independence lies in approximately 1000 m of water on a relatively flat sand and mud plain approximately 20 miles off the California Coast within the boundaries of Gulf of the Farallones National Marine Sanctuary. U.S.S. Independence (CVL-22), the fourth ship named Independence in the U.S. Navy, was a United States Navy light aircraft carrier and served during the Second World War in the Pacific. Converted from the hull of a cruiser, she was built by the New York Shipbuilding Corporation and commissioned in January 1943. She took part in the attacks on Rabaul and Tarawa before being torpedoed by Japanese planes, having to be repaired and refitted in San Francisco from January to July 1944. After repairs she launched many strikes against targets in Luzon and Okinawa. Independence was part of the carrier group that sank the remnants of the Japanese Mobile fleet in the Battle of Leyte Gulf and several other Japanese ships in the Surigao Strait. Until the surrender of Japan she was assigned to strike duties against targets in the Philippines and Japan. She would finish her operational duty off the coast of Japan supporting occupation forces until being assigned to return American veterans back to the United States. Independence was later used for nuclear weapons testing during Operations Crossroads. After being transported back to Pearl Harbor and San Francisco for study, she was later sunk in a reported depth of 1000 meters of water on January 27, 1951 with barrels containing used materials deployed in radiological decontamination of the ship (clothing, boots, respirators, etc.) near the Farallones. She now rests in the Gulf of Farallones National Marine Sanctuary. Independence was imaged in 2010 using the hull-mounted Kongsberg EM-301 multibeam echo-sounder on the NOAA ship Okeanos Explorer.

Brief Summary of What is Known of Target Area

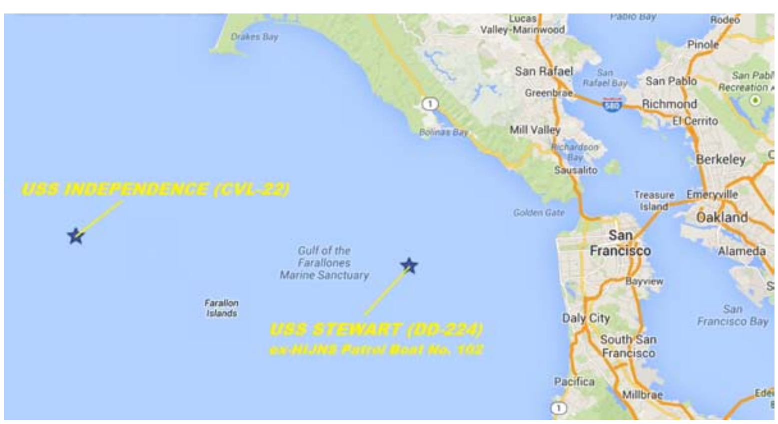
The wreck lies upright in an unknown condition in 1000 m of water. Surrounding it is a field of barrels, estimated to number ca. 40,000 of "radioactive waste" which consists of discarded boots, decontamination overalls, respirators and gloves, as well as sand used in attempts to remove irradiated steel.

Feasibility of Studying Target Area

High- the wreck location is known and it has been charted. It has not been characterized or mapped, imaged or studied.

Educational and Outreach Potential of Target Area

High - the wreck is well known but unstudied. The significance of the vessel as an historic site is represented both by its WWII career - the first of a class that included the carriers from which two future Presidents (Ford and Bush) would fly, Independence's own battle career, and its role in the first atomic tests, as well as the platform for the first U.S. Navy radiological safety school, as well as the potential for study of nuclear blast effect, ongoing radiation (which should be negligible if even measurable based on previous work done at Bikini on those sunken target ships), and what grows on the wreck now will be compelling to a national if not international audience.



Battle of Midway Survey and Characterization of USS Yorktown

James Delgado (NOAA ONMS Maritime Heritage Program)

Collaborators

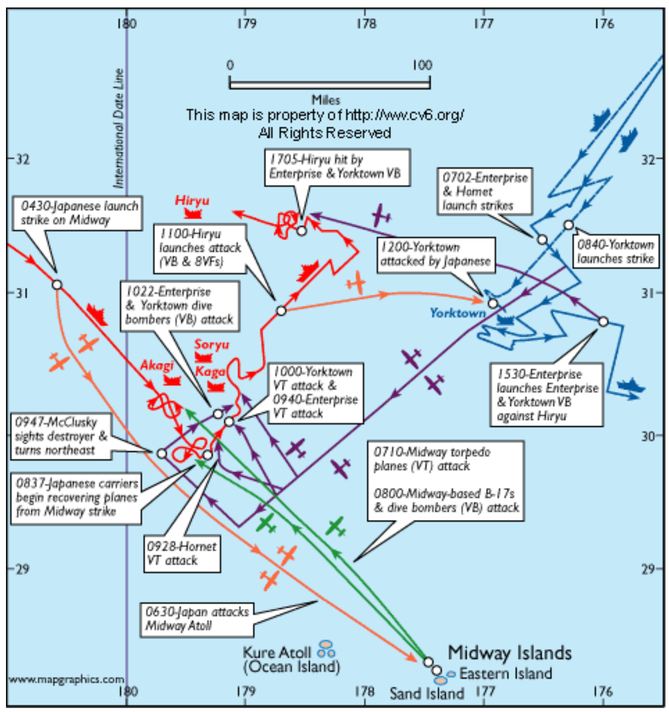
Hans Van Tilburg (NOAA ONMS MHP)
Russ Matthews (TIGHAR)
Jerry Ostermiller (NOAA ONMS)
Michael Brennan (OET)
David Conlin (National Park Service SCR)

Region

Hawaii/Emperor Seamounts

Rationale for Exploration

Previous work by Ballard et. al. discovered the wreck of USS Yorktown, lost in this pivotal WWI naval air battle, which ultimately decided the contest for the Pacific. No assessment or characterization of Yorktown has been done since. A portion of HIJMS Kaga was subsequently located, but the location, identification and characterization of other wrecks - USS Hammann, HIJMS Akagi, Hiryu, Soryu, and much of Kaga, as well as downed aircraft has not taken place. Understanding more than each individual component but rather the entire undersea battlefield landscape is an emerging high level approach to UCH; as well, a coordinated science mission looking at geology, geography, biology and oceanology as telepresence-enabled exploration would be a major achievement.



Brief Overview of Target Area

The battlefield ranges over a large area of ocean and hundreds of square miles. Bottom topography is unknown. Considerable historical research exists which can be used to define closer boxes for survey to locate ships and aircraft.

Brief Summary of What is Known of Target Area

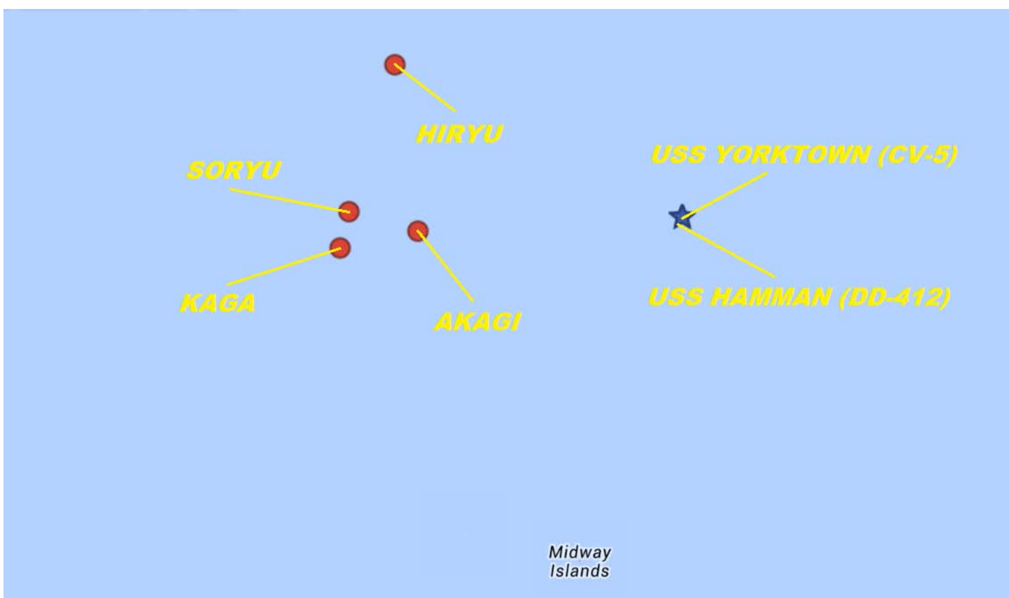
Ballard et. al. have located USS Yorktown; coordinates and basic characterization is known and available. Historical data exists and is sufficient in quantity and quality to determine search areas.

Feasibility of Studying of Target Area

Feasibility to be determined; media and outreach partnership opportunities may exist which could help drive a project forward. Depth is a concern as Yorktown and other ships likely lie outside of Nautilus' current range.

Educational and Outreach Potential of Target Area

Considerable and significant. This is one of the greatest naval battles in human history, determined the Pacific War's outcome, and represents an opportunity to reassess the battle through the integration of the physical data represented by the fallen ships and planes, which is powerful.



Deep Oases: Seamounts and Food-Falls (Monterey Bay National Marine Sanctuary)

Andrew DeVogelaere (Monterey Bay National Marine Sanctuary)

Collaborators

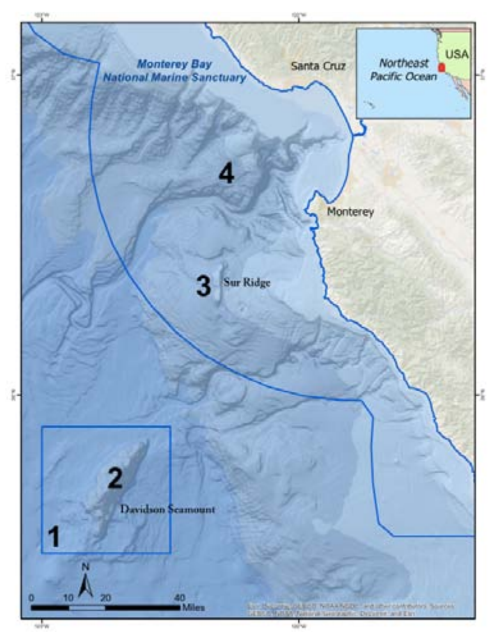
Monterey Bay Aquarium Research Institute
Monterey Bay Aquarium
MBNMS Exploration Center in Santa Cruz
MBNMS Coastal Discovery Center in San Simeon
Stanford University

Region

NE Pacific Basin

Rationale for Exploration

Davidson Seamount, within Monterey Bay National Marine Sanctuary, is a relatively recent addition to the National Marine Sanctuary System and was designated largely because of its spectacular coral and sponge communities. However, smaller species on the seamount as well as those on the continental rise/abyssal plain around the seamount have not been characterized. MBNMS proposes to conduct a first-of-its-kind exploration mission to this deepest point of any national marine sanctuary (3,875 meters), including deploying and filming baited traps of animal carcasses and kelp to attract organisms. This exploration would attract deep-sea organisms in a never before visited location (Figure 1, location 1; see attachment), combined with an area of known spectacular corals and sponges (Figure 1, location 2; see attachment). This project is an exciting exploration effort, addressing important resource management issues, with many associated education opportunities. It would have huge potential for education through social media and live discussions, as well as through standard scientific publications.



The two projects presented below are exciting exploration efforts, addressing important resource management issues, with many associated education opportunities. The first exploration would attract deep-sea organisms in a never before visited location (Figure 1,location 1), combined with an area of known spectacular corals and sponges (Figure 1, location 2). The second exploration would locate and assess deep sea “time capsules” of lost shipping containers, building on the first study ever of a container lost in the deep

(Figure 1, location 4). Both projects have huge potential for education through social media and live discussions, as well as through standard scientific publications.

Brief Overview of Target Area

The mission would be conducted over several days. The first dive to the deepest point in the sanctuary would include deploying "the bait" and conducting initial observations of the species and habitat in that area. Video and still images as well as core samples to evaluate organisms in the sediment would be conducted.A camera system would be deployed at the bait to take sequential still images. In addition, water samples would be collected for the new technique of environmental DNA assessments, where skin cells of bypassing organisms are used to describe the local fauna. The bait would also be deployed on top of the seamount as well as on the continental rise. While the still cameras are working for 1 – 2 days, the ROV would measure the growth of four deep-sea corals marked in 2006, and revisit transects at the top of the seamount to assess changes of the flora and fauna on the seamount through time, and to obtain high quality imagery. At the end of the mission, the ROV would return to each bait station to retrieve the cameras and video any organisms that had occupied the bait station. Sequential photos would be analyzed to determine what had been attracted to the bait.

Brief Summary of What is Known of Target Area

By and large, seamounts especially those in particularly deep water (3,000 m) are poorly studied, however due to work by ONMS and partners – NOAA Office of Exploration, MBARI, and the BBC – Davidson Seamount has had considerable study. Conducting a new mission there will, like past missions, have a high likelihood in discovering new species and making new discoveries. Moreover, there will be considerable opportunities for public outreach as past missions have garnered significant public attention and led to many publications. There is a formal Davidson Seamount Management Zone Management Plan for the Monterey Bay National Marine Sanctuary, but it has lots of research/exploration left to be done.

Feasibility of Studying of Target Area

Davidson Seamount is located 70 nautical miles SW of Monterey, California. The Davidson Seamount Zone ranges from 1,250-3,875 meters deep.

Educational and Outreach Potential of Target Area

Numerous science questions and areas of particular interest for the public are possible from this mission. Topics for associated education discussions include:

- Excitement for the deep, a place never visited before
- Seamounts as areas of high productivity
- Cold temperatures, darkness, and color in the deep
- How species locate food in the deep
- Ocean acidification greater at depth; corals as "canaries in the coal mine"; ocean acidification impacts on the ability of deep sea organisms to locate food
- Deep-sea coral age and growth rates
- Monitoring change through time (Sanctuary monitoring and sentinel sites)
- The new predatory sponge species identified from

- Davidson Seamount
- Importance of taxonomy and exploration
- Marine debris on Davidson Seamount
- New technology to measure environmental DNA, potentially allowing for inexpensive characterization of large places

Lost Shipping Containers in the Deep: Trash, Time Capsules, Artificial Reefs, or Stepping Stones for Invasive Species?

Andrew DeVogelaere (Monterey Bay National Marine Sanctuary)

Collaborators

Monterey Bay Aquarium Research Institute
Monterey Bay Aquarium
MBNMS Exploration Center in Santa Cruz
California State University, Monterey Bay
Central and Northern California Ocean Observing System

Region

NE Pacific Basin

Rationale for Exploration

Ninety percent of everything bought in the United States arrives in this country in shipping containers. At any one time, 5 – 6 million containers are in transit. An estimated 10,000 containers are lost at sea every year. Only one container across Earth's oceans is being studied for its impacts to the deep sea, and this is in Monterey Bay National Marine Sanctuary. MBNMS along with partners at MBARI have studied this one container leading to a number of interesting discoveries as well as enormous public and media attention. This exploration would locate and assess deep sea "time capsules" of lost shipping containers, building on the first study ever of a container lost in the deep (Figure 1, location 4; see attached file). This project is an exciting exploration effort, addressing important resource management issues, with many associated education opportunities. It would have huge potential for education through social media and live discussions, as well as through standard scientific publications.

Brief Overview of Target Area

When the one known container was lost, the shipping company carrying it confirmed it had lost another 14 containers in the Sanctuary at the same time. The other 14 have never been found. MBNMS would like to capitalize on Dr. Ballard's renowned expertise in finding shipwrecks and artifacts in the deep and to collaborate with him to locate the additional lost shipping containers in the Sanctuary. Our proposal is to bring Dr. Ballard to Monterey in the next six months to work with MBNMS staff and scientists from MBARI to evaluate known data on where the containers were lost, where the known container was found, and ocean currents, and from there develop a search area for the missing containers. MBNMS has settlement funds that could then be used to deploy new AUV technology to map the seafloor in the search area and look for debris signals that could be the containers. Once targets are identified with the AUV, Ocean Exploration Trusts' ROV would be used to determine whether a signal is a container, and if so the condition of the container. The likely depth of the containers is between 150 – 3,000 meters water depth, in and around Monterey Bay. Findings would be compared to the one container, at 1,200 meters in the oxygen minimum zone, which has been studied for 10 years.

Of considerable interest in the science and resource management communities are the impact these lost containers have to marine ecosystems. For instance, for the one known container in Monterey Bay, past studies have confirmed it crushed the organisms beneath it, modified the sediment size and ecology of organisms around it, introduced pollution, and appears able to persist for hundreds of years. Organisms settle on it, but perhaps not to the extent settlement occurs on natural substrate (rock for instance). Is that due to paint on the container? Is it due to the container's location in an oxygen poor area? Without other containers to study, it is impossible to address the impact this global pollution problem has on the oceans and the special protected places where they may rest.

Hence a final element of this mission would be to compare the unnatural habitat this and other containers provide to adjacent rocky substrate areas. A dive would be conducted to the spectacular Sur Ridge (Figure 1, location 3) where corals and chemosynthetic communities are in the same depth range. Sur Ridge was first explored only six months ago for the first time and considerably more science and discovery await the next mission to Sur Ridge.

Brief Summary of What is Known of Target Area

There is extensive work by MBARI in the Monterey Canyon and Smooth Ridge, where a cabled observatory exists. However, the broader areas around the canyon are rarely visited. Hence, the need to map these areas to locate and visit 14 missing shipping containers.

Feasibility of Studying of Target Area

The known lost shipping container is located 25 nautical miles NW of Monterey, California, in 1,281 meters of water. The other 14 lost containers may also be located in this vicinity. Sur Ridge is located 29 nautical miles SW of Monterey, California, and ranges from 825-1,220 meters deep.

Educational and Outreach Potential of Target Area

Numerous science questions and areas of particular interest for the public are possible from this mission. Topics for associated education discussions include:

- Are lost containers good habitat, ticking time bombs, or benign?
- What is the process for locating lost shipping containers?
- How models of current patterns might assist a search for containers?
- How do found containers compare in community developments and in structural deterioration based on depth and oxygen availability?
- What are the management opportunities to minimize container loss?
- How is the general public connected to container loss, on a day-by-day basis?
- How is the world economy tied to the shipping container business?

Channel Islands Early Sites and Unmapped Wrecks

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Carl Lipo (CSULB)
Wendy Teeter (UCLA/CSUN)
Matt Becker (CSULB)

Region

NE Pacific Basin

Rationale for Exploration

A search for submerged cultural remains in the target area is intended to allow us to ask and answer essential questions about early people settling in the Americas. Chance finds made by passionate, avocational explorers (e.g. the "Naia" skeletal remains found in the Yucatan) and targeted work by archaeologists in coastal and island regions demonstrate the existence of early Holocene settlers. Archaeologists have been developing improved models to aid in identifying site locations that would have afforded people with access to diverse marine resources. Many predicted locations are now submerged and archaeologists working on these questions recognize that systematic investigation of these areas is essential. The cutting edge of prehistoric archaeological research now lies underwater. Additionally, thousands of attested but still unmapped wrecks from all historic periods of navigation in this region constitute an invaluable form of cultural heritage.

Human habitation sites and landforms in the southern California borderlands have become submerged by ocean level rise since the Last Glacial Maximum more than 20,000 years ago. This includes a fairly abrupt rise in the ocean level around 14,500 years ago, a period of compelling interest. Buried cultural sites that are located in now-submerged terrestrial landscapes represent a wealth of data that is essential to assessing models of the peopling of the Americas and to exploiting GIS models designed to predict the location of early sites. Simply put, more exploration and data are needed in order to confirm or revise these models.

The objectives of a study in this target area are:

(1) To investigate areas with a high potential of preserving paleo-cultural landforms. Paleo-cultural landforms are sites where early people lived or exploited resources. The ones we seek date to the early Holocene, a time when research elsewhere indicates that small groups of early people lived inland or on the margins of the southeastern United States. We are in search of the earliest traces of the people who eventually ended up in sites in Baja, Mexico and even South America. If they arrived on the coast of our continent and subsisted using the diversity of consistently available marine resources, then we are seeking the location of the earliest cultural heritage of the Americas along its former western coastline. Paleo-shorelines, deltas, and estuaries that lie under 150 meters of ocean water today could have been accessible, open-air sites to early Holocene people in the Channel Islands.

To accomplish this, we will field test geospatial models that have been designed to aid in finding the submerged landscapes that are most likely to harbor traces of settlement. We will identify, characterize and classify locations within the study areas using existing remote sensing data, seafloor maps, and in these locations, gather new remote sensing data and take stratigraphic core samples.

(2) A second rationale for locating exploration in this study area is the high number of later cultural heritage sites that lie on the Pacific Ocean seafloor. The recent BOEM inventory of coastal sites predicts that only 10% of many thousands of unmapped wrecks have been mapped, based on recent thorough, historical archival work. Unlike some areas (e.g. Gulf of Mexico or certain Atlantic coastal areas), a smaller percentage of wrecked vessels in the California continental borderlands lie within easy reach of divers, so that the overwhelming majority of the wrecks that are known to exist have never been documented as to their specific location. Both the cultural heritage sites that represent discrete archaeological or historical events (the wreck sites) and the biological communities that colonize them as they settle into the seafloor, remain unknown and unmapped.

Brief Overview of Target Area

Compared to Florida's relatively smooth, western continental shelf, the continental borderlands of California are the wild west. Here we speak of the southern California bight and adjacent borderlands rather than a smooth, sloping extensive continental shelf. Here the thin, ancient coastal margins of the Channel Islands (the portions now submerged) lie close to tectonically active, hydrothermally productive, deep basins and channels that support diverse, complex ecosystems rich in marine food resources. Here is where we expect to find traces of America's early people in submerged coastlines and buried, relic estuaries and deltas where they could have been protected from the ocean's energy. Additionally, as a ship of exploration transects the deep basins and passages between the target study areas on the Channel Islands, we gain the opportunity to survey unmapped wrecks that lie in deep and shallow waters so that their testimony to wars, trade, and travel can be recovered.

Torben Rick of the Smithsonian and his colleagues describe the Channel Islands as a North American Galapagos where distinctive flora, fauna and environmental adaptations flourish. As elsewhere, these islands have been trimmed down to their current size through ocean level rise that extended throughout the entire history of human habitation. The islands remain largely undeveloped but use of the islands can be intensive and destructive of cultural heritage and ecological resources. Paleo-cultural landforms and wrecks are subject to numerous threats, including recreational beach use; coastal erosion; earthquakes; infrastructure development; dredging, trawling and other commercial fishing activities; anchoring; and intentional recovery of ancient or historical materials during recreational SCUBA and avocational ROV use, including wreck diving, personal collecting and commercial sales in antiquities markets.

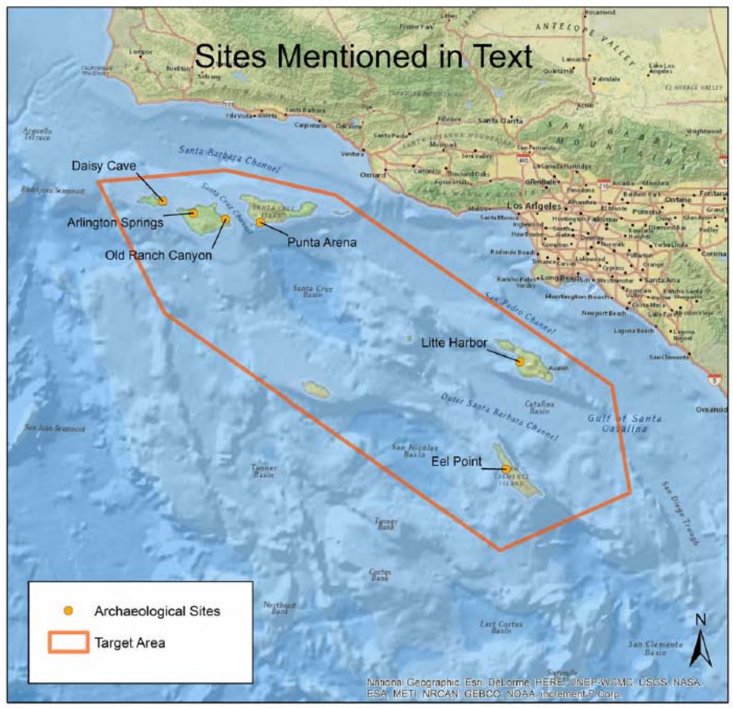
The Channel Islands are owned and managed by a variety of federal agencies and private organizations and the scientists collaborating on this project have relationships established with these entities. The Northern Channel Islands and Santa Barbara Island form the Channel Islands National Park. Western Santa Cruz is owned by the Nature Conservancy while San Miguel is owned by the US Navy. San Nicolas and San Clemente both are administered by the US Navy which maintains a presence there. Santa Catalina (known as Pimu or Pimunga to the Tongva or Gabrielenos) contains the only large formal city on the Channel Islands (Avalon) and has a permanent research station (Wrigley Marine Research Institute). Otherwise, most of Catalina is managed by the non-profit Catalina Island Conservancy.

Target Areas

A and B - Santa Rosa Island and San Miguel Island are home to two of the older sites in the Channel Islands: Arlington Springs (12,685 BP) and Daisy Cave (10,500 BP). We plan to collect cores offshore from these terrestrial sites in order to assess the paleo-geomorphological and environmental contexts for early Holocene sites. Could an even earlier site lie near the paleo-coastline, which might be contemporary with sites lying further south, such as those in Baja and Yucatan, e.g. Isla de Cedros, Isla Espiritu Santo and Hoyo Negro?

C - Another, slightly later site on Santa Rosa is Old Ranch Canyon (8180–7850 BP). It is of special interest because the cultural remains there are similar to the Western Pluvial Lakes Tradition. Were these people adapted to exploit a river, marsh, or estuary environment filled with smaller game, birds, and fish? We aim to look for traces of this paleo-environment in cores near the site in deep water.

D– On Catalina Island, a Holocene site has been investigated at Little Harbor (7800 BP). Additionally, looking outward from the coastline toward deeper water, reconstruction of the paleo-landforms around Catalina indicate that Farnsworth Bank, which lies off the coast of Catalina Island on its southwest side and is now submerged, would have been above water and easily visible, if not actually connected to the island. By considering the southwestern coastal settlements of Catalina Island together with Farnsworth Bank, which is located at the edge of the deep Santa Barbara passage and near the deep slope of the underwater Catalina Canyon, we gain an opportunity to investigate an extensive, culturally significant landscape at its interface with the rich marine resource catchment that sustained it. Additionally, this study region in the target area allows investigation and survey of the ecology and biology of the deep water purple hydro-coral communities that live in the picturesque rocky pillars of Farnsworth Bank. This species, deepwater purple hydrocoral (Stylaster californicus) constitutes a sensitive, biological community located in an ecological preserve with a presumed range up to 110m although it has been reported well below 300 m. This imprecision could be redressed through visual survey that is (in part) analyzed using crowd-source interpretation techniques, such as those used in the Mongolia, Valley of the Khans Project. An assessment of the success of this ecological preserve since the 1970s, or of its limitations, will be funneled into the creation of educational resources for the communities making these impacts and for citizen scientists and students.



The extent of significant commercial and recreational impacts including marine debris such as nets and lines, which affect other marine species also, has not been systematically studied and would be a target of investigation.

E – Intentional survey while moving between target areas. In deep, colder water, we expect wrecks to be preferentially protected from the predations of warm water species, wave or current energy, and recreational scavenging. Recent research by BOEM indicates that the locations are known for less than 10% of the more than 5800 historically-attested wrecks.

Brief Summary of What is Known of Target Area

The southern California portion of the NE Pacific Basin has been the object of study for many decades for a patchwork of reasons and with coverage that has not focused systematically or extensively for the recovery of these kinds of remains underwater. Until very recently, nearly all baseline characterization of early human settlement has been concentrated on land. As previous expeditions by the Nautilus have ably demonstrated, sea level rise over the past 22,000 years has had dramatic effects on the visibility of the earliest sites of human settlement. Recent GIS-based settlement modeling now considers isotonic rebound and other environmental factors and the predictions are even clearer: early human habitation should be able to be located in the coastal margins of the Channel Islands. In all periods for which a data set has been developed, population density is highest near the coastline. The recent Pacific Coastline Site Assessment by BOEM estimated that the Channel Islands, including Catalina and Santa Rosa, have some of the oldest paleo-shorelines, with extensive areas dating back to 18,000 BP, which would have provided the necessary locations for settlement or seasonal exploitation in the targeted time period at the end of the Pleistocene and early Holocene.

Scientists interested in the peopling of our continent have long sought the Early Holocene sites in southern California. Early sites on the Channel Islands include Daisy Cave on San Miguel Island, Eel Point on San Clemente Island and Arlington Springs on Santa Rosa. Earlier sites have been located in the northern Pacific Coast, and also in southern California on the mainland, for instance the Surf site in western Santa Barbara country or the Cross Creek site in San Luis Obispo county. To the south, in Baja California and Yucatan, e.g. Isla de Cedros, Isla Espiritu Santo, and Hoyo Negro, remains of some even earlier sites have been located, predating those found so far in the Channel Islands by a millennium. Locating the sites that account for a millennia or more of human movement and settlement along the coastline is a compelling target. Path-breaking research discoveries are being made underwater by identifying the submerged paleo-landforms, paleo-environments of estuaries, deltas and former beach terraces near which buried midden accumulate, and the resources (e.g. chert), flora and fauna on which Early Holocene people in the Americas relied.

Mapping and multi-beam imaging of the continental margin recently has provided a transformational reservoir of data for a range of geological, tectonic and other research. In the case of archaeological research, ground trothing remains absolutely essential for these data sets to be exploited appropriately. These data allow for the development of multi-faceted investigations. The Southern California Earthquake Center's Borderlands Working Group reports provide important detail relevant to tectonic analysis and paleo-sedimentary profiles. Seismic reflection data for many areas now augments the high resolution multi-beam imaging and those sedimentary profiles created in certain areas. Researchers invested in identifying tectonic structures have been able to document the highly variable sedimentation profile (ranging from massive to thin) of the near-shore regions along the California coast. Others have identified multiple relic shorelines of the northern Channel Islands (Reeder-Myers 2012). Both are relevant to this investigation and we will evaluate these data in the coming months as we plan optimal research locations. Meanwhile, other researchers pursue agreements with petroleum companies in order to access decades of high quality seismic reflection, which is a type of testing that no longer can be undertaken.

Multi-beam imaging, when paired with coring, lays bare the hidden realities of deeply buried and submerged ancient landscapes in which early people lived. Characterization of natural and anthropogenic structures and materials (whether tectonic, foraminifera, bacteria, or marine debris) and the potential future impacts constitute compelling, and possibly even urgent, research domains which could be undertaken in tandem with cultural research. Detailed characterization of the outer continental shelf is a planned priority of BOEM, which has already undertaken a surficial inventory of cultural sites and wrecks. Otherwise, little systematic work to locate wrecks has been undertaken, although enterprising recreational divers know where a number of the unmapped, shallow water wrecks are located.

Feasibility of Studying of Target Area

The target area provides easy access to support from coastal and island research and provisioning facilities. With the exception of the areas which are subject to active drilling off the Santa Barbara coast, military reserves, and shipping lanes, there are no particular impediments to access in the target area, to gaining necessary permissions to undertake scientific research, or unknown hazards to navigation in these waters.

The modeling of the ocean level rise following the Last Glacial Maximum provides a foundation for investigations of this paleo-geomorphology and for systematic attempts to locate buried and submerged traces of early human habitation. Coring will enable discovery, dating and description of estuaries or other coastal and near shore environments. Shallow coring and seafloor sampling will provide chrono-stratigraphy; deep-tow and remotely operated vehicle high-resolution seafloor and sub-bottom imaging can support on-the-fly imaging and inform mission decisions, telepresence participation, and later analysis; acoustic imaging of Holocene strata associated with active faults remain priorities that will derive data applicable to a range of science goals, from tectonic to cultural.

Educational and Outreach Potential of Target Area

Without intending to overstate our case, we believe that public interest and the educational and outreach potential for scientific exploration in this target area will be significant. Documenting the deep time impacts and details of humans' ability to cope with a changing climate, coastline, and resource base is a core deliverable of the cultural focus of this project. While 9000 years of occupation may be considered sustainable by modern standards, the early human settlement of the Americas is also increasingly understood as the opening act of the Anthropocene which left massive traces of human action scattered around the globe for future generations to find. We continue this process today, with billions more people contributing to the effort.

Marine debris (abandoned nets, lines, traps) on Farnsworth Bank off Catalina Island and ordinance dumped in the deep canyon west of Catalina are stories that concern us as members of the public. Marine debris cause fish to die needlessly, and dumping takes munitions out of circulation. These transforms create new environments for biological diversity and underwater "no go" zones. A citizen scientist and student "crowd source" analysis is envisioned here, which has longitudinal benefits as more imagery can be delivered and processed in the future.

Future seismic risk assessments are of great interest to our coastal population because people remain concerned about tsunamis, earthquake damage and injury in a society that is still ill-prepared to mitigate catastrophic impacts on older structures and infrastructure (e.g in May, 2014, Los Angeles passed a council resolution to instigate the first seismic inventory of older buildings).

We anticipate, and will encourage, a high degree of interest from media, documentary film makers, environmental groups, local governments, STEM-focused NGOs and educators, researchers and students. We expect that students in university Biology, Environmental Science, Earth Science, Archaeology, Anthropology, Cinematic Arts, Engineering and Spatial Sciences graduate and undergraduate programs will participate via telepresence in our missions. The collaborating scientists will create entry points for other researchers and students to this work. Through this a greatly enlarged group of scientists and mentored student scientists will derive short and long term education and research benefits from these scientific missions.

For the documentation of the unique coral community on Farnsworth Bank, Karla Heidelberg (Director, USC Environmental Studies) and her students will develop a freely available film resource for use by students, scientists, educators, and the Catalina Island Conservancy. It will provide introduction to mid-depth benthic community structure around Catalina Island and inform recreational and commercial users about ways they can continue to use this place without destroying it. Students can see Ballona Creek and the adjacent wetlands on the California coast with its intensive settlement sites as a living example of a paleo-estuary that may now lie 100 meters below the waves.

As archaeologists, we plan to make educational components for our students and the public. Some of us who already have had experience with media (e.g. Archaeology Channel) and we are aware of the potential of connecting through social and other media, which we would do throughout the mission. In general, Southern California is home to a range of K-12/university collaborations that are well advanced and in which the collaborators' home institutions and the researchers personally are deeply invested. For instance, USC's Wrigley Institute for Marine Research has a multi-decade commitment to K-12, university educational outreach and a long tradition of involving students at all levels in research experiences. Wrigley and USC have island and mainland facilities to enable telepresence participation, so that a wide range of stakeholders, students and researchers can be engaged in this research. USC also has a well-established outreach program to schools in Los Angeles Unified School District.

Loihi Seamount

Brian Glazer (University of Hawaii)

Collaborators

Katrina Edwards (USC)
Dave Emerson (Bigelow)
Craig Moyer (WWU)

Region

Hawaii/Emperor Seamounts

Rationale for Exploration

Loihi Seamount offers at least four distinct microbial habitats that support an ecologically and biogeochemically significant class of microorganisms, the iron oxidizing bacteria: sites of 20-50-degree-C, iron-rich hydrothermal vents at the volcano's summit (~1,000m depth), sites of 6-degree-C, diffuse iron-rich microbial mats at 4,700m, sites of 1.8-degree-C, ultra-diffuse iron-rich microbial mats at 5,000m, and sites of bare basalts with no localized active hydrothermal fluids. Additionally, Loihi's summit intersects the Pacific Oxygen Minimum Zone, providing a natural laboratory for studying C & Fe biogeochemical transformation processes.

Brief Overview of Target Area

Loihi Seamount is an iron-oxidizing microbial playground across a wide range of spatial and temporal scales spanning from the hydrothermally-active summit (1000m) to recently-discovered cold microbial mats at the base (5000m). Loihi plays host to mid-plate hot spot dynamics, hydrothermal plume dispersion biogeochemistry, and fine-scale microbe-mineral interactions. It is readily accessible to researchers through Honolulu, HI.

Brief Summary of What is Known of Target Area

The Loihi Summit is relatively-well-studied. More exciting from an exploration perspective are the recently discovered features at the base of the Seamount. Edwards et al. (2011) describes a recently discovered, low-temperature hydrothermal field at 5,000 m depth off the southern flank of Loihi seamount (hereafter referred as FeMO Deep) that is characterized by laterally extensive (100's of m), massive Fe-oxyhydroxide deposition, in some cases up to 2m thick. Preliminary mineralogical, morphological, and biological evidence indicate that neutrophilic iron oxidizing bacteria (FeOB) are largely responsible for the widespread Fe-oxyhydroxide deposition that results in formation of laterally extensive, Fe-rich microbial mat ecosystems.

Laterally extensive iron deposits at FeMO deep likely formed from hydrothermal fluids that are enriched in Fe, Mn and Si that have cooled and mixed with seawater in the subsurface.

Feasibility of Studying Target Area

Studying the known summit sites and hydrothermal plume dispersion is entirely feasible, and to a large degree, would be incremental over what has been done in recent years.

Exploration at 4700-5000m is what is really needed, and entirely feasible given capable vehicles. ROV-Jason-II and AUV Sentry have made a handful of dives to the base of Loihi over recent years.

Educational and Outreach Potential of Target Area

Educational and public outreach potential is extremely rich for work at Loihi.A network of interested Hawaiian school groups and summer classes is already in place, as well as connections to key public venues including Waikiki Bishop Museum, and Volcanoes National Park.

Battle of Midway Sunken Aircraft Survey

Kelly Gleason (NOAA/ONMS/Papahanaumokuakea Marine National Monument)

Collaborators

Bert Ho (National Park Service, Submerged Resource Center)
Jennifer McKinnon (East Carolina University)
Pete Kelsey (Autodesk, Inc.)
William Lange (Advanced Imaging and Visualization Laboratory, WHOI)
Eve Conant (Freelance Journalist)

Region

Hawaii/Emperor Seamounts

Rationale for Exploration

This project proposes to explore sunken aircraft associated with the Battle of Midway adding an important maritime heritage component to our understanding of the broader history of World War II in the Pacific. The material culture associated with this Battle is critical to understanding connections and making comparisons between Pacific regions, and better comprehending the Pacific Front of WWII.

Sunken aircraft represent the tangible evidence of our nation's naval maritime and aviation legacy and hold potential for engaging the public as well as the application of cutting edge technology and multidisciplinary survey. This project proposes to investigate legacy magnetometer anomalies, collect and ground-truth additional magnetometry data, and make discoveries that enrich the maritime and aviation history of Midway Atoll. Additionally, it serves as an opportunity for progressive multidisciplinary invasive species survey in collaboration with PMNM's resource protection program and advanced 3D imagery documentation and analysis as potential outreach products. The success of this project's exploration is increased through a newly applied refined methodology of combined oral history research and remote sensing. Further, the multidisciplinary nature of the project is exemplary in demonstrating the comprehensive nature of maritime heritage survey, from exploration to interpretation and dissemination, and inclusive of remote sensing, archaeological, and biological survey through advanced technologies.

Brief Overview of Target Area

Few places represent the legacy of World War II like Midway Atoll. Located within Papahānaumokuākea Marine National Monument and World Heritage Site (PMNM, the Monument), the sunken history left undiscovered at Midway represents the material remains of one of the most significant events in the history of the naval base. The potential for exploration at this remote atoll in the Northwestern Hawaiian Islands is remarkable, and the possibilities are demonstrated with the recent discovery of a rare Brewster F2A-3 Buffalo located in shallow waters of the Midway Atoll lagoon.

Brief Summary of What is Known of Target Area

Archival research identifies 31 plane crashes within three miles of Midway Atoll (Linville, 2010). Of these, 22 were American and 9 were Japanese and all considered war graves. The Battle of Midway is considered one of the most decisive U.S. victories of WWII and is referred to as the turning point of the war in the Pacific. To date, two sunken aircraft have been located and documented by archaeologists at Midway Atoll (Papahānaumokuākea, 2011); dozen more remain undiscovered.

The primary objective of this project is to uncover the sunken history of the Battle of Midway through remote sensing, anomaly testing and historical research. To date, three magnetometer surveys have been conducted at Midway Atoll: a 2003 survey by Panamerican Consultants, Inc., a 2010 survey by SEARCH, Inc. and a 2012 survey by NPS/SRC (Figure 1, demonstrating areas of intended survey in 2012). These surveys have proven to be effective in detecting ferrous anomalies (over 70 anomalies located), but few have been investigated due to the remote location of the NWHI (Burns 2010; Ho 2012). This proposal builds upon existing survey data by conducting a more comprehensive survey of the inshore and offshore portions of Eastern and Sand Island as well as anomaly testing.

Ability to test anomalies from the 2012 survey was limited by time at the site. While WWII aircraft are largely aluminum alloy, which is not detectable via magnetometry, certain ferrous elements such as engine blocks, cast iron machine guns, or ferrous landing gear can be detected.Additionally, some early grades of stainless steel, like 300-grade, were used in WWII-era aircraft which can also be detectable. With only six of the 70-plus known anomalies having been visually inspected, we believe that there is a strong probability for making discoveries of lost aircraft using the existing data outside of the lagoon and new data collected inside.

Survey operations will focus on pre-determined blocks representing areas that have high probability of discovery based on historical data, bathymetry, and oral histories. Preliminary target areas include the end of the runway on Eastern Island, west end of Sand Island, and areas in the north and east within the lagoon. These areas in the lagoon are known to have been where both Japanese and U.S. fighter planes crashed, as recollected by veterans.

Based on the recent discovery of the F2A-3 Brewster Buffalo in the same shallow water, dynamic environment, detection of any lost aircraft is probable.

Feasibility of Studying Target Area

Though a combination of pioneering technology, original methods, and experience based strategies for survey and logistics, the team will achieve a wide suite of goals that focus on exploratory survey, resource protection and getting exciting discoveries to a wide audience from a remote atoll with a heritage that includes one of the most significant battles of World War II and an important site for interagency management. Based upon the team's experience and site familiarity, the feasibility is extemely high.

Educational and Outreach Potential of Target Area

PMNM proposes at least 14 days of exploratory remote sensing survey at Midway Atoll in specific areas of reported and probable aircraft loss during the Battle of Midway. Exploration for sunken aircraft sites will also serve as an opportunity for progressive multidisciplinary survey through collaboration with PMNM's resource protection program to survey for alien invasive species on anthropogenic structures at Midway Atoll (specifically sunken aircraft).Additionally, the project will prioritize the development of cutting edge education, media and outreach products through innovative technology, award winning in-house journalists, and a strategy to create captivating materials that will remotely bring the place and the project to people all over the world.

In addition to magnetometry, this project will make use of AutoDesk Recap Imaging Software.AutoDesk, a world leader in developing software for computer aided design and computer aided manufacturing (CAD/CAM), has committed to supporting the project with Recap, an innovative 3D imaging software.(See Appendix A, Letter of Commitment from AutoDesk) This aspect of the project will be led by Brett Seymour,SRC's Audio/ Video Production Specialist, and it will require multiple photographs to be taken of each new aircraft discovery to create a usable research and outreach product. With photo documentation being the sole documentation tool for this exploratory project, it is crucial that the photos and subsequent products produced from the photos are both accurate and useful for study, but also visually available to the world via the internet. Autodesk's software accomplishes the outreach objectives of this project by bringing new discoveries to life in a 3D image format so that they are available for viewing and study by more than the research team. Autodesk's new imaging software is designed to be cloud-based with processing and merging of photos into a complete three-dimensional image completed on a dedicated central computer offsite. Because the images taken of new discoveries will be in high-resolution, their file size will be large and will likely overwhelm the slow internet connection at the USFWS offices on Midway. Autodesk has committed a staff participant to bring and operate their processing computer to render the 3D images onsite, producing ready-to-view images that are scalable and can be used in archaeological analysis and for pubic interpretation. The following images are examples of what the software can produce immediately upon image download.

With no archaeological mapping planned for new discoveries, we feel that Autodesk's Recap software is an effective and innovative method of collecting meaningful data for study, interpretation and management. It is also by the nature of 3D, an excellent form for outreach and educational material to engage and inform the public about the past.

Deep Bioluminescence and Biofluorescence Exploration

David Gruber (City University of New York/American Museum of Natural History)

Collaborators

Vincent Pieribone (Yale University/John B. Pierce Laboratory)
Brennan Phillips (URI)
Chris Roman (URI)
John Sparks (American Museum of Natural History)
Dan Tchernov (University of Haifa)

Region

Hawaii/Emperor Seamounts
NE Pacific Basin
Galapagos/Cocos Ridge
SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise
W Central Pacific/Line Islands
Tuamoto Archipelago/Austral (Tubuai) Island/Cook Islands

Rationale for Exploration

Over the past few years, the collaborators of this project have been designing underwater camera equipment to study and record both biofluorescence and bioluminescence. With the assistance of Chris Roman, we have specifically designed this equipment so it could be compatible with ROVs deployed from exploration vessels Nautilus and Okeanos Explorer. Our objectives are to conduct a comprehensive field survey of bioluminescence and biofluorescence in midwater and benthic fauna. This would be one of the first studies to broadly investigate biofluorescence and bioluminescence and the project would provide valuable insight into the distribution and potential function of fluorescence and bioluminence in both midwater and deepwater species. Collaborators of this application are credited with the discovery of over 30 of the 120 published fluorescent proteins and are well prepared with cloning novel biofluorescent genes and have recently reported for the first time, over 180 new biofluorescent species (Sparks et al 2014).

One striking finding that has arisen from deep ocean exploration is that, unlike in the shallow ocean, a majority of deep sea organisms exhibit bioluminescence. This has been demonstrated and studied using deep sea submersibles and ROVs (Haddock and Case 1999; Heger et al. 2008; Heger et al. 2007; Herring and Widder 2004; Johnsen 2005; Widder 1992). Studies have found bioluminescence in pelagic and benthic organisms and across most marine animal taxa. Bioluminescence in the deep ocean takes many forms and subserves range of different apparent functions.As bioluminescence has developed, independently, across numerous phyla, it utilizes a range of different biochemical pathways and processes. Luciferases, luciferins and photoproteins vary dramatically in nature among different taxa. Manyluciferins and the functional groups of photoproteins remain to be determined.

We have developed a camera system that allows imaging in nearly complete darkness with high resolution. The system consists of a Hamamatsu Orca 4.0v2 sCMOS camera assembled into a water tight housing (2300 meter depth rating) with a Full CameraLink® connection to an ultrafast embedded computer (Copperhead, Versalogic, OR) streaming to two RAID0 coupled SSDs. This allows the streaming of full resolution (2048 x 2048) image streams at up to 100fps directly to disk. This allows us to visualize a low-resolution image stream to aid in the identification and collection of bioluminescent organisms in complete darkness (1.9 electrons rms read noise). This camera is controlled by remote access via fiber coupled GigE. This underwater camera systems allows us to visualize bioluminescent specimen for collection. This camera can be attached to or ROV Hercules. Red filters will allow us to focus some dives on only red emitting creatures. Filming biofluorecence is an advanced scientific process that our research team has perfected over the past decade. In doing so, we invented techniques that illuminates the underwater marine environment with high intensity spectrally pure blue light (that mimic the spectra qualities of coral reef water) and we also engineered sensitive cameras equipped with scientific grade dichroic emission filters. This allow only the light produced by fluorescence to be captured on camera. To accurately visualize fluorescence from small Stoke-shifted fluorophores (those present in biology), we use strong scientific-grade blue illumination (450-490nm) light and place long-pass emission filters (>500nm) over our masks and cameras. The excitation and emission filters used need to be of scientific quality with very sharp out of band rejection (>100x). As such, we used microscope-quality dichroic filters and not theatrical grade dichroics (NightSea) or simple colored glass. The difficulty in creating wide-area illumination systems with dichroic filters is that LED light must arrive incident on the filters in a collimated beam perpendicular to the filter surface. Light not arriving highly collimated will not be filter corrected allowing out of band energy to pass through the filter. Traditional underwater LED lamps are composed of collections of small white LEDs which cannot be collimated prior to filtration. In addition, white LEDs produce the majority of energy outside the desired wavelengths. Finally, to visualize the fluorescence effect at a distance, the brighter the excitation light the better. For these reasons we have designed and built our own underwater fluorescence excitation LED lamps comprised of ultra-bright LEDs, collimating lenses, large dichroic filters (Semrock) and exit diffusers all contained within watertight housings.All the proposed instruments were engineered and completed and successfully tested. URI Graduate student, Brennan Phillips is also interested in running the Hamamatsu in and around hydrothermal vent plumes, to use the light-stimulated bioluminescence response to assess the macrozooplankton population distribution relative to the plume. If the ship was on-site over a vent field, this could occupy perhaps 2 days of work, depending on the site size/depth/etc. Guaymas Basin is ideal, in that the GoC has an extensive midwater population that exists around the vent field and the plume is smack in the middle of it. East Pacific Rise is also interesting and very well-studied, so there's good data to put whatever we find in context. Guaymas is relatively unexplored, in contrast.

Brief Overview of Target Area

The Guaymas Basin is a submarine depression located on the seabed in the central area of the Gulf of California, result of activity from several spreading centers. The mouth of the Gulf of California is a region of well-developed oceanic fronts that strongly impacts the horizontal distribution of epipelagic species. We propose to explore the bioluminescent animals constituent of this zone, possibly one of the more unique centers of bioluminescent activity.

Brief Summary of What is Known of Target Area

Relatively unexplored.

Feasibility of Studying Target Area

The underwater housing is currently rated to 2300 meters, so that will be a limitation of the dives. Efforts are underway to make this housing to full ocean depth rating.

Educational and Outreach Potential of Target Area

Exploration in this target area would also provide the highest resolution bioluminescent and biofluorescent imagery ever obtained –that can be shared with the general public. Collaborators of this application curated “Creatures of Light: Nature’s Bioluminescence” one of the most popular temporary exhibits at the American Museum of Natural History and the Field Museum in Chicago.

Western Aleutians at the Amchitka Pass

Katherine Kelley (URI)

Collaborators

Elizabeth Cottrell (Smithsonian Institution)

Region

Aleutian Trench/Bering Sea/Gulf of Alaska

Rationale for Exploration

The western Aleutian island arc has been called “a nursery for the generation of continental crust.” In this unique tectonic setting, calc-alkaline mag mas erupt through the oceanic lithosphere and crust and thus provide an ideal locality to study the generation of continents. The Amchitka pass represents a spatial gap in the otherwise regular occurrence of subaerial volcanoes in the western Aleutians. Recent studies of the regional bathymetry and dredge samples o f the seafloor suggest, however, that volcanism is diffusely distributed along local faults and thus remains largely submarine. Although the Aleutian island volcanoes, including many in the western Aleutians, are broadly well-studied, little is yet known about the submarine Aleutian arc. Exploration of this area, where submarine volcanism is documented but has not yet been explored in detail, will pro vide essential constraints o n the magmatic activity and pro cesses in this key part o f the Aleutian arc.

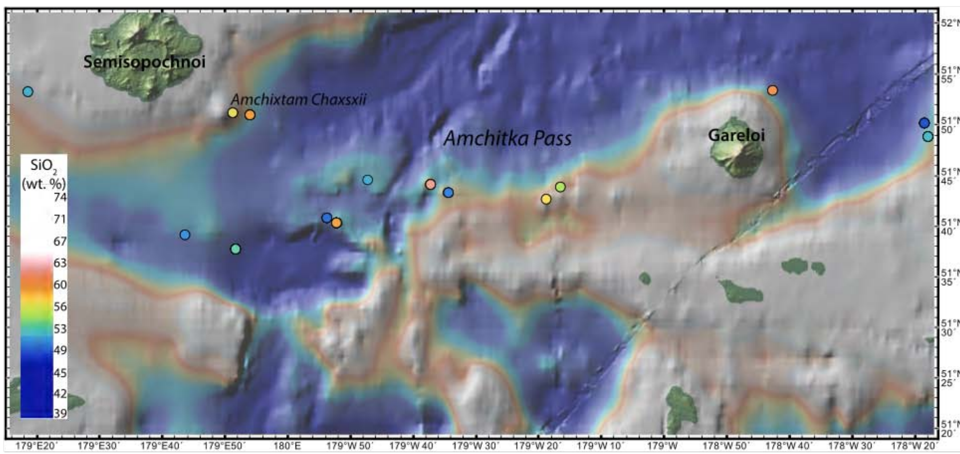
Volcanoes in the western Aleutians erupt lavas of composition similar to Earth’s bulk continents, and observing and sampling these rare volcanoes in a submarine setting, which preserves volcanic glass and pre-eruptive volcanic gases, is necessary for understanding how they formed, and ultimately how Earth’s continents were built. Volcanism in this region spans a broad range of compositions (e.g ., Fig . 1), however, and direct observations of submarine volcanic structures, paired with precision sampling o f volcanic features, are essential to establishing the relationships of these lava types to each other (e.g ., did they erupt from the same volcano ?), and to determining the extent of young submarine volcanic activity in this area (e.g , are the volcanoes sedimented? Are any actively venting , erupting , or supporting biological communities?)

Brief Overview of Target Area

The Aleutians are a subduction-related chain of volcanoes in the northern Pacific Ocean. The Pacific plate approaches perpendicular to the Aleutian trench in the east, but the convergence angle becomes strongly oblique towards the west due to the curved morphology of the arc. The change in convergence direction is accompanied by along-strike changes in erupted lava chemistry, such as Fe and Si content, Mg#, and isotopic composition. Importantly, lavas in the western Aleutians have many chemical characteristics in common with Earth’s continental crust. This has led some researchers to propose that the style of subduction in the western Aleutians directly and uniquely reflects the processes by which Earth’s continents were made.

Brief Summary of What is Known of Target Area

The first submarine volcano in this region (Amchixtam Chaxsxii) was discovered by a NOAA expedition in 2002, and was mapped by NMFS team in 2003 (R/V Davidson). In 2004, work by R/V Revelle and Jason II ROV mapped coral distributions and submarine habitat in the pass. The broader region, including much of Amchitka pass, was surveyed and sampled by dredging on the 2005 WAVE Expedition (R/V Thompson; TN182). Samples of the volcanics include a wide variety of lava compositions, ranging from basalt to dacite (Fig. 1). The Alaska-Aleutians subduction zone is presently designated as a focus site by the decadal NSF-GeoPRISMS program, so funding for a broad range of geochemical and geophysical studies will be directed at this area over the next several years., making work in this region timely and increasing the potential for broad dissemination of activities and results.



Feasibility of Studying Target Area

The bathymetry in the region in <2000 m depth, so fully accessible by ROV Hercules. The nearest major deep water port to the study area is Dutch Harbor, AK, though there should be opportunity for resupply from Adak. The general area has been successfully accessed by scientific vessels using ROV and dredge sampling.

Educational and Outreach Potential of Target Area

Water column sampling could reveal if there is any active submarine hydrothermal activity in the area. If so, there is potential for observations of extremophile fauna and active volcanological processes, including hydrothermal venting and volcanic outgassing. Through Nautilus Live, the NSF GeoPRISMS program, and Cottrell's connections with outreach through the Smithsonian, this research has the potential to reach very broad audiences. The National Museum of Natural History (NMNH), Smithsonian Institution, offers unparalleled opportunities to engage public audiences in ocean exploration. Potential vehicles for public engagement include "Live from Q?rius" webcasts (customized to align with middle school Earth Science curricula) and exhibition of retrieved materials and multi-media footage in NMNH's new Sant Ocean Hall or new public outreach hall, Q?rius. Meet-the-scientists engagement events, public lectures, and online social media experiences accessed through Smithsonian's popular "Ocean Portal" (http://ocean.si.edu) or iTunes University series could all be leveraged. ROV footage of volcanic edifices and basalt sampling could be paired with interviews with members of the scientific team for live and archived broadcast online (e.g., the Ocean Portal's "Vents and Volcanoes" pages) or for in-house events. By taking advantage of these existing structures we have the potential to bring the Nautilus experience to tens of thousands of school children and members of the lay public (domestic and international).

Surveys of Deep Habitat in Bodega Canyon and Continental Slope in Cordell Bank National Marine Sanctuary Proposed Expansion Area

Danielle Lipski (Cordell Bank National Marine Sanctuary)

Collaborators

Kaitlin Graiff (Cordell Bank National Marine Sanctuary)

Region

NE Pacific Basin

Rationale for Exploration

Submarine canyons and shelf-break regions have been documented as areas of high coral abundance and diversity due to their rocky habitats and higher slope environments as well as localized upwelling and hydrographic features associated with these bathymetric features. T he patchy and complex nature of these seafloor features highlights the vulnerability of these communities in their ability to recover from disturbance. Work is needed to better understand the physical, geological, and biological processes influencing the distribution of these largely unstudied deep sea communities. In particular, deep water canyon and slope regions of the Cordell Bank National Marine Sanctuary (CBNMS) proposed expansion area are excellent candidates for submersible exploration. Results from this exploration will contribute critical information for filling in the gap of knowledge of features in this area and their potential as suitable habitat for cold-water coral and sponge communities. It will aid in our understanding of how these communities are linked across multiple scales and will provide essential descriptions of habitat that may be eligible for designation as special habitat, such as new EFH areas. Additionally, results from this work will aid in our understanding of areas of highest sensitivity to disturbance, which could inform both fisheries and sanctuary management.

Brief Overview of Target Area

Although the main feature within the existing boundaries of Cordell Bank National Marine Sanctuary (CBNMS), the bank itself, has been surveyed using the Delta Submersible, and shallower areas have been explored by technical divers, other areas within the sanctuary and proposed expansion area have never been surveyed. Within the proposed expansion area, several unique features are excellent candidates for exploration using the submersible. In particular, Bodega Canyon and adjacent habitat on the continental slope are features that are important to the ecosystem dynamics of the Cordell Bank region and may contain deep water corals and sponges. CBNMS lacks the appropriate technology to explore the deep areas of Bodega Canyon and the adjacent continental slope. T he canyon ranges from 300 to 1000 m and the slope extends beyond to depths reaching 3000 m. Available multibeam data for this area, collected by Okeanos Explorer, indicates that hard substrate may be present. Also, observations of nearby habitat suggest that the deep slope habitat could contain fascinating habitat and specimens. For example, submersible surveys conducted in the early 1990s off the continental slope west of the Farallon Islands revealed deep sea corals at approximately 3,000 meters- including primnoids, bamboo corals (Keratoisis sp.), and black corals (Bathypathes sp.). Some of these individuals were estimated to be approximately 1 meter tall. T hese deep water observations are the first and only in-situ observations of these types of corals for the region at such deep depths. In addition, deep sea coral species may also be living in the deepest depths of Bodega Canyon. Surveys conducted in 2011 using an Autonomous Underwater Vehicle (AUV) were limited to depths less than 500 meters. From these surveys there were numerous observations of deep sea corals, particularly primnoids, as well as a variety of deep sea sponge species. Explorations in the deeper areas of the canyon and slope may reveal a variety of other corals and sponges that have not been previously observed within the sanctuary.

Brief Summary of What is Known of Target Area

Although the depths of the target areas have not been explored, multibeam bathymetry and interpreted habitat layers exist for this area. Previous cruises at shallow depths have allowed us to groundtruth the interpreted habitat and improve our understanding of the bathymetry. As mentioned earlier, previous surveys near the Gulf of the Farallones in the 1990's offer and intriguing suggestion of the possibility of corals in the target area. However, very little in known about the target area.

Feasibility of Studying Target Area

The feasibility of studying the area is high. Shipboard oceanographic and ecological research regularly occurs in these waters off the San Francisco and North Bay coasts and successful submarine, ROV, AUV, and camera sled cruises have been completed nearby. The location of the features are approximately 60 miles from the entrance of San Francisco Bay where there are adequate docking and marine facilities to accommodate large research vessels. The most favorable ocean conditions for research normally occur between August and October, although research cruises take place as early as May in some years. In addition, Cordell Bank National Marine Sanctuary staff are local and familiar with regional facilities and conditions and would be prepared to assist the expedition.

Educational and Outreach Potential of Target Area

National Marine Sanctuary staff excel at ocean education and outreach and are excited about the opportunity to create novel products and reach audiences with footage and stories from newly explored habitat. High definition imagery from this project would be integrated into various education and outreach products and programs at Cordell Bank National Marine Sanctuary and can be used for promoting sanctuaries, ocean exploration, and the importance of marine conservation. Ideas for products include underwater fly-through imagery, story mapping using video clips, embedding video into exhibits, creating new interactive curriculum, and working with museums and visitor centers to stream video or host exhibits. CBNMS has a network of schools, educators, partners, and public constituents through which we could reach new and eager audiences.

Trask Knoll and Santa Cruz Canyon

Jay Lunden (UC Santa Barbara)

Collaborators

Gretchen Hofmann (UC Santa Barbara)

Region

Southern California Bight

Rationale for Exploration

Deep sea habitats are among the most vulnerable to anthropogenic stressors, including ocean acidification – the reduction in seawater pH due to the uptake of atmospheric carbon dioxide. Ocean acidification is of particular concern to calcifying organisms, as it drives the shoaling of the aragonite saturation horizon (Orr et al. 2005). With sustained shoaling of the aragonite saturation horizon, organisms that precipitate calcium carbonate as aragonite, including foundation species such as cold-water corals, will experience increased difficulty precipitating skeletal material and may be subjected to dissolution (Guinotte et al. 2006), thus limiting their distribution and provision of habitat for associated invertebrates and fishes. However, due to the general lack of exploration, there are limited documented observations of cold-water corals and other benthic calcifiers in the NE Pacific Ocean.

Here, we propose to explore sites in the Southern California Bight that are likely vulnerable to ocean acidification. The Southern California Bight is influenced by two major hydrographic features: the California Current (CC) and the Southern California Crosscurrent (SCC). The California Current is characterized by frequent upwelling events that deliver corrosive, low pH waters to the continental shelf (Feely et al. 2008), exposing coastal areas to waters that are undersaturated with aragonite. These upwelling events have already been linked to the dissolution of calcium Carbonate structures in marine species (Bednarsek et al. 2014). However, the documented occurrence of cold-water corals within these regions may suggest a potential resilience to ocean acidification, and the populations of cold-water corals within these areas may serve as evolutionary “hotspots”, thus necessitating their discovery and protection. We propose to specifically target Santa Cruz Canyon and Trask Knoll within the Southern California Bight. The target areas lie adjacent to the Channel Islands National Marine Sanctuary (CINMS), a marine sanctuary administered by the NOAA National Marine Sanctuary program. To our knowledge, exploration of the area surrounding the CINMS has been limited; however, previous work from 2010 revealed the presence of cold-water coral communities on the nearby Piggy Bank seamount, including occurrences of the scleractinian corals Lophelia pertusa and Desmophyllum dianthus (Yoklavich et al. 2011). The occurrence of scleractinian corals in this region is of particular significance to ongoing studies of ocean acidification in the deep sea – data from the region suggest that the areas are routinely exposed to corrosive, low pH seawater (Alin et al. 2012). Continued exploration of the nearby area would likely extend our knowledge of the spatial extent of cold-water coral communities within the region and would also provide us with opportunities to collect additional biological and chemical samples that will augment our understanding of ocean acidification in the deep sea. Additionally, the Santa Barbara Channel (on the north side of the Channel Islands) is an active area of hydrocarbon seepage (Clark et al. 2000), so it is possible that chemosynthetic fauna may occur within the target region. Furthermore, the area is significant in both a historical and cultural context - over a hundred known shipwrecks are found within the waters of the CINMS, and the Native American Chumash people have lived on the Channel Islands for over 13,000 years, thus archaeological findings are also possible.

An additional benefit of our laboratory's involvement would include coupling an autonomous pH sensor – the SeaFET (Martz et al. 2010) – with the ROV Hercules. T he first generation of the SeaFET has been widely employed by the ocean acidification community to monitor pH dynamics in a number of coastal marine systems; however, until now investigations have been limited to depths shallower than 70 meters due to pressure sensitivities of the sensor itself. A deep-sea version of the SeaFET – rated to 6000 m – is now in beta-testing and will be commercially available to the research community by February 2015 (Ken Johnson, MBARI, pers. comm.). Coupling the deep-sea model of the SeaFET with ROV Hercules (or Argus) in the Southern California Bight would generate unprecedented spatial and temporal coverage of pH at depth.

Brief Overview of Target Area

Santa Cruz Canyon lies 3 nautical miles due south of Santa Cruz Island and extends to a depth of roughly 1600 meters into the Santa Cruz Basin. T he entire area of interest encompasses approximately 300 km2. The nearby Trask Knoll is approximately 20 nautical miles due south of San Miguel Island and lies at approximately 1500 meters depth.

Brief Summary of What is Known of Target Area

Limited information is available for the target area. However, a cruise in 2010 surveyed the nearby Piggy Bank seamount and found numerous species of cold-water corals and sponges, thus verifying the occurrence of cold-water corals within the region.

Feasibility of Studying Target Area

This proposal falls within the planned region of the 2015 field season, and the area of interest is within 70 miles of Santa Barbara Harbor. Trask Knoll and Santa Cruz Canyon are roughly 30 nautical miles from each other, resulting in a short (~3 hr) transit between sites, thus maximizing the amount of bottom time while underway. Exploration of the areas would likely require 7-10 days at sea, and with a short transit from port (~ 3 hours from Santa Barbara or Port Hueneme) no days would be lost to completely to transit. One potential logistical limitation at Trask Knoll would be poor weather, but alternative dive sites within Hueneme Canyon could easily be selected if necessary.

Educational and Outreach Potential of Target Area

Exploration within and around the Channel Islands has significant educational and outreach potential for UCSB students, the Santa Barbara community, and the coastal region of Southern California at large. We would utilize the state-of-the-art telepresence technology to communicate our findings to the scientific community and to the broader general public audience. Depending on bunk space, we would bring graduate students (and potentially) undergraduate students to sea with us. Also, there are numerous opportunities to collaborate with and leverage the existing outreach frameworks from both the Channel Islands National Park (Dept. of Interior) and the Channel Islands National Marine Sanctuary (NOAA). These platforms would facilitate broad dissemination of the project goals and findings.

Exploration of the Mesophotic Coral Reef Ecosystems of the Au'Au Channel

Jonathan Martinez (NOAA Office of National Marine Sanctuaries)

Region

Hawaii/Emperor Seamounts

Rationale for Exploration

This mission would explore the deepest half of the photic zone in the Au'Au Channel to gather information for resource protection and exploration over several days. A major advantage for exploratory studies in the Au'Au Channel is the fact that fieldwork may be done at any time of the year due to the relatively protected and sheltered conditions that the surrounding islands provide. The priority tasks for this mission are:

1. Assess bottom type in strategic locations in the Au'Au Channel to characterize sensitive habitats and ground truth predictive models where proposed infrastructure projects may occur. An ONMS funded 2012 predictive modeling study by NCCOS revealed potential locations for mesophotic coral reef ecosystems in the Au'Au Channel, which have yet to be fully explored or documented. A renewable energy project being considered by the State of Hawaii is to connect Maui and Oahu through an interisland grid tie by installing an energy transmission cable along the seafloor of the 'AuAu Channel. The lack of data in this area makes it difficult to analyze the potential environmental impacts of this project. This study would assess bottom type locations along these proposed routes using submersible diving, ROVs, visual observations and photo and video analysis over several days. Technical divers from the Papahanaumokuakea Marine National Monument Research Team will be used to supplement the survey effort.

Large aggregations of mesophotic coral reef ecosystems are predicted and can be fully surveyed through this mission. In addition, these coral beds often overlap in distribution with black coral and the ecological communities of mixtures of both of these groups are not well understood. Further, an invasive octocoral Carijoa rissei is known to overgrow and compete with black coral but it is also not well understood how this species overlaps with mesophotic coral species such as Leptoseris sp.

2. Assess coral species distributions and sample specimens for genetic connectivity studies between mesophotic patch reefs. Mesophotic coral reefs in the Au'Au Channel are not contiguous and are often discrete in distribution. This mission will locate mesophotic coral reefs in Task 1 and will opportunistically sample coral fragments for genetic analyses to assess intraspecies diversity at a given reef and connectivity to nearby reefs. A combination of submersible, ROV and technical divers can sample coral from multiple discrete patches of mesophotic reef. Some coral reefs that experience extreme conditions such as low light or other stressors are often composed mainly of a

few specific clonal genotypes that are adapted to these conditions. An assessment of diversity is crucial for resilience and resource protection assessments.

3. Assess baseline water quality parameters at this deeper and stratified location including critical irradiance levels needed to sustain mesophotic coral. Photosynthetic organisms such as coral living in extremely low light levels depend on access to light and thus clear water. Discharges from floods, sewage and nutrients can all directly impact water clarity. As locations are observed from Task 1, water will be sampled and analyzed for nutrient content. The observation equipment (submersible, ROVs, tow sled etc.) will tow a logging photometer to collect data that can be used to generate light-depth profiles in areas where mesophotic coral reefs are observed and where they are not observed in areas that have been predicted to support these ecosystems. This information will aid in refining prediction models and assessing the dependence of light quality for mesophotic corals.

4. Opportunistically observe interactions between Humpback Whales and the seafloor. It has long been suspected that humpback whales utilize the seafloor habitat, but the reasons are not well understood and moreover this has been rarely documented. An advantage of conducting the mission during humpback whale season (Nov - April) is that humpback whale behaviors can be observed at mesophotic depths to gain a greater understanding of habitat use. Projects that alter the seafloor may have the potential to impact humpback whale habitat and behavior. This research objective can be achieved simply using photos, video, hydrophone or other sound recording devices to document humpback whale behaviors at a variety of depths and along the seafloor.

Brief Overview of Target Area

Mesophotic Coral Ecosystems are coral-dominated communities that occur in the deepest half of the photic zone. These deep reefs are currently understudied due to their secluded existence. Understanding these ecosystems and specifically their supportive role in the maintenance of shallow water reefs is a priority management focus for the sanctuary. The Au'au Channel is located in the Hawaiian Islands between the islands of Maui, Lanai, Molokai and Kahoolawe. T he channel reaches depths of 140m however the majority of the seafloor is in the mesophotic depth range between 40 and 90 m deep. T he topography on the channel floor consists of numerous drowned solution basins and ridges, sediment plains, and conical reef pinnacles. These were exposed during periods of low sea level during multiple glacial periods over at least the last 800,000 years. Reef growth in the Channel during the Holocene consists of a thin veneer a few meters thick on those topographic highs.

Image 1. A brightly colored school of reef fish inhabits a reef of *Leptoseris* corals at a depth of approximately 75 m in the Au'au Channel. Photo Credit: HURL.

Brief Summary of What is Known of Target Area

The Au‘au Channel is a priority region for the sanctuary and other researchers for variety of reasons. In addition to being a focus of humpback whale activity in the winter months, it is also the historical center of the black coral jewelry industry in Hawai‘i. This has led to extensive interest in seafloor surveys of coral beds by divers for jewelry production and even harvesting with ROVs and submersibles. More recently, research on the unique geology and reef communities of this region has increased due to the broad area of potentially suitable mesophotic habitat and the recent discovery of some areas with extensive coral coverage and Halimeda beds at mesophotic depths.

Feasibility of Studying Target Area

This mission would explore the deepest half of the photic zone in the Au‘Au Channel to gather information for resource protection and exploration over several days. A major advantage for exploratory studies in the Au‘Au Channel is the fact that fieldwork may be done at any time of the year due to the relatively protected and sheltered conditions that the surrounding islands provide. Ma'alaea Harbor on Maui Island can support the launch of vessels and the surrounding coastline has numerous facilities to support a land based crew. Coast guard presence on Maui can supports emergency response.

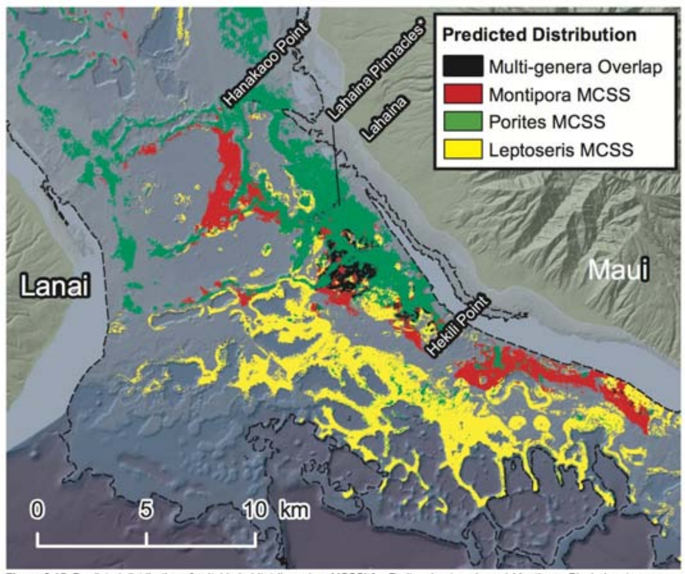


Figure 3.15. Predicted distribution of suitable habitat (based on MCSS) for *Porites*, *Leptoseris*, and *Montipora*. Black denotes co-occurrence of suitable habitat for all three genera. * denotes feature described in Grigg et al. 2002.

Educational and Outreach Potential of Target Area

This mission would contribute information about this little understood area for education and outreach. Live or delayed webcasts with video feeding from the mission could be shared through National Marine Sanctuaries networks including webpages and social media. Photos and video could be used for the development of outreach materials.

Rodriguez and Adjacent Seamounts

***Chris Mobley** (Channel Islands National Marine Sanctuary)*

Collaborators

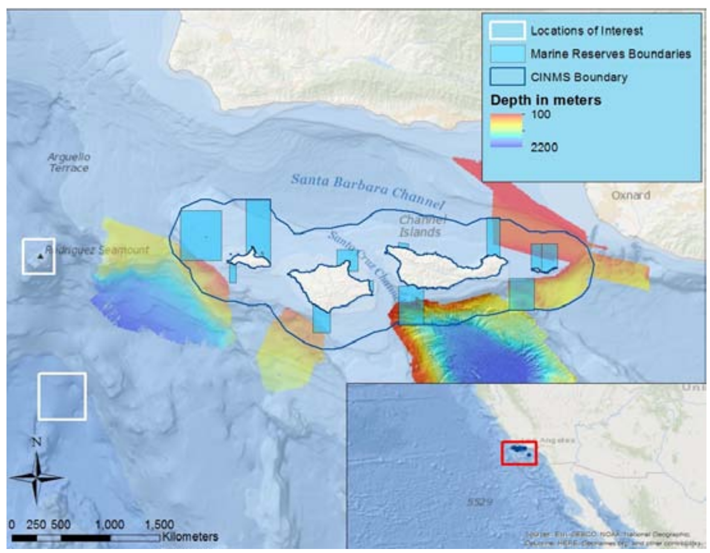
Peter Etnoyer (NOAA/NCCOS)
Brian Kinlin (NOAA/NCCOS)
Guy Cochrane (USGS)
Rocio Lozano Knowlton (MERITO Foundation)
Carol Blanchette (UC Santa Barbara)

Region

NE Pacific Basin

Rationale for Exploration

Seamounts are special places in the deep-sea that are characterized by steep bathymetric relief and unique biodiversity. There are many seamounts off the coast of California but only a few have been studied in any detail. The few areas that have been characterized have revealed a wide variety of ecological communities including chemosynthetic hydrothermal vents and deep sea corals (DSC). Channel Islands National Marine Sanctuary has a number of proximate seamounts (Rodriguez, Hancock, Seamount 109 and an adjacent unnamed seamount)to the west of the sanctuary that have not been significantly characterized, thus would benefit from targeted, high-definition video exploration to both elucidate the geologic processes that shaped them and identify endemic species that may reside there.



Exploration could provide data necessary to further delineate or characterize essential fish habitats, DSC and sponge communities. This information could serve as the nexus between deep-sea scientific discovery and informed (management) decision making.

Brief Overview of Target Area

MARE and USGS have surveyed areas around CINMS and created fine-scale resolution bathymetry products and some limited survey work. Exploration of these two seamounts would be useful to establishing a baseline or even any information on the ecological communities present on these seamounts. Data from these expeditions could be used to identify a possible relationship between the age of DSC and habitat formation.

Brief Summary of What is Known of Target Area

There is some limited geological information on Rodriguez Seamount from MBARI and NSF's Seamount's database. The flat top of Rodriguez is predominantly ancient sediment and sandstone that indicate the seamount was once above sea level. The seamount is also home to several volcanic cones. Seamount 109 is home to the largest aggregation of Lophelia, a DSC, found in the Santa Barbara basin so far. The abundance of this species makes this site a valuable habitat for exploration. Hancock Seamount has had some prior surveying work done by NOAA as well.

Feasibility of Studying Target Area

The target area is within the sanctuary and near the coastline which makes it relatively accessible compared to offshore locations. Vessels will be able to anchor off Santa Barbara Harbor and ferry into the harbor. A few vessels are available for support including CINMS' research vessels: the R/V Shearwater and R/V Sharkcat. This will improve access to the site for researchers, staff, and media as well as allow for easy loading and unloading of gear. The technical and scientific aspects of this mission will need to leverage expertise from NCCOS, MARE, USGS, UCSB, NMFS, OA lab, NOAA OA office so that on-water activities are conducted safely and efficiently.

Educational and Outreach Potential of Target Area

CINMS and its partners have the infrastructure to develop a large variety of educational products for the deep sea missions. Distance learning using near real time video feed from the mission could be transmitted to a number of venues. Local and national K-12 and college students will be engaged by using outreach partnerships with entities including the Aquarium of the Pacific (AOP), UC Santa Barbara, CSU Channel Islands, Ventura and Santa Barbara County Offices of Education, and others. This will give CINMS the ability to share the mystery of deepsea coral and sponge communities and the animals that inhabit them in a near real-time format. Students would also learn about the concept of ocean acidification, and its effect on delicate deep sea ecosystems. T he Multicultural Education for Resource Issues Threatening Oceans (MERIT O) program currently works with a number of local schools that could be used to engage underserved Title 1 schools distance learning. It would allow students to see science in action in a truly unique fashion. Another option for engagement is NOAA's teacher at sea program which allows teachers to assist on research cruises with the condition that they develop curriculum and outreach materials based on their real-world experiences. This can broaden our outreach potential beyond Southern California to a national level. In addition to these options, CINMS is well equipped to develop products for educational use including a taxonomic guide, educational pamphlets, lectures, and audio/visual products. CINMS is also interested in developing spherical display data products. These are educational visualizations that are built for spherical displays (Science on a Sphere, Magic Planet, etc.) and can show geospatial data as well as video footage and imagery. Developed data products can easily be shared among educational programs with these types of displays including CSU Channel Islands Boating Center, Santa Barbara Museum of Natural History, and Aquarium of the Pacific. NOAA would also create geospatial products that are accessible to audiences via Google Earth, including a DSC database.

Santa Cruz Escarpment

Chris Mobley (Channel Islands National Marine Sanctuary)

Collaborators

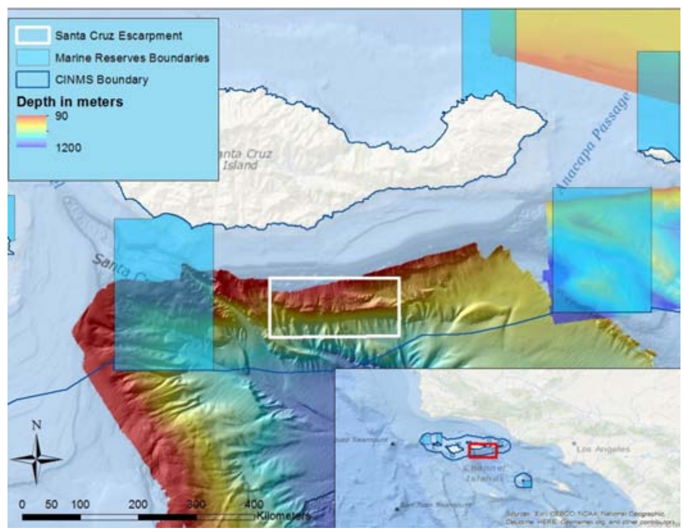
Peter Etnoyer (NOAA/NCCOS)
Brian Kinlin (NOAA/NCCOS)
Guy Cochrane (USGS)
Rocio Lozano Knowlton (MERITO Foundation)
Carol Blanchette (UC Santa Barbara)

Region

NE Pacific Basin

Rationale for Exploration

Past deep-water surveys around Channel Islands National Marine Sanctuary (CINMS) have identified interesting geomorphic features south of Santa Cruz Island, and in close proximity to a crustal fault. Because of tectonic activity, the marine communities in that area are likely impacted by the geologic processes related to faulting and slumping that expose scarps on shelf edges and uplift isolated rock ridges. These geological processes have created a complex bathymetry on the Santa Cruz Island Escarpment (440m - 1300m depth) that has caught the attention of researchers as bathymetric complexity is usually linked to increased diversity for deep water faunal communities.



Brief Overview of Target Area

MARE and USGS have mapped the area south of Santa Cruz Island and discovered the geological formation now known as the Santa Cruz escarpment. The area was marked as a possible biodiversity hotspot because of the high bathymetric complexity, especially the slumps in the upper end of the basin. These slumps are earthquake hazard features and the complex bathymetry is commonly associated with high level of fish diversity. Despite interest in the escarpment and its location within CINMS, research and exploration in the area has been limited and knowledge on this potential biodiversity hotspot is lacking. his area would benefit from targeted, high-definition video exploration to both elucidate the geologic processes that shaped those features and to look for evidence supporting the intermediate disturbance hypothesis for marine community development as geological changes may alter deep-sea community structure.

Brief Summary of What is Known of Target Area

Over the past two years NOAA's National Center for Coastal Ocean Science (NCCOS) and Marine Applied Research and Exploration (MARE) have conducted deep-water surveys around Channel Islands National Marine Sanctuary that have identified the Santa Cruz Escarpment as a potential biodiversity hotspot. High resolution bathymetry exists for the area, but no further data is currently available.

Feasibility of Studying Target Area

The target area is within the sanctuary and near the coastline which makes it relatively accessible compared to offshore locations. Vessels will be able to anchor off Santa Barbara Harbor and ferry into the harbor. T he target is in the eastern Channel Islands, which protects it from the heavy winds and adverse sea conditions that are common in the western islands. A few vessels are available for support including CINMS' research vessels: the R/V Shearwater and R/V Sharkcat. This will improve access to the site for researchers, staff, and media as well as allow for easy loading and unloading of gear. T he technical and scientific aspects of this mission will need to leverage expertise from NCCOS, MARE, USGS, UCSB, NMFS, OA lab, NOAA OA office so that on-water activities are conducted safely and efficiently.

Educational and Outreach Potential of Target Area

CINMS and its partners have the infrastructure to develop a large variety of educational products for the deep sea missions. Distance learning using near real time video feed from the mission could be transmitted to a number of venues. Local and national K-12 and college students will be engaged by using outreach partnerships with entities including the Aquarium of the Pacific (AOP), UC Santa Barbara, CSU Channel Islands, Ventura and Santa Barbara County Offices of Education, and others. This will give CINMS the ability to share the mystery of deepsea coral and sponge communities and the animals that inhabit them in a near real-time format. Students would also learn about the concept of ocean acidification, and its effect on delicate deep sea ecosystems. T he Multicultural Education for Resource Issues Threatening Oceans (MERIT O) program currently works with a number of local schools that could be used to engage underserved Title 1 schools distance learning. It would allow students to see science in action in a truly unique fashion. Another option for engagement is NOAA's teacher at sea program which allows teachers to assist on research cruises with the condition that they develop curriculum and outreach materials based on their real-world experiences. This can broaden our outreach potential beyond Southern California to a national level. In addition to these options, CINMS is well equipped to develop products for educational use including a taxonomic guide, educational pamphlets, lectures, and audio/visual products. CINMS is also interested in developing spherical display data products. These are educational visualizations that are built for spherical displays (Science on a Sphere, Magic Planet, etc.) and can show geospatial data as well as video footage and imagery. Developed data products can easily be shared among educational programs with these types of displays including CSU Channel Islands Boating Center, Santa Barbara Museum of Natural History, and Aquarium of the Pacific. NOAA would also create geospatial products that are accessible to audiences via Google Earth, including a DSC database.

Footprint and Piggybank Reef

Chris Mobley (Channel Islands National Marine Sanctuary)

Collaborators

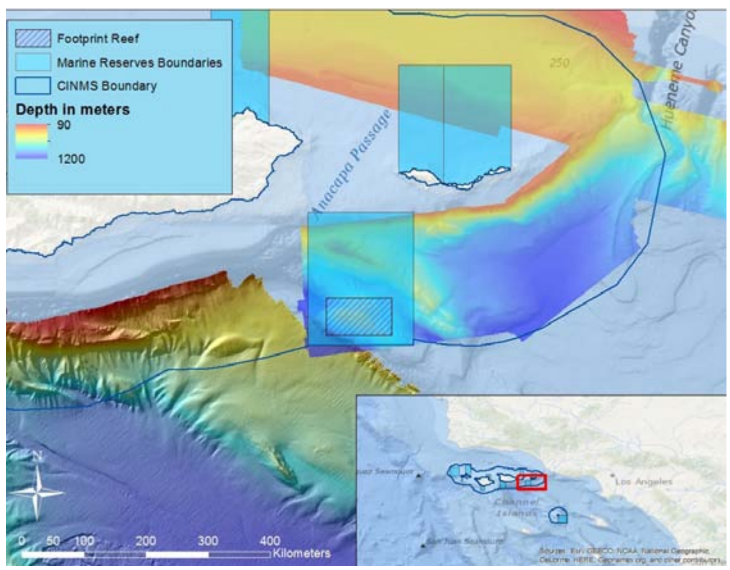
Peter Etnoyer (NOAA/NCCOS)
Brian Kinlin (NOAA/NCCOS)
Guy Cochrane (USGS)
Rocio Lozano Knowlton (MERITO Foundation)
Carol Blanchette (UC Santa Barbara)

Region

NE Pacific Basin

Rationale for Exploration

Ocean Acidification (OA) is an emerging threat oceans face as an aspect of climate change. T he phenomena is marked by falling oceanic pH levels and causes aragonite, a calcium carbonite mineral, to fall below saturation levels. This hinders the calcifying process for a multitude of calcareous organisms that provide biotic habitat structure and support ocean food webs. Understanding the impacts of ocean acidification has rapidly become an area of needed research as the field is new. Understanding how this acidity levels will impact marine ecosystems is critical to address mitigation options and plan for adaptive management. Information is particularly limited in deep water habitats where baseline data is scare; but there is evidence of adaptation to low aragonite concentrations. Channel Islands National Marine Sanctuary (CINMS) proposes an exploration of Footprint reef (See attached Figure) to document the OA phenomenon and its impacts on deep water reef ecosystems.



Brief Overview of Target Area

Piggy Bank and Foothill reefs are within a marine reserve in the Channel Islands National Marine Sanctuary and has been a targeted habitat of prior deep sea surveys. T his rich deepwater habitat contains a diverse set of deep-sea corals (DSC) and sponges that represent a high level of biodiversity for the area. Because there is concern that persistent low aragonite concentrations will cause declines in DSC and sponge populations, exploring the health and condition of these communities will help us understand if we have reached a tipping point where the effects of chronic exposure to conditions associated with ocean acidification are being realized on deep-sea corals and sponges.

Brief Summary of What is Known of Target Area

Over the past two years NOAA's National Center for Coastal Ocean Science (NCCOS) and Marine Applied Research and Exploration (MARE) have conducted deep-water surveys around CINMS that have identified uniquely diverse deep-sea coral (DSC) and sponge assemblages at Piggybank and Footprint reefs. Interestingly, populations of the coral Lophelia pertusa on those reefs (150m – 450m depth) seem to have adapted to conditions below the aragonite saturation horizon but sponge populations are beginning to show signs of stress and morbidity. Further research is needed to address why the community appears to exhibit some resilience to low aragonite conditions as well as how OA may effect community composition. Staff at CINMS propose an exploration of Footprint reef (See attached Figure) to continue documenting this phenomenon. By having a continuing dataset of surveys, researchers can begin to document interannual changes in community composition of this unique habitat.

Feasibility of Studying Target Area

The target area is within the sanctuary and near the coastline which makes it relatively accessible compared to offshore locations. Vessels will be able to anchor off Santa Barbara Harbor and ferry into the harbor. The target is in the eastern Channel Islands, which protects it from the heavy winds and adverse sea conditions that are common in the western islands. A few vessels are available for support including CINMS' research vessels: the R/V Shearwater and R/V Sharkcat . T his will improve access to the site for researchers, staff, and media as well as allow for easy loading and unloading of gear. T he technical and scientific aspects of this mission will need to leverage expertise from NCCOS, MARE, USGS, UCSB, NMFS, OA lab, NOAA OA office so that on-water activities are conducted safely and efficiently.

Educational and Outreach Potential of Target Area

CINMS and its partners have the infrastructure to develop a large variety of educational products for the deep sea missions. Distance learning using near real time video feed from the mission could be transmitted to a number of venues. Local and national K-12 and college students will be engaged by using outreach partnerships with entities including the Aquarium of the Pacific (AOP), UC Santa Barbara, CSU Channel Islands, Ventura and Santa Barbara County Offices of Education, and others. This will give CINMS the ability to share the mystery of deepsea coral and sponge communities and the animals that inhabit them in a near real-time format. Students would also learn about the concept of ocean acidification, and its effect on delicate deep sea ecosystems. T he Multicultural Education for Resource Issues Threatening Oceans (MERIT O) program currently works with a number of local schools that could be used to engage underserved Title 1 schools distance learning. It would allow students to see science in action in a truly unique fashion. Another option for engagement is NOAA's teacher at sea program which allows teachers to assist on research cruises with the condition that they develop curriculum and outreach materials based on their real-world experiences. This can broaden our outreach potential beyond Southern California to a national level. In addition to these options, CINMS is well equipped to develop products for educational use including a taxonomic guide, educational pamphlets, lectures, and audio/visual products. CINMS is also interested in developing spherical display data products. These are educational visualizations that are built for spherical displays (Science on a Sphere, Magic Planet, etc.) and can show geospatial data as well as video footage and imagery. Developed data products can easily be shared among educational programs with these types of displays including CSU Channel Islands Boating Center, Santa Barbara Museum of Natural History, and Aquarium of the Pacific. NOAA would also create geospatial products that are accessible to audiences via Google Earth, including a DSC database.

Northern Channel Islands Shelf Region

Craig Nicholson (UCSB)

Collaborators

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Alexander Simms (UCSB)
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Cristiane Elfes (UCSB)
Daniel Livsey (UCSB)

Region

NE Pacific Basin
California Borderland

Rationale for Exploration

The northern California Channel Islands shelf region adjacent to the southern California coast is ideally and uniquely situated to record and preserve some of the most important geological, archeological, environmental, and biological records of a very critical period in North American evolution. This is the period of the last deglaciation from about 15,000 to 8,000 years ago. During this crucial time period, sea-level was rapidly rising, human habitation in North America was just beginning, and extreme environmental and climate changes occurred that were likely related to a possible cosmic impact event. These rapid changes led to the extinction of several species of North American megafauna and the decimation of the incipient 'Clovis culture' human population. Onshore sites in the northern Channel Islands have already provided some of the oldest records of human habitation in North America, and some of the first direct evidence (including nanodiamonds, magnetic and carbon spherules, and other impact debris) for a cosmic impact over North America at about 12.8 kyrs ago. However, deciphering this important history continues to be hampered because the previous extensive coastal lowlands where many of the most important records should be best preserved now lie below sea level and are difficult to explore.

Following the last glacial maximum, sea level was ~120 m below present and the four northern Channel Islands were amalgamated as one large island landmass, called Santarosae (see figure 1). During this time of deglaciation and rapid sea level rise, many fundamental changes occurred on the islands and surrounding shelf region due to a number of factors including the rise in sea level itself and associated sedimentological deposits, the arrival and influence of humans, climate change reflecting the transformation from glacial to interglacial conditions, and a wide range of devastating effects associated with a proposed cosmic impact at 12.8 kyrs ago. The effects of a cosmic impact would include major biomass burning and wildfires, extinctions, and highly anomalous climate changes. Because some of the oldest evidence for human occupation in North American has been found on the northern Channel Islands at a time when sea level was ~100 m lower than present, it is thus quite possible that even older sites or other evidence of human occupation are preserved on the shelves surrounding the islands.

Expeditions under the jurisdiction of the Ocean Exploration Trust using RV Nautilus can begin to remedy this situation using the advanced array of remote sensing capabilities. We propose to explore a range of carefully selected targets with high potential for advancing knowledge about this Channel Island history, and even with broader implications for North American development. Such targets would include the offshore extensions of Arlington Springs, Santa Rosa Island and Daisy Cave, San Miguel Island, and more.

Potential target sites would focus on discovering critical records related to specific aspects of this crucial time period. They would include: 1) Evidence for human habitation such as exposed or buried middens: Such discoveries hold the potential to reset the oldest age of human habitation and contribute towards better understanding of human cultural change and development. 2) Extinction of Island megafauna; namely the pygmy mammoths and associated biogeographic insights as well as history of Island dwarfism. The coastal lowlands, now submerged, were likely the most productive habitat for these animal populations before they became extinct. 3) Further evidence for a cosmic impact (or viable alternative explanation) as documented by the abundance of nanodiamonds and other unusual related deposits at 12.8 kyrs ago, including evidence of massive island conflagration (biomass burning) and related major ecosystem disruption. 4) Simultaneous and probably linked abrupt cooling to near glacial conditions of the Younger Dryas cool episode at 12.8 kyrs ago and return, about one thousand years later, to interglacial conditions of the Holocene. 5) Rapid sea level rise and associated major sediment transportation to the continental shelves. A deglacial sea level chronology can potentially be developed using careful radiocarbon dating of materials collected from the submerged coastal lowlands and correlated sediment stratigraphy. This would have the further potential of detecting local tectonic effects of uplift and subsidence superimposed on the deglacial sea level rise. 6) Deep water ecology and its relation to substrate sediment type. Seafloor sediment type data are needed because fishery distribution is largely controlled by sea-floor sediment. Data from the Nautilus would provide important insights into habitat location and distribution of economically important species already depleted in shallower waters. 7) Active faulting and potential landslide development. This information is important to evaluating earthquake and tsunami hazards, as well as properly modeling tectonic uplift and subsidence components of the shelf region which together with sea-level changes would influence paleo-drainage and locations of likely early human habitation sites.

In summary, the Northern Channel Islands have already demonstrated a special significance in terms of making major contributions to North American archeology, as well as to our understanding of climate driven environmental history and potential catastrophic geological events, such as cosmic impact. Major new discoveries thus await extensions of this work to the submerged coastal lowland environments.

Brief Overview of Target Area

The Northern Channel Islands are located 40 km south of Santa Barbara, California. The waters extending 10 km offshore the islands are under the jurisdiction of the Channel Islands Marine Sanctuary. The marine sanctuary covers 4,294 square kilometers and is home a diverse array of marine mammals, fishes, kelp beds, and invertebrates. Water depths within the proposed study area extend from ~ 60 m to ~ 4 km. The northern continental slope of the Channel Islands is markedly less steep than the southern continental slope (Fig. 1). The Northern Channel Islands are tectonically active, with various sections of the island and shelf regions undergoing tectonic uplift or subsidence.

The active faults that define much of the island shelf topography are also responsible for localizing seeps and other related hydrogeological activity. This unique depositional environment has resulted in one of the highest resolution marine paleoclimate records in the world being deposited and preserved in the adjacent Santa Barbara Basin. The result is that a well-dated seismic stratigraphy is available to help map and correlate important geologic sedimentary deposits around the islands and up onto the shelf regions. Vintage industry and public seismic reflection datasets exist around the islands, as well as multibeam bathymetry and side-scan sonar data collected by MBARI, the USGS, NOAA, and CalState Monterey.

Brief Summary of What is Known of Target Area

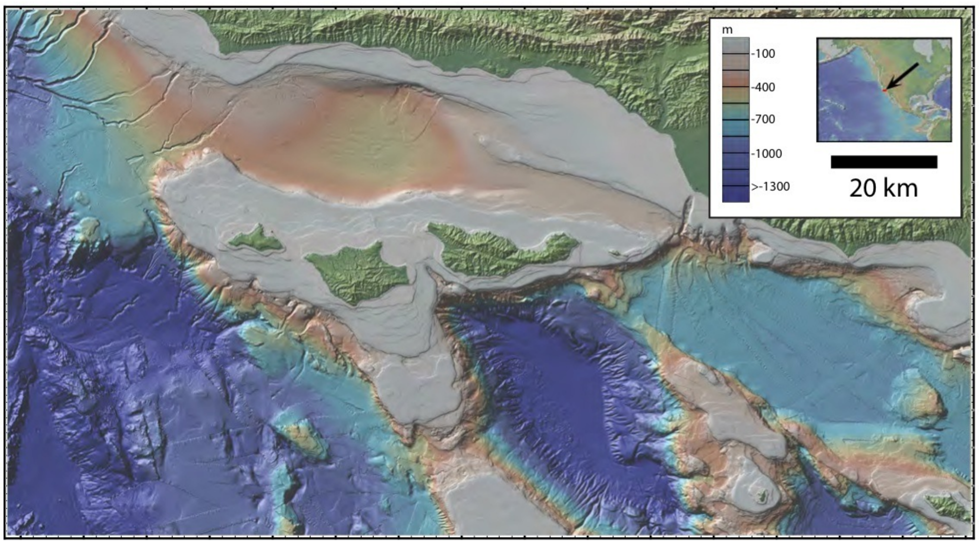
The marine ecology of the water surrounding the islands has been extensively studied and is managed under the National Marine Sanctuary program, but much of this work has been conducted in relatively shallow water. Past geology, paleontology, and archaeology studies within the Northern Channel Islands were mainly conducted onshore. These studies have shed light on some of the earliest peoples ever found in North America, on the environmental response across the Younger Dryas climate anomaly, on testing the Younger Dryas cosmic impact hypothesis, and on various megafaunal extinctions. Nearby marine studies have provided insights on Pleistocene to Holocene climate and sea level change, and on the Cenozoic tectonic deformation of the California Borderland region. These datasets indicate that important geologic and archeological records likely exist on the shelf region that can substantially improve our understanding of these critical events during this most recent deglaciation. Existing multibeam and high-resolution seismic reflection datasets can provide preliminary targets for further investigation.

Feasibility of Studying Target Area

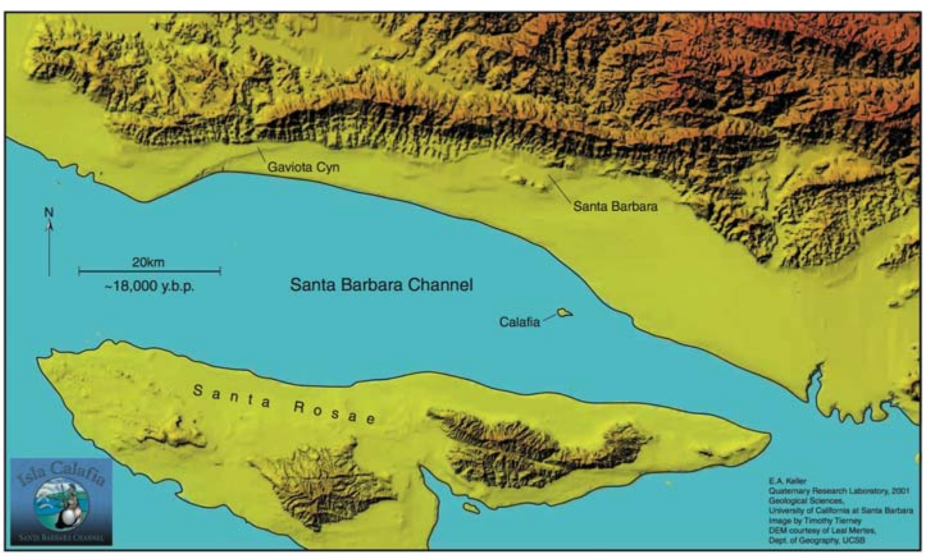
The study area is located along the RV Nautilus planned route from the Gulf of Mexico to San Francisco. The northern shelf region is in the protected waters of the Santa Barbara Channel. The study area is in close proximity to numerous ports, including Los Angeles and Port Hueneme for ready logistical support. In terms of ship scheduling, early fall is the optimal time window for a survey, as these are usually the calmest sea conditions. November-December and April-May typically correspond to Gray whale migration, and June to September corresponds to the peak in residency of endangered blue and humpback whales.

Educational and Outreach Potential of Target Area

Numerous local agencies interested in public outreach can and will help partner to provide excellent opportunities for education and outreach to the public. Some of these agencies and institutions include: Channel Islands Marine Sanctuary with headquarters at UCSB, Santa Barbara Natural History Museum, Santa Barbara Maritime Museum, California Coastal Conservancy, National Park Service, and the Departments of Earth Science and Ecology, Evolution, and Marine Biology at UCSB, and UCSB research institutions like the Marine Science Institute and Earth Research Institute. There are also numerous other colleges and universities with undergraduates and graduate students who would be eager to participate in such exploration activities, including other campuses of the UC and CalState systems.



Shaded relief of Northern Channel Islands



Amatignak Spur and Canyon, Aleutian (Ridge) Islands

David Scholl (USGS & University of Alaska Fairbanks)

Collaborators

Robert Stern (UT Dallas)
Susan Kay (Cornell University)
Brian Jicha (University of Wisconsin)
Jennifer Reynolds (University of Alaska Fairbanks)
Tracy Vallier (USGS Emeritus)

Region

Aleutian Trench/Bering Sea/Gulf of Alaska

Rationale for Exploration

Finding and dating exposures of the oldest igneous rock of the Aleutian arc massif has long been a quest of Aleutian-Bering Sea researchers. The oldest Ar-Ar radiometrically dated exposures of basement rock formed at ~46 Ma. Two exposures are known, each was collected from the ridge's crestal area by either offshore dredging or island sampling. The oldest known exposures are minimum ages for the inception of arc volcanism because they were collected from the top, or near the top, of the ridge's 25-30-km thick crustal structure. The dated specimens exhibit moderate alteration suggesting that their Ar-Ar ages are also minimum ones. A zenolith of granulite enclosed in a younger volcanic rock was radiometrically dated at ~48 Ma.

Short of drilling to reach them, it is generally supposed that exposures of some of the oldest Aleutian basement can most profitably be sought in the deeply submerged forearc along fault-controlled tear canyons. The effectiveness of using ROV technology to explore and sample basement in Aleutian canyons was demonstrated in 2005 by the deployment of JASON-II to Adak Canyon (Jicha et al., 2006, Revised age of Aleutian Island Arc Formation implies high rate of magma production: Geology, v. 34, no. 8, p. 661-664).

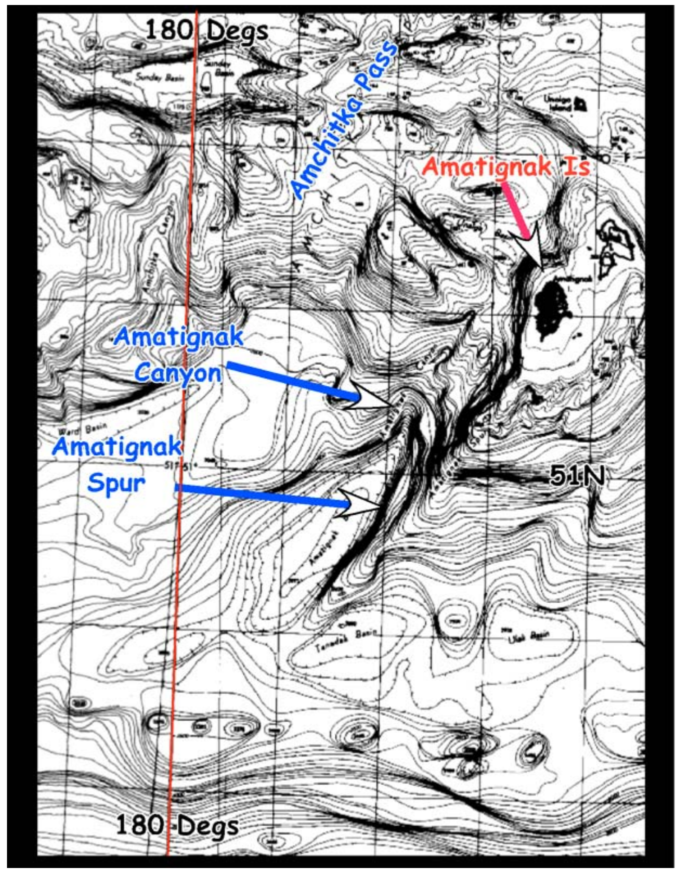
The eroded fault scarps that dissect the Aleutian forearc expose formerly deeply buried basement. The flanks of Amatignak Canyon, but in particular the steep, west-facing, deeply submerged (2000-5000 m) wall of nearby Amatignak Spur, are thus prospective target areas for ROV exploration and recovery of samples of the oldest exposed rock units of Aleutian arc basement (Attachment 1 and 3).

Brief Overview of Target Area

The primary target area, the west-facing scarp of Amatignak Spur, is the trenchward continuation of ridge's wave-eroded summit platform above which Amatignak Island, the seaward most (southernmost) island of the Delarof Island group, rises (Attachment 1). The island, located ~60 km east of the 180° meridian, is constructed of a tilted, well-lithified sequence of sedimentary rock intruded by 26-36 Ma gabbro and diorite. Although virtually an unexplored sector of the Aleutian Ridge, older igneous basement must underlie the deeply submerged Amchitka Spur that leads seaward of the island virtually to the floor of the Aleutian Trench. One exploratory single-channel seismic reflection line (collected in 1970) was recorded across the deeper reaches (4500-5000 m) of the spur. It reveals that basement rock is exposed along the spur's steeply sloping west-facing scarp.

Brief Summary of What is Known of Target Area

The steep walls and fault scarps bordering Amatignak Spur and Canyon offer perhaps the best opportunity to recover samples of the oldest basement rock units exposed along the Aleutian Ridge (Attachment 1). Amatignak Island, at the NNE end of the spur, exposes Eocene sedimentary sequences that must overlie older igneous basement. Exposures of older basement rocks are posited to occur along the steep fault scarp bordering the western side of the deeply submerged (2000-5000 m) Amatignak Spur. Radioisotopic dating of these samples will provide the best estimate as to when the underlying Aleutian subduction zone formed. This information will also constrain the formation age of the marginal sea of the deep-water Aleutian-Bering Sea region that borders the NW corner of the Pacific Basin and the complex plate boundary separating the Pacific and North America plates.

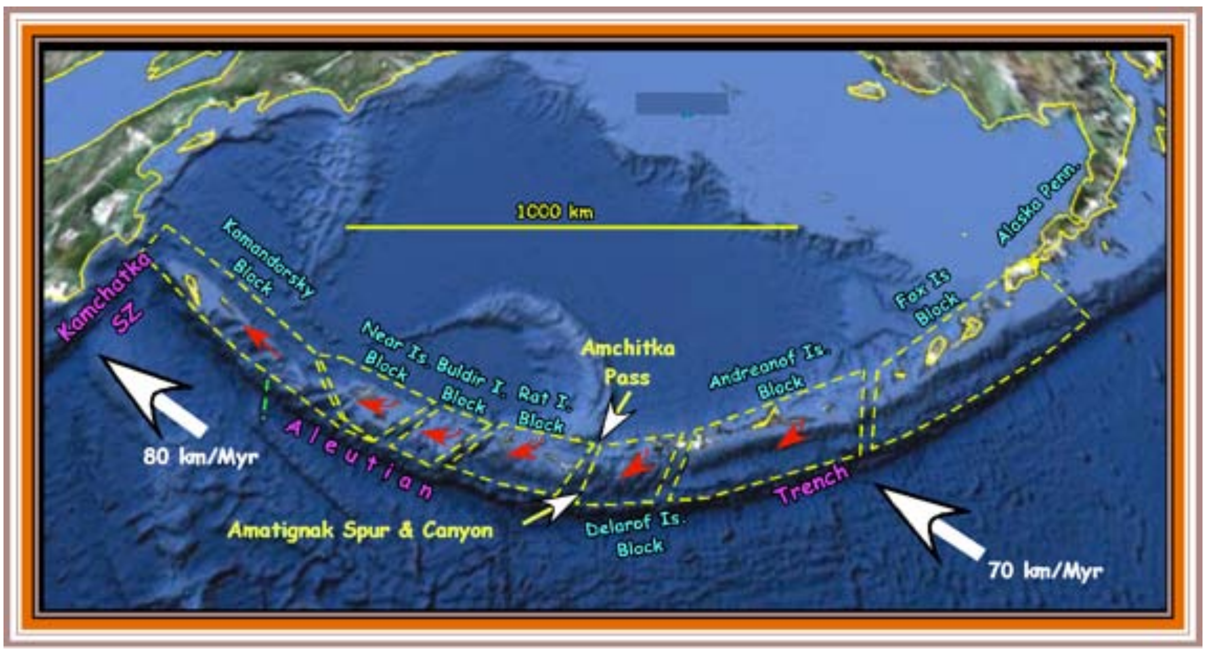


Feasibility of Studying Target Area

Between late June and early September weather and sea state in the Amatignak target area (51.0 to 51.5° N; 179.0 to 179.5° W) are amenable to marine research. The embarkation port of Adak and its airfield are less than a day's sailing (~15 hrs at 10 knots) to reach the target area of Amatignak Spur.

Educational and Outreach Potential of Target Area

The public is aware that subduction zones underlie the "Pacific Ring of Fire" and are the habitats of explosive volcanism and also the world's largest earthquakes and the destructive tsunami they can launch. Not known by the public is that soon after WWII studies along the Aleutian Ridge (arc) resulted in the first grasp and visualization that the underthrusting, i.e., subduction, of oceanic crust beneath the crust of an island arc is the cause of arc volcanism and the even more dangerous landward dipping seismic Wadati-Benioff zone (Coats, 1962). This important discovery preceded the hypothesis of plate tectonics by several years. The interest of the public would be served to know that the Aleutian subduction zones—the “mother” of all subduction zone--is targeted to determine when it formed and began to build the igneous mass of the Aleutian Ridge and its visually crowning jewels of explosive stratovolcanoes. Of additional importance is the impact of biological collections, which will enhance our understanding of deep-sea north Pacific and Aleutian habitats including, just north of the target area of Amatignak Spur and Canyon, that of young, newly discovered volcanoes submerged beneath Amchitka Pass. The proposed ROV imaging and sampling of basement rock at Amatignak Spur and Canyon have the potential to involve students in undersea research in one the most remote and scientifically exciting places along the periphery of the Pacific Basin.



Alaska-Aleutian Transition Zone

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Region

Aleutian Trench/Bering Sea/Gulf of Alaska

Rationale for Exploration

The area includes a unique combination of geological, natural hazards, historical, and benthic ecology targets of high significance. It is one of the few areas around the world where a sharp transition occurs along a subduction zone between continental (Alaska Peninsula) and oceanic (Aleutian Islands) overriding crusts. This transition is expressed in the morphology of the continental slope. Historical seismicity in the target area is spatially variable. Great (M>8) earthquakes occurred during the 20th century east of Shumagin Islands, south of Unimak and southwest of Unalaska, and left seismic gaps between them (Shumagin and Unalaska gaps in the attached figure). The spatially punctuated activity may be reflected in the structure of the slope extending to the trench (e.g., Wells et al., 2003; Song and Simons, 2003). T he effects of natural hazards from this area are also profound. Kirby et al. (2012) identified the target area as the primary source of tsunami hazard to the U.S. West Coast and Hawaii (Ryan et al., 2012; SAFFR Tsunami Modeling Working Group, 2013), should an earthquake rupture propagate through the aforementioned seismic gaps, a similar scenario to the rupture that produced the recent Tohoku earthquake. The M8.6 great Scotch Cap earthquake of 1946 generated one of the most destructive tsunamis in the Pacific Ocean, causing 150 deaths in Hawaii alone (e.g., Ryan et al., 2011 and references within). It also destroyed the Scotch Cap lighthouse (see attached map), which was located 35 m above sea level. The destruction of the lighthouse could only be explained by a landslide or by rupture along a splay fault, but detailed geophysical studies have not been conducted in this region to characterize the tsunami source region. Mapping the target area may not only help find the source of the local 1946 tsunami, but will also serve as a baseline for possible changes in the sea floor as a result of future earthquakes. Differential bathymetry has been one of the most successful strategies used to characterize recent near-trench deformation associated with tsunamigenic earthquakes (Kodiara et al., 2012), but requires there to be high-quality bathymetric mapping prior to any large events. Fluid venting sites have been observed near the deformation front between the tectonic plates in the target area. T hey appear to be controlled by active and depositional structures, such as fault scarps, tight folds, and outcrops of bedding planes (Suess et al., 1998). T he venting sites are characterized by methane plumes within the water column, and by patches of vent biota colonies and calcium carbonate and barite (barium sulfate) precipitates on the seafloor. Studying these sites can serve to estimate the fluid flux through the forearc region (Suess et al., 1998) and map its plumbing, as well as to identify variations in the benthic communities in the northern Pacific.

Brief Overview of Target Area

The study area extends from 158°W to 168°W and from 52°N to 54.5°N. It is part of the Alaska-Aleutian subduction zone, a 3000-km long plate boundary stretching from Kamchatka to the middle of the Gulf of Alaska. Here the Pacific Plate subducts in a northwest direction under the North American Plate at a rate of 54-76 mm/yr. The subduction process is responsible for the arc of volcanoes, located about 100-250 km north of the trench. At least 29 of these volcanoes have been active since the arrival of Europeans in 1760 (e.g., Ryan et al., 2011 and references therein). The study area encompasses the most significant change within the entire subduction zone between Mesozoic-age subduction under the continental lithosphere east of Unimak Pass and Cenozoic-age subduction under oceanic crust west of the pass. Prior to ~50 Ma, the subduction zone may have in fact extended from Unimak Pass to the NE along the Bering margin (Scholl et al., 1987). T he change in the nature of the overriding crust is expressed in the width of the exposed landmass and the morphology of the margin. Three great earthquakes took place in the target area in the 20th century. The M8.3 1938 earthquake ruptured the plate boundary east of Shumagin Islands.

The M8.6 1957 earthquake ruptured an 1150-km-long segment of the plate boundary west of Unalaska Island and caused substantial tsunami damage in Hawaii. T he M8.6 1946 Scotch Cap earthquake ruptured a 180-km long part of the boundary near Sanak Islands. This earthquake was unusual in its slow rupture speed, causing a much larger tsunami than expected from an earthquake of this size (Lopez and Okal, 2006). The extensive tsunami damage in Hawaii and California from this earthquake prompted the establishment of the Hawaii/Pacific Tsunami-Warning Center. GPS data indicate that most of the target area, including the 1946 rupture area, is creeping and does not accumulate seismic stress (Freymuller et al., 2008). This region also appears to be one of the most energetic sources of seismic tremor along the margin, similar to the tremor activity associated with slow slip events in the Cascadia margin (Wech and Freymuller, 2013). T he apparently complex spatial and temporal variations in plate locking there likely affects the distribution of future large earthquakes and tsunamis. Seep biota consisting of bacterial mats, pogonophorans, vestimentiferan and large colonies of bivalves were discovered during the 1994 FS Sonne cruise SE of Shumagin Islands and farther east off Kodiak Island. They include abundant colonies of vesicomyid clams, solemyid protobranchs, private pogonophorans, and new, unusual vestimentiferans (Suess et al., 1998). These benthic communities are thought to be dependent on carbon dioxide delivered from anaerobic methane oxidation, performed by archaea working in syntrophic co-operation with sulfate-reducing bacteria (Elvert et al., 2000)..

Brief Summary of What is Known of Target Area

An excellent summary of earthquakes and tsunamis in the Eastern-Aleutians-Alaska subduction zone is given by Ryan et al., 2011. T he predicted tsunami impact from a megaearthquake (M≥9) in the target area on the southern California coast is given by

Kirby et al., 2012. Analysis of the 1946 M8.6 earthquake, which caused extensive tsunami damage in Hawaii and destroyed Scotch Cap lighthouse, is provided by Lopez and Okal, 2006. Fluid venting and benthic communities were detected, photographed, and analyzed south of Shumagin Islands and farther east along the accretionary prism (Wallmann, K., et al. 1997 and Suess, E., et al. 1998; Elvert et al., 2000). Some of the FS Sonne multibeam and seismic data were published in von Huene et al. 2012.

Feasibility of Studying Target Area

- Multibeam bathymetry: The proposed survey area is 700 km long by ~90 km wide at water depths ranging from 800 – 5500 meters. A multibeam bathymetry survey with an average swath width of 9 km and an average ship's speed of 8 kt (15 km/h) will cover the area in 11-13 days.
- Diving: Active venting sites were found and photographed at depths of 4000-5000 m (Suess et al., 1998). While these depths are beyond the current capability of the OET and OER ROVs, water-column mapping would provide a means to expand the baseline identification of plumes for further investigation. In addition, venting sites might exist at shallower waters along the slope, but have so far not been searched.
- Logistics: The region is located 60 n.m. from Dutch Harbor, a major supply port and an airport.

Educational and Outreach Potential of Target Area

- The densely aligned volcanoes of the Alaska Peninsula, Unimak, and Unalaska offer a visual illustration of a volcanic arc and its root in deep earth processes. For example, Shishaldin volcano near the center of Unimak, is a spectacular symmetric cone with base diameter of approximately 10 miles. A small summit crater typically emits a noticeable steam plume with occasional small amounts of ash. Makushin volcano on northern Unalaska is a broad, ice-capped stratovolcano and the site of frequent steam and minor ash eruptions. Okmok volcano, on the northeast part of Umnak Island, in the far western section the target region, erupted explosively in 2008, sending an ash plume 50,000 feet into the air.
- Fluid venting from the forearc is another illustration of the cycle of fluids that enter the trench with the subducting plate and return to the Earth surface through the arc and forearc regions, sustaining life and changing the face of the planet.
- Variations in the bathymetry of the continental margin will be exploited to explain how plate tectonics shape the surface of the planet and how margin morphology influences great earthquakes in Alaska.
- More than half of the people living in the Aleutian Islands, reside on Unalaska, and others live on Akutan Islands. Involving the native communities in this geologically-dynamic region may help focus on the interaction between humans and their changing environment. The combination of dramatic and often coupled subaerial and submarine landscapes/environments and the hardy humans irking their living from this environment has the potential for discovery and exploration of unique geologic features and biologic habitats. Exploration of such unknown and potentially diverse environments would provide an outstanding opportunity to engage and educate the public.

CENTRAL, EQUATORIAL & SOUTHWEST PACIFIC

Kermadecs

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Region

S Pacific Basin
Tonga/Kermadec Trenches

Rationale for Exploration

What makes this target area unusual is the diversity of deep-sea features occurring within relative close proximity. These include abyssal plain, ridge, seamount, deep-basin, and trench environments, spanning a depth range from a few hundred metres to just over 10,000 m and a temperature range from 1 °C in the trench, to over 300 °C at the hydrothermal vents. Such a suite of environments is expected to support a broad range of biological communities, which have previously been either sparsely sampled or completely un-sampled. The target area is part of a Benthic Protection Area (BPA) closed to bottom trawling and has been proposed as a Pew Global Legacy Area, although there have been limited investigations to support either of these designations. There have also been prospecting licences granted for deep-sea mining.Exploration of the geological environment and associated biological communities will help provide the information currently lacking for the ecosystem to be characterised, and the area to be effectively managed.

Brief Overview of Target Area

The general target area is a large section of the New Zealand EEZ, just north of North Island. It encompasses approximately 630 000 km2 of seabed around the sub-tropical Kermadec Islands. The exact location of study sites within this general target area will depend upon the time available for the research voyage, but the general premise for deciding upon the extent of the target area will be to maximise the diversity 2 of deep-sea habitats that can be explored in a single voyage. It is envisaged that these locations will be distributed in a band across the general area (see figure).

The area spans a range of seabed features. Going from west to east, these include the abyssal plain of the South Fiji Basin, the Colville Ridge, the deep-basin of Havre Trough, the seamounts of the Kermadec volcanic arc, the Kermadec Ridge and the Kermadec

Trench. These features formed as the Pacific Plate to the east was forced under the Australian plate. Many of the arc seamounts are hydrothermally active and support chemosynthetic communities. The Kermadec Trench is one of the deepest in the world.

The currents within the target area are dominated by warm water within the Tasman Front section of the Subtropical Gyre, flowing eastwards across the target area. This flow is characterised by giant eddy formation, stirring the water to depths of 2 km, potentially interacting with the complex topography of the target area and influencing the biological communities.

Brief Summary of What is Known About Target Area

Scientific investigations across the target area have been scarce to date. The regional bathymetry is known mostly from commercial ship track data and satellite altimetry analyses, although many of the seamounts along the Kermadec volcanic arc, and parts of the Kermadec Ridge, have been mapped at highe resolution by multibeam acoustic surveys. Going from west to east, the South Fiji Basin within the target area has not been sampled, with little known of its geology or biology. The section of Colville Ridge within the target area has only been sporadically sampled for either biology or geology, and the geological features along the ridge are thought to be some of the oldest within the region. Because of this, it is likely that the seamounts along the Colville Ridge will host different seamount communities to those found 3 elsewhere within the target area. The Havre Trough, spanning the basin between the Kermadec Ridge and the Colville Ridge, has only been sparsely sampled.Along the Kermadec volcanic arc, many of the sixteen seamounts in the target area have been identified as hydrothermally active by hydrothermal plume mapping, but seafloor photographic surveys and biological sampling have been restricted to a handful of these seamounts. The section of the Kermadec Trench that falls within the target area has also been subject to very limited sampling efforts. Sampling of similar environments to the south of the target area has found deposit feeding echinoderms and burrowing crustaceans and worms on the abyssal plains; a diverse array of filter feeding corals, sponges and echinoderms on the ridges and seamounts;chemosynthetic communities including stalked barnacles, shrimp and mussels at the hydrothermal vents and giant scavenging crustaceans and fish within the trench.

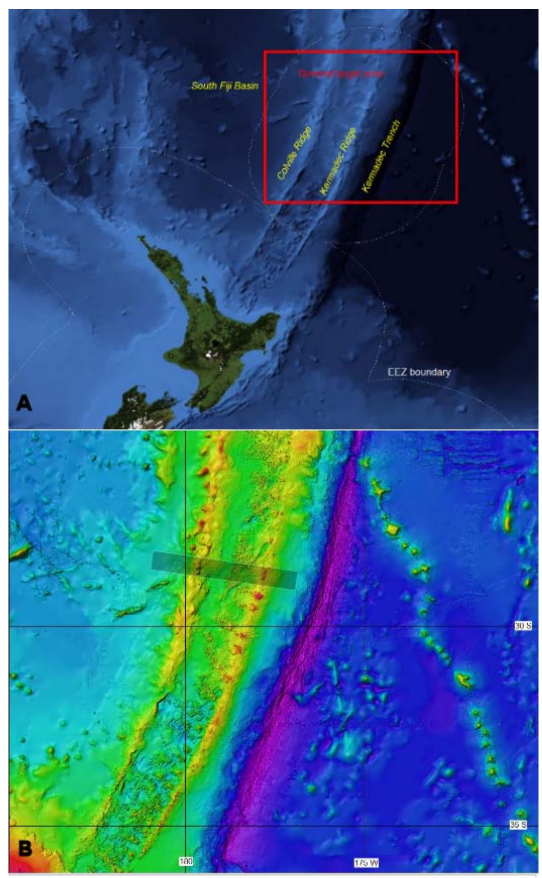

Fig. 1. A: General location map for Kermadec target area (red box).
B: Indicative sampling area (shaded box).

Feasibility of Studying Target Area

The project team has considerable experience in deep-sea voyages, both within the NZ EEZ and elsewhere, with the knowledge and background required to conduct the proposed work. The target area is within the NZ EEZ, making permitting relatively straight forward. NIWA has sampling permits for the NZ EEZ and is familiar with the regulations surrounding the permissions necessary to sample within the EEZ. NIWA and GNS have substantial experience of operating research voyages within the wider Kermadec area. The port of Auckland is close and would be a suitable site for mobilising EV Nautilus. NIWA has a base in Auckland that can provide logistical support, with NIWA Vessels Company able to offer assistance, if required, for mobilisation. NIWA can also provide sampling equipment or supplies to complement those available on EV Nautilus if required. Biological samples can be received and curated to international standards by the nationally 4 recognised NIWA Invertebrate Collection.

Sir Peter Blake Trust has extensive experience in providing educational experiences for young people, whilst both NIWA and GNS have active media and communication departments with experience in science outreach and communication.

Education and Outreach Potential for Exploration at Target Area

Deep-sea exploration around the world has to date tended to focus on one or two environments per research voyage, such as hydrothermal vents or seamounts. Relatively little attention has been given to the broad range of environments of the deep sea and how diverse the geological settings and biological communities are within a region. The proposed area includes hydrothermal vent habitats which often host spectacular communities generally popular with the public, with the advantage that most of those within the target area have not been previously explored. The area is also expected to offer an exciting selection of other deep-sea habitats. These include previously uninvestigated seamounts on the Colville Ridge which may have deepwater coral assemblages, with their slow-growth and high diversity in direct contrast to the low diversity yet highly dynamic vent communities. The soft sediments of the abyssal plain and deep basins are expected to be more akin to a desert when compared to the biological oases of seamounts and vents, which in turn will contrast with the alien-like crustacean and fish inhabitants of the Kermadec Trench. The broader geological and tectonic setting of the area is also of public interest for its relation to underwater volcanic eruptions, earthquake activity and tsunami risk for mainland New Zealand.

The diversity of the Kermadecs will attract a broad range of scientific interest, giving the audience, educators and students the opportunity to connect with a diverse range of science and scientists. At the local level, exploring the northern Kermadecs will provide opportunities to connect and engage not just with the New Zealand public, but also those in the Pacific Islands, particularly Tonga immediately north of the target area.

Exploration of the PRINM and of Seamounts With Mining Potential

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Henry Reiswig (Royal British Columbia Museum)

Region

E Equatorial Pacific
W Central Pacific/Line Islands

Rationale for Exploration

Seamounts and oceanic islands are prominent features of the world's underwater topography. They represent a unique deep-sea environment, providing benthic habitat in otherwise pelagic realms. They are productive ecosystems, with hard substrate habitats often dominated by magnificent octocoral forests, sponge gardens, and deep-water coral reefs, along with their highly diverse associated invertebrate communities. Seamounts are thought to be isolated and many have been shown to have high levels of endemicity. Thus each newly explored seamount or seamount group may be a treasure-trove of novel species, however this also means that seamounts may be especially vulnerable to anthropogenic impacts.

Reviews of seamount studies by the Data Analysis Working Group (DAWG) of the Census of Marine Life's CenSeam (Global Census of Marine Life on Seamounts) program, indicate that seamounts, and mid-ocean seamounts in particular, are poorly sampled, with the central and western Pacific (CWP) identified as a major data gap for seamount biogeographic studies across taxa. NOAA's State of the U.S. Deep Coral Ecosystems Report has also identified the CWP as a major gap for US deep-sea coral studies (Parrish and Baco 2007). Therefore, exploration of representative seamounts or oceanic 2 islands in this region represents an exciting and bold foray into the unknown seamount data void of the Pacific, likely to yield many species new to science as well as data critical to understanding the biogeography of seamount fauna.

Studies in the CWP have an additional motivation, as there is a rapidly escalating interest in CWP seamounts for mining cobalt-rich ferromanganese crusts. Mining of these crusts will involve removal of the hard substrates and any associated fauna from up to 20% of the surface of seamounts above 2500 m water depth. Were this not enough justification for baseline exploration of targets in the CWP, yet another motivation for studies of CWP seamounts and islands comes from the recent establishment, in January 2009, of the Pacific Remote Islands National Monument (PRINM). This monument includes 86,607 square miles of the US remote insular areas, almost every deep-water square kilometer of which is completely unexplored.

Overview of Target Area

Any site within the CWP and PRINM would be an exciting exploration target. Some potential features would include Johnston Atoll – which is the closest emergent feature to the Hawaiian Archipelago and also has some of the thickest and most cobalt-rich manganese crusts. This feature has also had some submersible work with the Makali'I to depths of about 400m. Other potential targets include the Line Islands, Marshall Islands, Micronesia, Howland and Baker.

Brief Overview of What is Known About this Area

There is almost no data on any of these features, however habitat suitability modeling suggests a number of them have suitable habitat for deep-water corals, especially octocorals.

Feasibility of Studying this Target Area

The choice of target largely depends on transit costs. Locations closer to a major port or along a transit line to another region of study would be the the ideal choices. Johnston is closest to Honolulu. Several other have proposed work in the Line Islands. Permits may be required to work in the PRINM.

Education & Outreach Potential for Exploration at this Target Area

Any time a new area is explored there is great potential for education and outreach. T he discovery of fields of new species of charismatic deep-sea megafauna such as corals and sponges provides ample visuals for outreach efforts. Another exciting aspect to exploration in this area however will be that it can draw attention to the impending manganese crust mining in the region, and provide some of the first information on the fauna that will be impacted by mining efforts. A number of developing countries also fall within this region and exploration on their slopes will help provide education to local communities on the value of their deep-water resources.

Phoenix Islands

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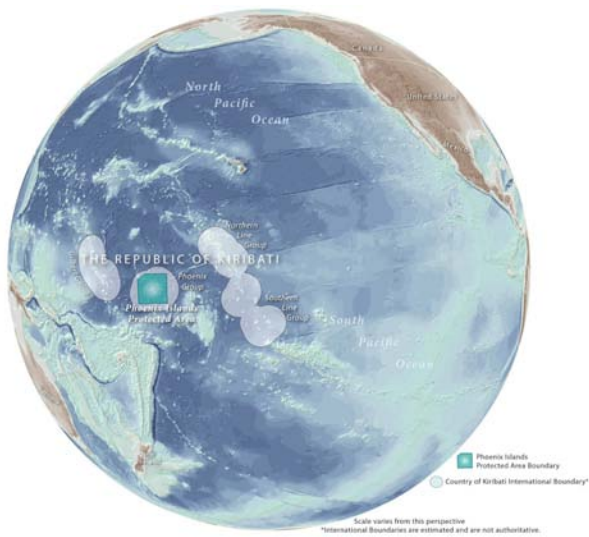
Region

W Central Pacific/Line Islands

Rationale for Exploration

The Republic of Kiribati's Phoenix Islands Protected Area (PIPA), located in the equatorial central Pacific, is the largest and deepest UNESCO World Heritage Site on earth. Created in 2008, it was the first Marine Protected Area (MPA) of its kind (at the time of inception, the largest in the world) and includes eight low-lying islands, shallow coral reefs, submerged shallow and deep seamounts, and extensive open ocean and ocean floor habitat. As PIPA moves forward with its management objectives, it is well-positioned to be a global model for large MPA development and maintenance in similar contexts. Shallow reef and terrestrial ecosystems have already shown benefits from protection, but there is no existing baseline for deep-sea communities in the region. The pending full closure of PIPA, effective Jan 1 2015, will create a no-take zone 405,755 km2 (99.4% of the MPA). The remaining ~0.6% will remain a restricted use zone around Kanton Island. This size of closure, representing a substantial area of deep-sea and seamount habitat, provides a unique opportunity to determine the impact of a no-take zone on the deep-sea environment.Establishing a baseline habitat assessment including deep-sea coral biodiversity (from limited, targeted collections) and distribution (from ROV transect surveys), frequency and fidelity of associated communities (from video and still photography), and status (visual evidence of previous disturbance or not) is critical to evaluating the impact of the MPA over time.



Brief Overview of Target Area

The Phoenix Island group straddles the central region of Kiribati (where the Equator crosses the International Dateline), positioned distantly between the Gilbert Islands to the west and the Line Islands to the east. Located directly north of the Tonga-Kermadec ocean trench, the Phoenix Islands sit atop the Tokelau Ridge, incorporating some of the many Tokelau volcanoes aligned along a 550 km segment of the ridge.Beyond the Tokelau seamounts there is a well-defined cluster of volcanoes about 200 km to the east, all within about a 100 km radius. Rising from an average depth of 4,500 m and a maximum depth of

6,147 m, a dozen of these massive volcanoes host shallow reefs and the highest peaks reach the surface, capped by low elevation islands and atolls. Four are topped by true coral atolls (Orona, Manra,Kanton and Nikumaroro), six present as low reef islands (Birnie, Rawaki, McKean and Enderbury in Kiribati,Baker and Howland in US territory) and two are shallow submerged reefs (Carondelet and Winslow). These represent only the highest of numerous large and long-extinct volcanoes. Most of the large volcanoes are greater than 200 m below the surface and are therefore technically classified as seamounts. The catalogued seamounts include Fautasi,Siapo,Polo, Tai, Tanoa, Tau Tau, Gardner, and four unnamed seamounts.

Brief Summary of What is Known of Target Area

PIPA's atolls and low reef islands are rather small, ranging from 1.03-17.5 km across, but are surrounded by some of the most untouched shallow coral reefs in the world. These support a remarkable abundance and diversity of marine life (Obura 2011). Over 450 fish species have been recorded, including abundant populations of large parrotfishes and wrasses that have elsewhere been severely overfished (Allen and Bailey 2011). The coral species assemblage is typical of the Central Pacific region and expeditions to the Phoenix Islands early in this century found the reefs to be in excellent condition, with twice the coral cover of the recent average for southern and western Pacific coral reefs (Obura and Stone 2002; Obura et al. 2011), and broadly overlapping with what can be considered pristine conditions (Bruno and Selig 2007, Sandin et al. 2008). Limited mesophotic reef surveys (down to 200 ft) suggest a thriving mesophotic coral community. No information is as yet available on deep coral or other benthic communities below 200 ft. The best studied set of islands in the central Pacific are the Hawaiian Islands, where approximately 20% of the deep-water scleractinians are thought to be endemic (Parrish & Baco 2007). However, this is most likely due to the complete lack of deep-water surveys of other archipelagos in the region. Regional studies suggest that there are some very widespread species of deepwater corals (e.g. Bamboo corals, Smith et al. 2004; but see Baco & Cairns 2012), but that initial surveys of new seamount chains can reveal high proportions of new species (Richer de Forges et al. 2000). It is therefore highly likely that our surveys will result in new species of deep-sea corals, and further emphasizes the essential role of baseline studies in the evaluation of the effectiveness of this unique MPA in an entirely unexplored region of the deep sea.

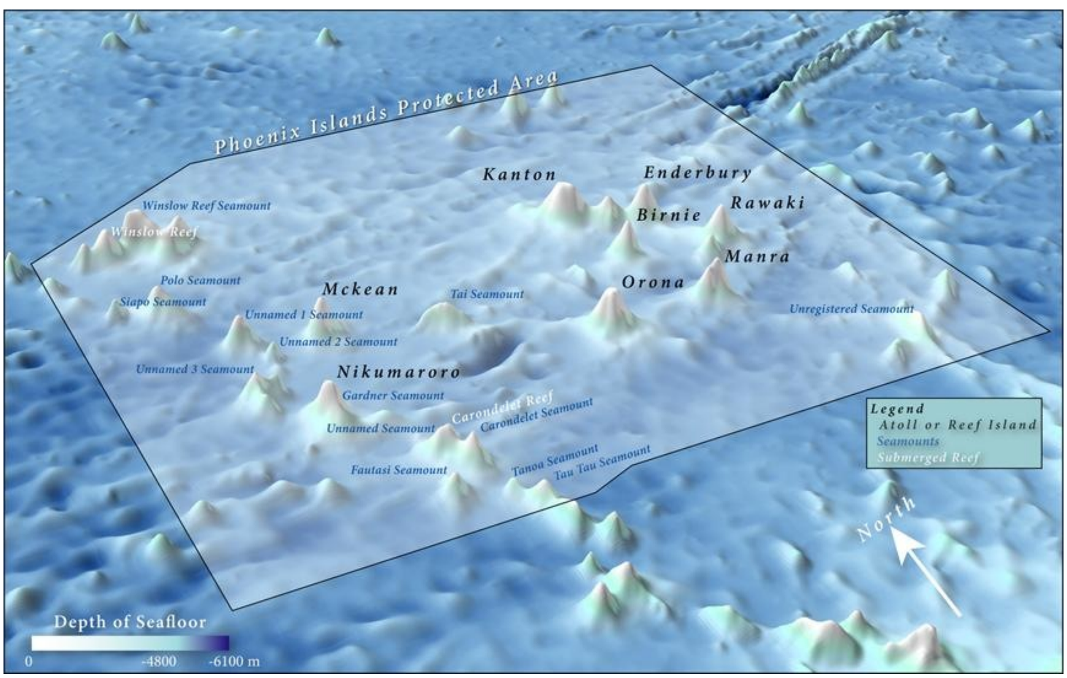
The archaeology of the Phoenix Islands remains largely unexplored. Along with the Line Islands, they are known as the "mystery islands" because of the lack of human occupation at the time of European discovery. Studies of basalt artifacts indicate that there was active exchange among the Phoenix and Line Islands groups and Samoa and the Marquesas (Di Piazza and Pearthree 2001). In the late 1800s, Howland and Baker Islands were mined for guano, and these islands were an active area of shipping in the early 1900s. Airstrips were built on Howland, Baker, and Kanton in the 1930s and 1940s to support trans-Pacific flights, and both Howland and Baker were involved in US-Japanese conflicts during World War II. Most famously, Nikumaroro is thought to be a possible resting place for Amelia Earhart's Lockheed Electra.

Feasibility of Studying Target Area

Assuming a consistent 10 kts, the PIPA is a 2.5 day steam from Samoa, 4 from the Line Islands, 4.5 days from Fiji, and approximately 7 days from Oahu. Because this cruise will be one component (but the only deep-water component) of a larger research program, all applicable permits are already in-hand, or easily attainable. Further, co-PI Rotjan chairs the Scientific Advisory Committee for the PIPA, which aims to uphold and maintain the 10-year research vision (2010-2020) for the PIPA, where deep-sea exploration and MPA efficacy are stated goals.

Education and Outreach Potential of Target Area

PIPA maintains an active website, facebook page (>1700 likes), and blog (>154,000 page views) (pipa.neaq.org) where updates can be regularly accessed. Further,PIPA is partnered with the New England Aquarium (NEAq), which has a public exhibit on PIPA that is seen by ~1.3 million visitors annually, and where updates are streamed and updated in our newly built Blue Planet Action Center, a space dedicated to engaging visitors in an intimate format to relay information related to climate change, ocean issues, and organisms. NEAq's programs provide multiple means for disseminating research related to this project including public lectures by PIs and collaborators in their IMAX theatre, which are then taped and broadcast on local television and on the web. These facilities would make the NEAq an excellent location for a new Ocean Exploration Center. Other programs include teacher professional development workshops, live reports from the field on the NEAq blog (which has been previously heralded by Education Week for its expedition coverage of PIPA), and by NEAq publications (Seabits & blue), which together reach the entire member population of the institution.



Exploration of Bottomfish Habitat and Transition to the Deep Sea in the National Marine Sanctuary of American Samoa

Wendy Cover (National Marine Sanctuary of American Samoa)

Region

Tonga/Kermadec Trenches
Tuamoto Archipelago/Austral (Tubuai) Island/Cook Islands

Rationale for Exploration

The National Marine Sanctuary of American Samoa is comprised of six protected areas designated in 2012 and covering 13,581 square miles of nearshore coral reef and offshore open ocean waters across the Samoan archipelago. By virtue of its isolation, very little of the area has been thoroughly explored, leaving many questions as to what organisms and habitats lay hidden at depth. The proposed project would further our knowledge of these newly protected areas, while addressing important management goals and providing outstanding outreach material for local communities.

Sanctuary sites around the islands of Tutuila and Aunu'u contain important bottomfish and mesophotic reef habitat, some of which is utilized by local fishermen, some of which is protected. In all sites, this reef area transitions to depths greater than 250m that are completely unexplored. We propose to use the submersible to conduct transects from mesophotic reefs to the adjacent depths, including the submarine canyons of Fagatele and Fagalua/Fogama'a bays, as well as the escarpment and cliffs that constitute the as yet undocumented "Research Zone" off the island of Aunu'u. Through collaboration with the NOAA Deep Sea Coral Program, high-resolution video would be analyzed for bottomfish habitat, deep sea corals, and to look for potential depth refuges of the destructive crown-of-thorns starfish which has been consuming large swaths of reef in shallow zones and are thought to originate from the depths. Baited stations may be used to attract bottomfish and survey species and abundances.

Additionally, collection of limestone rock samples along the wall from 100 to 350 m would allow for dating of the shelf that extends around Tutuila and Aunu’u Understanding and documenting these critical habitats, especially around Aunu’u, is a high priority for sanctuary management. Having them linked to the adjacent but completely unknown deep sea habitats would provide a unique perspective for management and enable more effective and directed management efforts in the deepest sanctuary zones.

Brief Overview of Target Area

Fagatele Bay, designated a sanctuary in 1986 to protect its impressive coral reefs, is a collapsed volcanic crater off the southwest coast of Tutuila Island. It supports perhaps the greatest diversity of marine life in the National Marine Sanctuary System, with 168 species of corals, more than 1,400 species of algae and invertebrates, and 271 species of fish. As of 2012, take of any marine life within Fagatele is prohibited. The bay drops steeply into a submarine canyon that extends to a steep dropoff at 300 m.

The coves of Fagalua and Fogama'a lie within a bay directly adjacent to Fagatele, serving as a replicate system for research. Together, Fagalua/Fogama’a and Fagatele constitute a hotspot for coral cover, as well as coral and fish species richness. Aunu’u is a small, volcanic island 1.2 miles southeast of Tutuila. This sanctuary area encompasses 5.8 square miles, and includes a 3.9 square mile research zone where reef and bottomfish are protected (but trolling is allowed), and a 1.9 square mile multiple-use zone. This area is a hot spot for coral cover, fish biomass and species richness. It encompasses shallow-water fringing reefs, an extensive mid-water shelf with bottomfish habitat, and deep-water regions.

Brief Summary of What is Known of Target Area

Nearshore areas around Tutuila island have been mapped and the habitats in shallow depths are fairly well-studied, but beneath recreational scuba depths, very little is known. There has been one mesophotic reef camera tow survey conducted around the island by NOAA Honolulu's Coral Reef Ecosystem Division, with maximum depths of about 150 m. Habitats and organisms found beyond this depth are largely unknown. Even the depth at which scleractinian coral growth ends is not known.

Feasibility of Studying Target Area

All three proposed sites lie around the main island of Tutuila and are easily accessible by boat. Operations can be based out of Pago Pago, with assistance from the National Marine Sanctuary of American Samoa. March tends to have the calmest seas and fewest storms. Work could be conducted under collaboration with researchers from the NOAA Deep Sea Coral Program, the University of Oregon, and the University of Hawai'i, all of which have past experience and interest in the region.

Education and Outreach Potential of Target Area

The opportunities for media exposure and public Target Area outreach are considerable. Video from the mission(s) can be shown to visitors and school groups on the Science on a Sphere exhibit in the Tause P.F. Sunia Ocean Center, which attracts 7,000 visitors a year from Samoa and worldwide. Footage can also be used for lectures and school/ village outreach conducted regularly by sanctuary staff.

Vailulu'u volcano and Muliava sanctuary management unit

Wendy Cover (National Marine Sanctuary of American Samoa)

Region

Tonga/Kermadec Trenches
Tuamoto Archipelago/Austral (Tubuai) Island/Cook Islands

Rationale for Exploration

The National Marine Sanctuary of American Samoa is comprised of six protected areas designated in 2012 and covering 13,581 square miles of nearshore coral reef and offshore open ocean waters across the Samoan archipelago. By virtue of its isolation, very little of the area has been thoroughly explored, leaving many questions as to what organisms and habitats lay hidden at depth. The proposed project would further our knowledge of the most remote of these newly protected areas, while addressing important management goals and providing outstanding outreach material for local communities. Further exploration of the undersea volcano Vailulu'u and surrounding features within the Muliava sanctuary management unit (also part of the Rose Atoll Marine National Monument) would almost certainly reveal more species and more habitats, including in the previously unexplored region beyond 1000 m depth.

Brief Overview of Target Area

First mapped in 1999 and videoed in 2005,Vailulu'u is the active volcanic hotspot that created the Samoan archipelago. Lying from 600 m to 5,000 m in depth, it is home to an array of deep sea organisms, from red polycheate worms in the Moat of Death, to swarms of cutthroat eels in Eel City. Much of the rest of the Muliava sanctuary management unit consists of open ocean over depths of approximately 5,000 m, including deep sea habitat that surrounds the seamount of Malulu and Rose Atoll.

Brief Summary of What is Known of Target Area

In 2005,Vailulu'u was the subject of nine submersible dives as deep as 1000 m. A report on the expedition can be found here: http://oceanexplorer.noaa.gov/explorations/05vailuluu/welcome.html. Aside from portions of the shallower areas of Vailulu'u, we know next to nothing about the nature of the deep sea habitat within the Muliava sanctuary management unit, including the unexplored seamount of Malulu. The Hawaii Undersea Research Program did at least one dive at Rose Atoll, for which there is archived video.

Feasibility of Studying of Target Area

Vailulu'u lies about 20 miles past the island of Ta'u in American Samoa, and Rose Atoll lies another 64 miles past that. Operations can be based out of Pago Pago, on Tutuila island, with assistance from the National Marine Sanctuary of American Samoa. March tends to have the calmest seas and fewest storms. Exploration of this deep zone at the base of Vailulu’u could include baited camera stations to attract the often sparsely dispersed deep-sea creatures. Work could be conducted under collaboration with researchers from the NOAA Deep Sea Coral Program, the University of Oregon, and the University of Hawai'i, all of which have past experience and interest in the region.

Educational and Outreach Potential of Target Area

The opportunities for media exposure and public outreach are considerable. Video from the mission(s) can be shown to visitors and school groups on the Science on a Sphere exhibit in the Tause P.F. Sunia Ocean Center, which attracts 7,000 visitors a year from Samoa and worldwide. Footage can also be used for lectures and school/village outreach conducted regularly by sanctuary staff.

Exploration of the NE Lau Basin - Northern Tonga Subduction Zone

Robert W. Embley (Pacific Marine Environmental Laboratory (PMEL), NOAA)

Collaborators

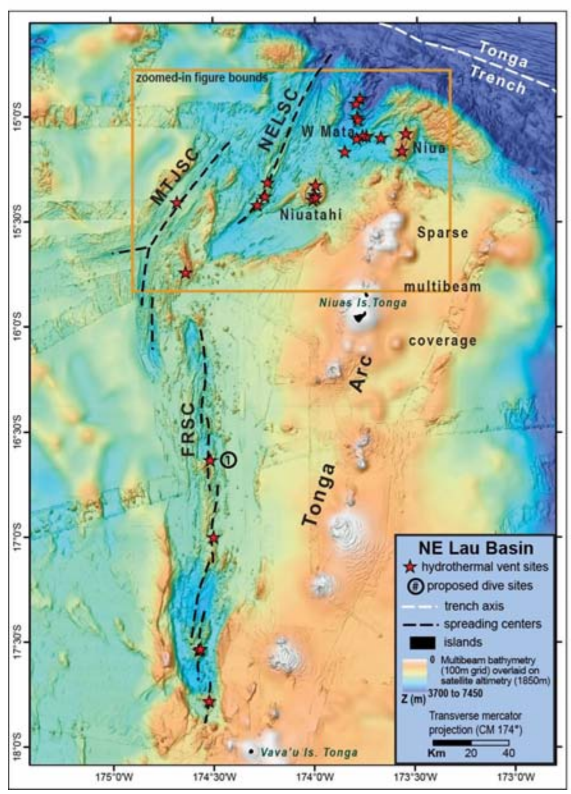
Joseph Resing (JISAO, U. Washington)
William Chadwick (CIMRS, Oregon State U.
Kenneth Rubin (SOEST, U. Hawaii at Manoa)
David Butterfield (JISAO, U. Washington)
John Lupton (PMEL, NOAA)

Region

Tonga/Kermadec Trenches

Rationale for Exploration

This area includes one of the most diverse and concentrated zones of backarc volcanic and hydrothermal activity on the planet as well as sections of the Tonga trench and magmatic arc. The very high convergence rate of the northern Tonga subduction zone (~17 cm/yr) and the underlying crustal tear associated with the active Subduction-Transform Edge Propagator (STEP) fault has resulted in the formation of a series of back-arc spreading centers, extensional zones, and other sites of submarine volcanism. The wide range of magma chemistries, water depths and geologic settings in this dynamic area provides an intriguing template for discovery of new types of hydrothermal systems and chemosynthetic biology within an arc/backarc setting.



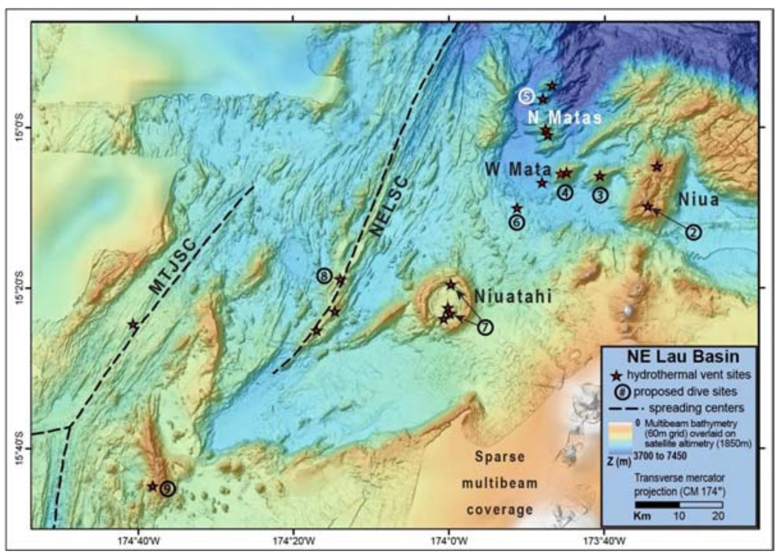
The discovery of two active submarine eruptions during the same week in 2008 underscored the potential of this area for studying young volcanism and hydrothermal activity. The eruption on the Northeast Lau spreading center produced intense event plumes that rose high above the ridge crest and which were tracked over a week. The second site was the boninite (a hot, volatile-rich magma formed in nascent island arcs and a few other subduction zone settings) eruption at West Mata seamount that gave the world its unprecedented images of an explosive deep-sea eruption and active submarine lava flows. A wide range of hydrothermal and volcanic sites have been identified by prior expeditions in the NE Lau, but only a small number of scientific ROV dives have been made here. This large investment in preparatory exploration enhances the potential for new discoveries using a deep submergence vehicle.

Brief Overview of Target Area

The area is the NE corner of the Tonga subduction zone. The Fiji islands lay to the SW, the Samoan islands are northeast and the northern Tongan islands are along the magmatic arc. Most of the area is within the Tongan EEZ. Geologic provinces include the full range of subduction zone environments including: (1) a deep trench bounding the area to the east and northeast (only partially shown on supplementary maps, (2) the trench inner wall/forearc region, (3) active and extinct sections of magmatic arc, (4) a suite of back-arc spreading centers including, from south to north, the Fonualei Rift spreading center (FRSC), the Mangatolu Triple Junction spreading center (MTJSC), and the Northeast Lau spreading center (NELSC), (5) the only historically active boninite province on Earth, including West Mata (actively erupting in 2009), (6) a 12-k- diameter silicic caldera (Niuatahi) with multiple hydrothermal systems, and and a recently active resurgent cone. Water depths over the region range from <100 m on the arc to >7000 m in the trench. The NE Lau backarc region ranges from ~ 500 m to ~4000 m.

Brief Summary of What is Known of Target Area

The northern boundary of this area is defined by a major change in plate geometry where the Tonga Trench turns west, shoals and becomes a strike-slip boundary. The magmatic arc here consists of a volcanically active younger arc (Tofua) offset to the west from an older arc. The NELSC and other extensional zones of the NE Lau basin are part of a diffuse triple junction as the trench rotates to an E-W trend and becomes a strike-slip boundary to the west. This complex tectonic setting and high heat flow yield diverse magma chemistries and volcano-tectonic styles. The area includes the Earth's only active boninite volcanism, effusive dacitic volcanism, small spreading centers, large arc and rear-arc volcanoes, and fields of monogenetic volcanoes. At least 22 hydrothermal sites in water depths from <500 m to ~2650 m water depth have been discovered in the backarc and arc here in the past 10 years by water column surveys (in depths ranging from <), but less than 50% of these have been explored with an ROV (and most of those with only one dive). In addition to the volcanic zones, there are other subduction zone terrains of diverse origin that could be host to seeps (inner wall of trench and forearc). However, very little is known about these zones because of sparse multibeam coverage.



Feasibility of Studying Target Area

The area is ~1 day from the Samoan ports of Apia and Pago Pago, about 1.5 days from Tonga (Nuku'alofa) and about 2 days from the large port at Suva, Fiji. Weather is mild except for the occasional cyclone. Most of the region lies within the EEZ of the Kingdom of Tonga, and previous expeditions have not encountered any issues with permissions for working within their EEZ.

A good baseline of data exists for the NE Lau basin, including EM300 and EM122 multibeam bathymety, water column surveys and, in some cases, high resolution AUV mapping and camera tows. Expeditions in 2004-2012 surveyed the backarc seafloor and portions of the magmatic arc with the latest generation multi beam systems and conducted ~100 water column stations. There has also been some near-bottom, high resolution mapping using AUVs and towed camera systems at a few sites.

Using this data base, limited exploration dive programs in 2009 (3 exploration dives) and 2012 (9 exploration dives) discovered eight new hydrothermal sites in the back-arc region of the proposed area. The historic mapping and water column data in this area is essential for a robust and productive exploration program using an ROV, given the relative remoteness, geologic complexity of the area, and limited time-on-site. Some of the arc volcanoes have multibeam mapping and limited water column surveys. Sites with the most promising potential for exploration discoveries, most with known hydrothermal activity but lacking exploration by scientific ROVs, include (also see supplementary maps for numbered site locations): (1) a large vent field on the central Fonualei rift discovered in 2011 using a towed camera system, (2) The southern summit of the enigmatic Niua volcano to further explore its extensive and complex vent fields, (3) the methane-enriched hydrothermal system on the summit of East Mata, (4) several sites on West Mata, to check on its level of activity and to explore a recently-discovered large deep lava flow, (5) Mata Ono, a probable sulfide site on one of the North Mata boninite volcanoes, (6) a deep site on the large silicic lava flow lying between Niuatahi and West Mata, (7) several large sulfide sites along the ring faults of the Niuatahi caldera, (8) a site on the NELSC near an historical lava flow, and (9) a small volcano in an unusual geologic setting within the overlap zone between the NELSC and the FRSC.

Educational and Outreach Potential of Target Area

The outreach potential of this area is excellent. The hydrothermal systems will likely vary dramatically in geology, chemistry and biology. It is also possible that West Mata volcano could be active as it was in 2009, in which case the world would have its first real-time view of a deep submarine eruption via telepresence. This area is also being actively prospected by several ocean minerals companies for polymetallic sulfide ore deposits. It is important that the scientific community and the public be able to have first-hand knowledge of the biologic communities that have evolved in this unique geologic setting before resource extraction activities commence.

Mesoamerican Trench

Elva Escobar (Universidad Nacional Autónoma de México)

Collaborators

Lisa Levin (Scripps)
Javier Sellanes (U. Concepción Chile)

Region

E Equatorial Pacific
Eastern tropical Pacific

Rationale for Exploration

The eastern Pacific is characterized by interesting deep sea ecosystems along a latitudinal gradient that invite scientists from diverse countries to collaborate and understand the processes that define the changes in biological diversity. Among the ecosystems of interests that can be suggested to teh Ocean Exploration initiative to survey along the eastern Pacific I would like to suggest the following:

A. Trenches
B. The Minimum Oxygen Zone (MOZ)
C. Vents and Seeps
D. Seamounts
E. Canyons

Many of these have been studied in isolated scientific or binational efforts by the coastal nations along the eastern Pacific, namely the MOZ (US, Mexico, Chile), the Vents and Seeps (US, Mexico, Costa Rica, Equador, Chile), Seamounts (US, Costa Rica, Chile), Trenches (Chile), Canyons (US) offering a new space for a multinational collaborative effort. Some of these ecosystems coexist spatially in the eastern Pacific region (i.e. MOZ and seamounts or canyons) or are placed nearby (i.e. MOZ and Vents and Seeps) offering new hypothesis on how deep sea species can evolve, or disperse. Our knowledge is limited and this initiative provides a great engine to curiosity and exploration.

Brief Overview of Target Area

A. Trenches The least studied regions of the sea are the trench formations (Ramirez et al., 2010) that run along tectonic plate boundaries at depths greater than 6000 m. Trenches are long narrow (width does not exceed 40 km), deep and asymmetrical depressions of the seafloor with steep sides (IHO, 2008). If infilled with sediment are called troughs, distinguished by their flat-bottom in contrast with the “V” in cross section shape, occasionally presenting bridges (Gardner & Armstrong, 2011).

Trenches occur within the EEZs covering an area of 1,967,350 km2, most of them in the North and South Pacific Oceans, accounting for 79.8% of all ocean trenches by area (Harrys et al., 2014). These geological features, associated with active margins and absent from passive margins, are considered unique deep-sea settings (Bruun, 1956), restricted to plate boundaries where subduction of lithospheric plates occurs. Their slopes can be up to 45 or more, making trenches extremely difficult to sample remotely. The trench floor is characterized by fine-grained non-calcareous sediments; the presence of turbidity currents, slides and collapses that can have catastrophic consequences on the local bentos (Danovaro et al., 2003). They are characterised by extreme pressure, complex topography and geographic isolation to which endemicity is an additional attribute (i.e. Amphipoda, Liparidae), where species have an abyssal origin in in most cases (Vinogradova, 1997). Diversity within a hadal trench is often low (Blankenship-Williams & Levin, 2009). The knowledge has improved in the last 60 years. Although numerous new species, genera and families have been described new taxa are yet to be identified (Belyaev, 1989) as based on photographic records. Fishes, holothurians and crustaceans are dominant scavenging components of the megafauna (Wolff, 1970; Belyaev, 1989; Jamieson et al., 2010). Calcareous taxa disappear in this zone due to under-saturation of carbonate. Soft-bodied or organic-walled foraminifera are are abundant at hadal depths (Todo et al., 2008), in contrast to calcareous forms (Gooday et al., 2008). Amphipods, polychaetes and bivalves are more abundant in the hadal zone than in the abyss (Wolff, 1970). Nekton species exhibit ontogenetic vertical zonation (Blankenship et al., 2006) and resource partitioning by diet (Blankenship & Levin, 2007).

The Vinogradova (1979) zoogeographical classification of the abyssal and hadal zones based into provinces, subregions and regions based on a species level analysis. The Belyaev (1989) biogeographical classification of t renches in 10 provinces. Hadal species distribution in these provinces has been referred to t rophic pelagic benthic coupling patterns and characterized by bipolar eurybathic species connected by deep cold waters (Vinogradova 1997) or following a circular pattern according to the margins of the ocean basins (UNESCO, 2009). The Goods report (UNESCO, 2009) recognized 10 hadal provinces based on the scheme presented by Belyaev (1989).The latest account recorded 56 trenches and 125 bridges (Harrys et al., 2014).

The eastern Pacific has three trenches: Kurile-Kamtchatka (Pacific Ocean Subregion) in northernmost portion, Middle America trench in the tropical region, and the Peru-Chile trench further south. Of all three the largest trench is the contiguous Kuril–Kamchatka – Aleutian Trench complex, which covers an area of 254,740 km2 (Harrys et al., 2014). Of these three, the Atacama trench has been the only one from which information is available in the region. It has been recognized as a deep oceanic trap (ca. 8,000 m) for organic material phytopigments, proteins, carbohydrates and lipids (Danovaro et al., 2003). Benthic microbial activity is large, meiofaunal abundance and biomass are two orders of magnitude higher than values reported in other hadal system and 10-fold higher than bathyal depths. A reduction of the mea nematode size in Atacama by ca. 67% at the deepest depths has been attributed to dominance of opportunistic species and the ability to tolerate better the high pressures (Gambi et al., 2003). Sediment limited nematode colonisation and explained in part the restricted diversity of the group in the Atacama Trench. A minimal number of trenches has been investigate (Blankenship-Williams & Levin, 2009). This current lack of understanding prohibits any possibility of applying effective long-term management or policy to these deep ecosystems. Modern exploration technologies (i.e. remotely-operated vehicles) are tools that help explore and investigate the deepest parts of the ocean as we have done with the shallowest can enhance hadal ecosystem.

Considering that each trench system can be characterised by extrinsic and intrinsic factors, the former being:

(a) geological age, likely to affect the degree of endemism;
(b) overlying primary productivity affecting POC flux and influencing food supply;
(c) hydrodynamics controlling oxygen supply (ca. 2.0 to ca. 6.9 mL L−1) and regional water temperature;
(d) proximity to land mass, slopes and turbidites affecting sediment influx and infilling;
(e) seismic activity as one of the driving forces for sediment flux or catast rophic disturbance;
(f) tidal cycles, that have a regional impact; and
(f) topography, determinings area, steepness or habitat heterogeneity.

And the latter structure the local ecology through:

(a) physiological adaptation of individual species;
(b) local depth, defining hydrostatic pressure (600–1100 atm) and local temperatura (stable and typically close to oC, exception the Hellenic Trench 14 (Tselepides & Lampadariou, 2004);
(c) trophic efficiency and food web complexity;
(d) local hydrodynamics attaining velocities that range from 10 to 32 cm s−1 aggregate or disperse organic matter;
(e) quality and quantity of food resources varying in time and space;
(f) nature of substratum, affecting type of organisms settling;
(g) life history (e.g. reproductive strategy or ontogenetic migration); and
(h) chemosynthetic processes, providing local changes in food supply.

Brief Summary of What is Known of Target Area

I submit for consideration to the Ocean Exploration the trenches as one possible ecosystem to explore. The following are questions that require an answer and provide an opportunity to improve our knowledge on trench ecology in a multinational transdisciplinary effort of coordinated international research:

Are there latitudinal trends to be observed in trench diversity and community structure? Can diversity be associated to the degree of gene flow between trenches along the eastern Pacific? Is trench biodiversity linked to evolutionary age and geology of each site? Are trenches along the eastern Pacific characterized by bipolar eurybathic species connected by deep cold waters? Do extrinsic and intrinsec factors define the changes observed in hadal community structure and function? Could there be a link between the eastern Pacific trenches and those from the Puerto Rico Province (Puerto Rico and Cayman Trenches) in the Atlantic Subregion? These three trenches ocurr along the EZZ of more tan one country and will require multinational collaboration.

Feasibility of Studying Target Area

High

Educational and Outreach Potential of Target Area

Very important

Salas y Gómez and Nazca Ridges

Scott France (University of Louisiana at Lafayette)

Collaborators

Eric Pante (Université de La Rochelle)
Les Watling (University of Hawaii at Manoa)

Region

SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise
S Pacific Basin

Rationale for Exploration

The vast area that encompasses the south Pacific Basin, including the Salas y Gómez and Nazca Ridges and scattered seamounts, shows up as a gaping hole in sampling of hard bottom fauna, and in particular octocorals, which are abundant and diverse in other deep-sea hard bottom habitats that have been explored but mostly unknown in this region of the Pacific. Our colleagues at MNHN have done extensive sampling of deep-sea hard bottom fauna in the SW Pacific providing a basis for comparison of his fauna, much of which is comprised of yet undescribed species.

Brief Overview of Target Area

The Salas y Gómez and Nazca Ridges are two sequential submarine mountain chains of volcanic origin in the South-Eastern Pacific Ocean. Together the ridges extend over 2,900 km. The Chilean government has recently declared part of this site a no-take Marine Protected Area into his jurisdictional waters.

(from http://www.wwf.se/wwf/1455095-deep-sea#1)

Brief Summary of What is Known of Target Area

Russian scientists conducted several cruises to the region in 1973–1987, including sampling of 22 seamounts, but to my knowledge there has been no in situ work, i.e. ROV or HOV. These assets have been used at hydrothermal vents on the southern EPR and Easter Microplate, but there has been no targeted effort at surveying communities from non-vent hard bottom habitat that I am aware of.

Feasibility of Studying Target Area

The general region is very isolated (which explains the lack of sampling) and would require significant transit time to reach.

Educational and Outreach Potential of Target Area

Seamount communities are rich in corals and associated invertebrates and fishes and provide great visual interest for the general public. There are a number of topics that can be discussed in relation to these communities that range from how the fauna find these isolated "mountaintops" to their ability to survive in the habitat. The complex geology of the ridges likewise provides educational opportunities.

Society Island Hotspot

Chris German (WHOI)

Collaborators

Colin Devey (GEOMAR)
Cindy Van Dover (Duke University Marine Lab)

Region

SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise
W Central Pacific/Line Islands
S Pacific Basin

Rationale for Exploration

In preparing a recent review of the latest seafloor hydrothermal exploration and discovery (Beaulieu et al., 2014) I noticed that there had been no significant new discoveries made in the interior of the Pacific since the 1980s. In parallel, we still do not understand, following the end of the Census of Marine Life decade what controls or prevents the dispersion of vent-endemic species' larvae from one locale to another. Yet, from a 3rd line of evidence, my US GEOTRACES cruise in Fall 2013 showed that chemical signals from the southern EPR extend all the way to 150W, close to where our cruise ended in Tahiti. Finally, our last station off the coast of Tahiti revealed there to be at least one hydrothermal vent present at that locale waiting to be explored: what might be living there and how might the fauna be related to southern EPR fauna?

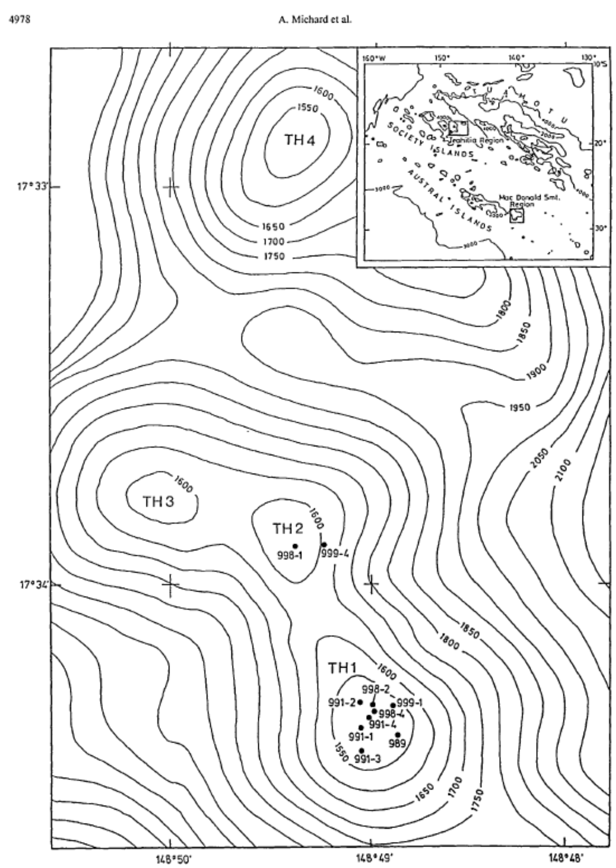


FIG. 1. Schematic seabeam map of Teahitia volcano. Inserted map showing the location of Teahitia volcano within the South Pacific area. Numbers indicate the sites of hydrothermal vent waters sampling by the submersible *Cyana*.

Brief Overview of Target Area

The Society Islands represents the subaerial component of a hot-spot trace across the South Pacific that is directly akin to the Hawaiian Island Chain and, hence, is undoubtedly host to submarine hydrothermal venting associated with the submarine components of the volcanism that arises there.

Brief Summary of What is Known of Target Area

When last studied in any detail in the late 1980s with the French submersibles Cyana and Nautile it was known that more than one of the seamounts to the South and East of Tahiti were volcanically active and that at least one of those sites hosted weak hydrothermal venting (Michard et al., GCA, 1992). When I returned to the site with the RV Thompson in late 2013 our single CTD cast revealed clear evidence for high temperature black-smoker venting at the same site.

Feasibility of Studying Target Area

Perfectly feasible so long as we can get a research ship to Tahiti and secure foreign clearance for the study. The seamounts are all within diving range of various vehicles and multibeam can be used to map all the seamounts easily (including searching for bubble emissions from the shallowest sites as further signs of activity). Since the sites are typically conical, a single CTD cast at each seamount should suffice to confirm whether active or not and, hence, whether to explore in detail by ROV or move on.

Educational and Outreach Potential of Target Area

Exceptional - wherever we dive we can anticipate stunning background biology in these highly productive waters. The locale should be sufficient to capture even the most jaded imagination. And then we have the added potential to discover completely new species at such highly remote vent sites.

Rarotonga Hotspot

Matthew Jackson (UC Santa Barbara)

Collaborators

David Valentine (UC Santa Barbara)
Katherine Kelley (URI)

Region

Tuamoto Archipelago/Austral (Tubuai) Island/Cook Islands

Rationale for Exploration

Hotspot volcanism, famously illustrated in the Hawaiian islands, is thought to be caused by buoyantly upwelling plumes that rise from the deep mantle and melt beneath the oceanic plate. Many oceanic hotspots in the Pacific are characterized by age-progressive chains of volcanoes, resulting from the oceanic plate moving over a relatively-stationary mantle plume. However, hotspot volcanism in the Cook-Austral volcanic chain does not show a clear age progression, and the lack of an age-progression at this hotspot has been used consistently to argue against the long-standing model that upwelling mantle plumes partially melt to generate hotspot volcanism.

An alternative model for volcanism in the Cook-Australs argues that the lack of a clear age progression results from four distinct mantle plumes spaced roughly 1000 km apart. Three of the proposed mantle plumes manifest as the Cook-Austral volcanic chain of islands and seamounts, whereas the fourth manifests as the Samoan hotspot, located 1000 km to the WNW. The term “hotspot highway” has been used to describe this area because of the unusual number of hotspots that may exist along this single volcanic corridor. Supporting the hypothesis of four separate hotspots along the hotspot highway, the islands and seamounts of Samoa and the Cook-Australs exhibit four age-progressive volcanic trends: The Tubuai trend, the Atiu trend, the Rarotonga trend and the Samoan trend (See Supplementary Document 1). The plume model for the generation of hotspots predicts that the eastern portion of hotspots on the Pacific plate should be anchored by an active (or exceptionally young) volcano. Indeed, the Tubuai trend is anchored in the east by the volcanically-active MacDonald seamount, the eastern portion of the Atiu trend is anchored by the exceptionally young (230,000 years old) Arago seamount, and the Samoan chain is anchored on its eastern terminus by a volcanically active seamount, Vailulu’u. The only volcanic trend on the hotspot highway for which an active volcanic anchor has not been discovered is the Rarotonga trend, and the existence of this “missing hotspot” is a critical test for the plume origin of hotspots. However, an oceanographic expedition to locate the active volcano anchoring the Rarotonga trend has never been undertaken. The location of such a volcano can be predicted by the age-progressive nature of plume-fed hotspots. The youngest volcano on the Rarotonga trend, Rarotonga Island, is 1-2 million years old, and the Pacific plate in the region of Rarotonga Island is moving 10 cm/year to the ENE. Therefore, the active volcano of the Rarotonga trend should be located approximately 100 to 200 km to the WSW of

Rarotonga Island. The gravity-based bathymetry of Smith and Sandwell reveals two seamounts located in the predicted region (see Supplementary Document 1). These seamounts, and the region around them, make up the targets for this proposed exploration.

The combination of E/V Nautilus and ROV Hercules is well suited to explore and study the target seamounts. The ROV Hercules is certified to reach the depths of both prospective targets where we could use the HD video system to capture stunning visual imagery. The multibeam system could be used to select dive targets on these structures, and perhaps to identify other volcanic structures. The ROV's CTD could be used to probe the water column above the seamounts to provide crucial information about active hydrothermal venting. The ROV's manipulator arms could enable the recovery of biological samples from the seamounts to evaluate the biological community composition; volcanic samples could be recovered to establish their volcanic age and geochemical pedigree. And finally, other measurement/sampling capabilities of the ROV Hercules, such as high resolution mapping, could be used to further exploration and scientific goals.

The discovery of a volcanically-active seamount at the leading edge of the Rarotonga volcanic trend would establish that each of the volcanic lineaments along the hotspot highway is anchored by an active hotspot. This discovery would suggest that volcanism along the four volcanic trends is not randomly distributed, but is in fact consistent with distinctive mantle plume origins for each of the four volcanic lineaments along the hotspot highway, an important scientific advance. The recovery of fresh lava, including volcanic glass, will bolster the limited global sample catalog and provide an unparalleled opportunity to characterize the deep mantle sources of such plumes, free from the detrimental effects of weathering and volcanic degassing. Furthermore, the discovery of a volcanically-active seamount presents the opportunity to study active hydrothermal systems and the novel ecosystems that exist near vents. The target area, together with the other known active hotspot volcanoes along the hotspot highway--MacDonald and Vailulu'u seamounts--provides a unique opportunity to investigate the biogeography of hydrothermal communities, both microbial and macrofaunal. The collection of preliminary samples on this expedition would be leveraged into subsequent biogeochemical, biogeographic and geochemical studies.

Data and samples obtained during the expedition will also serve to leverage NSF-funded expeditions to return to the Cook Islands.

Brief Overview of Target Area

The target area is located in the Cook Islands, between the islands of Rarotonga and Mangaia. The first target seamount is located 70 km ESE of Rarotonga, and the second seamount target is located 200 km ESE of Rarotonga (see Supplementary Document 1, included with this submission). Existing bathymetry indicates that summits of the target seamounts are 2100 and 3200 m water depth, respectively.

Brief Summary of What is Known of Target Area

The Cook Islands are located on the western region of a volcanic corridor—the hotspot highway—fed by several concurrently active hotspots. Active (or recent) volcanism has been identified on three of the four volcanic lineaments that constitute the hotspot highway. However, active volcanism anchoring one of the volcanic trends—the Rarotonga lineament—has yet to be identified, and this constitutes the "missing hotspot" on the hotspot highway. Available bathymetry in the Cook Islands is limited to a small number of ship tracks. Smith and Sandwell bathymetry identifies two notable seamounts in the Cook Islands, located in the region where we predict volcanism to occur.

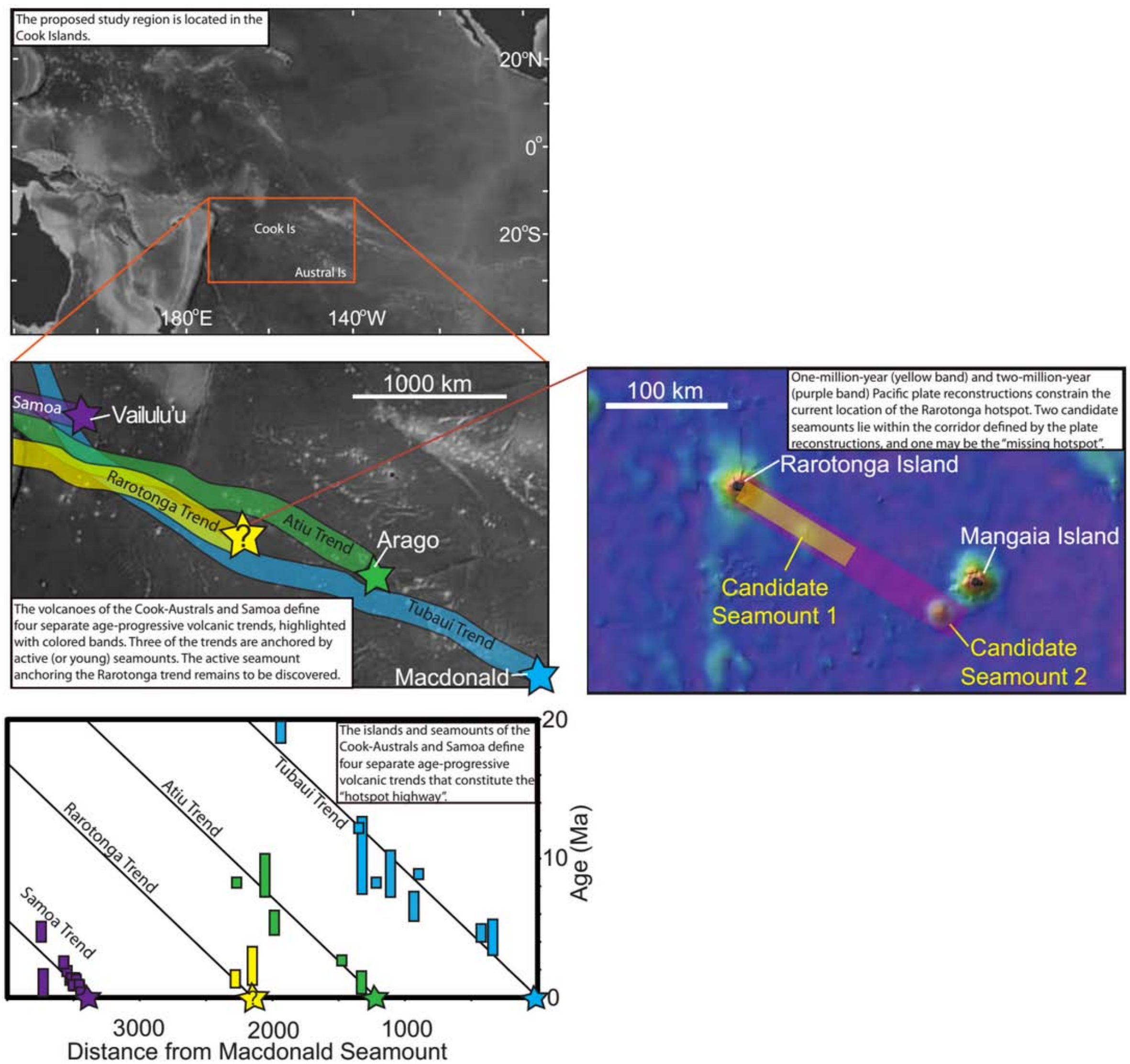
Feasibility of Studying Target Area

We believe there is a high probability of discovering a new, volcanically active seamount anchoring the Rarotonga volcanic trend. When seagoing expeditions made systematic efforts to locate volcanically-active (or exceptionally young) seamounts anchoring the other three hotspots (Samoa, Atiu and Tubuai) along the hotspot highway, a volcanically young seamount was discovered at the eastern terminus of each hotspot. We suggest that the reason the "missing hotspot" of the Rarotonga volcanic trend is still missing is because no oceanographic expedition has been conducted there.

The E/V Nautilus and ROV Hercules are well suited to the proposed targets. The water depths of the summits of the two target seamounts are 2100 and 3200 m, within Hercules' capability. The new multibeam system on the Nautilus will provide information about these seamount targets and may reveal other potential targets not apparent from the current, low-resolution (Smith and Sandwell) gravity-based bathymetry. The manipulator arms of the ROV are well-suited for sampling volcanic rocks for later age-dating and geochemical analysis. The capability to collect water samples and integrate sensors with ROV Hercules will further enable the detection and study of hydrothermal systems, and the ability to collect high-resolution bathymetry from the ROV Hercules will enable detailed visualization of these features Rarotonga Island has an international airport, but does not have a deep water port. However, there is opportunity for on-loading, off-loading and resupply at Rarotonga. The nearest deepwater port is located in Papeete, Tahiti (620 nautical miles from Rarotonga).

Educational and Outreach Potential of Target Area

We anticipate generating significant interest in this expedition. A press release could start: Ocean explorers discover new volcano, a fourth lane hotspot highway. The combination of exploration and discovery potential, along with rigorous scientific questions, render this a viable exploration target. The major proponents of this proposal, Matt Jackson and Dave Valentine, would work extensively with the UCSB campus to develop the outreach capacity that OET has been discussing with the campus. Should we discover the active volcano anchoring the Rarotonga hotspot, we believe the news will be met with very broad public interest. Streaming live images of active volcanism and hydrothermal venting to the world will be a powerful tool for engaging the general public (K-12 outreach and beyond) in ocean exploration. Both Jackson and Valentine are funded by NSF and would also leverage their own research programs to guarantee follow through with the collected samples. The population of the Cook Islands has shown significant interest in better understanding the origin of the volcanic islands. During previous fieldwork in the Cook Islands, Jackson interviewed with a local news source, the “Cook Islands News”, to discuss the ongoing research in the region. Jackson met with the Prime Minister, the Honorable Jim Marurai, to discuss future research plans in the region, and the Prime Minister was enthusiastic about oceanographic research in the islands. Jackson also spent a day teaching at an elementary school on the island of Mangaia, Cook Islands, and the students were fascinated to learn about the volcanic origin of their island, the ongoing erosion and subsidence of the island, and its ultimate fate as an extinct underwater volcano.



Forearc to Arc Transition in the Northern Tonga Trench

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Collaborators

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Region

Tonga/Kermadec Trenches

Rationale for Exploration

Exploration of the northern Tonga Trench will be used to observe submarine arc volcanoes, map eruption deposits, create a geologic map of the convergent margin, and search for hydrothermal activity. The lack of an accretionary prism at the trench makes this location ideal for studying the structure of the forearc lithosphere, from the mantle to the transition into active arc volcanism. Preliminary observations suggest the possibility of hydrothermal activity at a variety of depths, based on the alteration history of dredged forearc peridotites and anomalies in regional hydrocasts. Previous dredges have returned a range of lava compositions (basalt to rhyolite and possible boninites) erupted in close proximity and with a variety of morphologies (pumice, lava flows).Active volcanism in the northern Tonga arc, which terminates in the north at Niua volcano (see figure), is evident in very close proximity to localities where mantle peridotites have been dredged. The region hosts a number of volcanoes that have not been sampled or directly observed (e.g., East Mata; see Fig. 1).
The forearc region of convergent margins is relatively understudied compared to arcs and backarcs.

Exploration in this area will help constrain the relationship between subduction initiation, early arc magmatism and modern arc magmatism. Studies of the Mariana Arc have provided the first geologic map of a forearc region above a subducting slab, due to extensive sampling over the past decade. In contrast, Tonga – which has rapid slab rollback – remains largely unexplored, with the last major forearc sampling occurring in 1996. Tonga Trench is one of only four localities where forearc mantle peridotites have been collected. Some of the Tonga peridotites are also the freshest of any mantle samples collected in the oceans, including all ridge localities. The fast slab rollback may lead to rapid exhumation of the forearc region and account for exposure of fresh samples. In close proximity to the dredged peridotites, an abundance of volcanic samples have been recovered by dredging. The characteristics of eruption deposits in this area have not been studied in any detail.

Previously logged expedition notes (Leg SS07/2008 of R/V Southern Surveyor, see below) suggest white smoker-type, peridotite-hosted hydrothermal activity in the study region. There is growing interest in these submarine high pH, geochemically distinctive biogeochemical systems as a clement environment for development of the first successful microbial cells and early chemosynthesis. Mapping and sampling these vent fluids, escaping gases, and associated mineral particulates would establish this location as a new field site for study of the deep biosphere in serpentinites. Tonga could help to anchor new research in biogeography of the serpentinite-hosted microbiome, when integrated with recent work on the mineral towers at the Lost City Hydrothermal Field, numerous serpentinite mud volcano sites (e.g., Marianas), and also hyperalkaline spring sites sourced in continental serpentinites, which appear to host vestiges of deep subseafloor microbial communitites. Complementary characterization of solid phases, aqueous geochemistry, dissolved and free gas contents, and microbial community diversity and structure here would provide precious data in a critically understudied area.

We propose a program of ROV diving combined with water column observations via CTD-rosette. The visual observations provided by ROV diving will be used to understand the sequence and style of Tonga volcanism, including the transition from mantle to arc. They will provide visual observations of submarine Niua volcano and neighboring East Mata, in addition to lower crustal and peridotite outcrops in the fore-arc. Near-bottom observations of water properties will be used to search for hydrothermal seeps.

Brief Overview of Target Area

The Tonga Trench is a nonaccretionary convergent plate margin undergoing the fastest slab rollback of any subduction zone.Active subaerial and submarine volcanoes occur along its length.Although the subaerial volcanism in Tonga is relatively well-studied, the submarine component of volcanism has only been accessed within the last decade, with specific focus on the Lau back-arc basin, active volcanism at West Mata, and active venting at several regional volcanoes including Niuatahi (Fig. 1). Our proposed study area focuses on Niua and East Mata, which are relatively unexplored.Alteration to amphibole and serpentine in a subset of peridotites suggest active hydrothermal alteration at relatively high temperature. Fore-arc peridotites in the Marianas exhibit unique fluid seeps, produced as the peridotite is weathered to sperpentinite, and these are host to unique faunal communities. Active serpentinization of mantle rocks in the Tonga fore-arc may host similar biota.

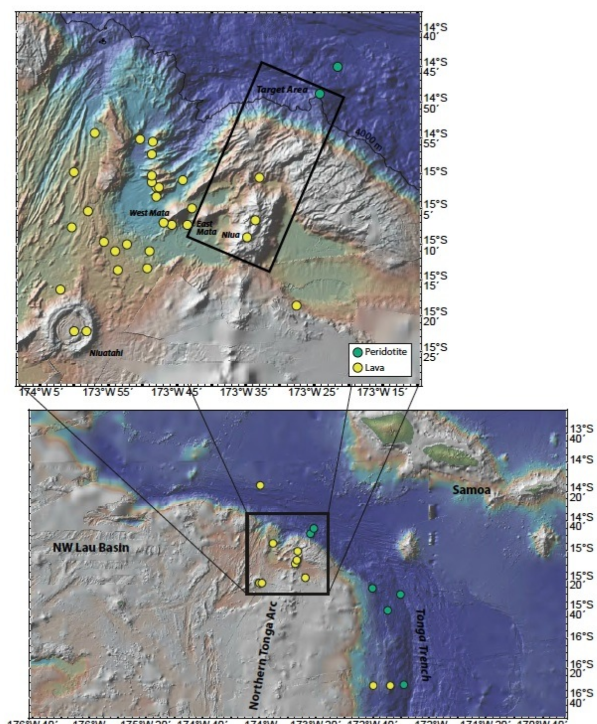

Figure 1. Regional map of the northern Tonga arc/trench system, with close-up of the proposed target area. Known dredge/grab samples are shown as circles, color-coded for lithology (see legend). The bathymetry base map is the Global Multi-Resolution Topography Grid v. 2.6 from GeoMapApp (Ryan et al., 2009).

Brief Summary of What is Known of Target Area

The Trench was dredged in the 1960s and 1970s and its bathymetry mapped in detail in the 1990s, but it has received little attention since then. The nearby Lau back-arc basin, located behind the Tonga arc, has been the subject of a focused US sampling campaign through the NSF decadal RIDGE2000 program. West Mata, a submarine, back-arc boninite volcano, has been the focus of intense study by ROV since it was discovered in mid-eruption in 2009. The broader back-arc area, including submarine Niuatahi volcano, has been sampled by dredge and ROV by recent cruises supported by NOAA's "Submarine Ring of Fire" program, among others. The arc has also been sampled recently by Australian cruises, but the forearc to arc region has thus far been under-studied. Based on the potential for high impact discoveries at Tonga, including the potential to greatly improve our understanding of arc initiation and discover new life-supporting habitats, the time is ripe to revisit the Tonga forearc.

Eight dredges were recovered in the region of the target area (~15S, 173W) during the 1996 Boomerang Leg 8 Cruise. Two of these dredges contain peridotite and the other 6 consist of lavas of a variety of compositions (Fig. 1). The trench in the target area shallows from a depth of >4000 m to <1000 m over a distance 30 km. Peridotite and dacite have been recovered in close proximity, making this the best target area for constructing a lithosphere transect by ROV. In the trench, some of the shallowest Tonga peridotites have been dredged at a depth of 4000 m. On the plateau, dacite to rhyolite lavas have been recovered in the region around Niua, and ROV dives at 3 locations on Niua have revealed active black smokers, a liquid sulfur pool and CO_2 venting, and abundant extremophile fauna. The region in between (depth range 4000-1000 m) has not been sampled, but should yield either lower crustal lithologies or evidence for faulting to bring the peridotites in proximity to the lavas. In either case, exploration by ROV will yield important information about the structure of forearc lithosphere and the transition into arc magmatism. Abundant lavas of a variety of compositions (picrite, basalt, andesite, dacite and possible boninite) have been recovered from the shallow submarine portions of the forearc and arc region. Lava morphologies range from pumice to massive jointed lavas, suggesting a variety of eruption styles. Trenchward, about 30 km to the northwest of Niua, dredging recovered picrites and basalts, along with possible boninites at a depth of 2600 m. Submarine Niuatahi volcano, located 50 km southwest of Niua, is a 15 km circular caldera with a young volcanic cone at its center that is hydrothermally active, and was recently explored in 2012 by ROV Quest 4000. Dredging of Niuatahi caldera recovered glassy andesitic to dacitic flows. To the north, on the downgoing plate, pillow basalts with manganese coatings have been recovered and provide the opportunity to study one of the inputs into the Tonga volcanic system.

Hydrocasts in the region during Leg SS07/2008 of R/V Southern Surveyor indicate the occurrence of thermal, pH and particulate anomalies suggestive of a serpentinizing hydrothermal plume that may support unexplored biological communities. The same hydrocasts, in the region of Niua, indicate multiple possible plume sources in this area, including a broad transmission anomaly from 1915-2500 m depth that may be related to activity at Niua itself. In summary, the proposed target area includes an enormous diversity of geological and biological activity, from exposed mantle sections and basaltic lavas to rhyolitic pumices and hydrothermal seeps. The capabilities of the Nautilus ROV will be used to uniquely map the relationships between these features, thereby greatly improving our understanding of subduction processes, volcanism, and the Earth's mantle.

Feasibility of Studying Target Area

The northern Tonga Trench (the region near 15S 174W) is located within 1 transit day of ports in Samoa (e.g., Apia), and 1-2 days transit from other nearby ports on Tonga and Fiji. The targeted lithologies, from young volcanoes to mantle peridotite, are all known to be within the 4 km depth range of ROV Hercules.

Educational and Outreach Potential of Target Area

Exploration of submarine volcanoes and serpentinizing peridotites that host active hydrothermal vents or cold seeps is a rare opportunity to document physical and biological processes ongoing in these inaccessible realms. Live footage of these processes is visually striking and among the most engaging submarine environments to encourage and promote public interest in the geosciences and oceanography. The mantle to-volcano sequence that we plan to explore provides a unique platform for education about the structure and composition of the Earth.

Beyond the unique and engaging "Nautilus Live" webcasts of ongoing science, our group is poised to interface with the very broad-reaching outreach and education mission of the Smithsonian Institution. The National Museum of Natural History (NMNH) offers unparalleled opportunities to engage public audiences in ocean exploration. Potential vehicles for public engagement include "Live from Q?rius" webcasts (customized to align with middle school Earth Science curricula) and exhibition of retrieved materials and multi-media footage in NMMH's new Sant Ocean Hall or new public outreach hall, Q?rius. Meet-the-scientist engagement events, public lectures, and online and social media experiences accessed through Smithsonian's popular "Ocean Portal" (http://ocean.si.edu/) or iTunes University series could all be leveraged. ROV footage of volcanic edifices and basalt sampling could be paired with interviews with members of the scientific team for live and archived broadcast online (e.g. the Ocean Portal's "Vents and Volcanoes" pages) or for in-house events. By taking advantage of these existing structures we have the potential to bring the Nautilus experience to tens of thousands of school children and members of the lay public (domestic and international).

Vailulu'u Seamount, Samoan Volcanic Chain

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Region

S Pacific Basin
Tonga/Kermadec Trenches
Samoan Islands

Rationale for Exploration

The Pacific Ocean hosts only a handful of submarine volcanoes that have been documented as active in the last decade. Although some of these have been monitored with seismic and deformation-based methods (e.g. Loihi, Axial Volcano), the active end of the Samoan hotspot chain, known as Vailulu'u Seamount (Fig. 1), has gone unchecked for nearly a decade, despite documented volcanic activity in 2005. Vailulu'u volcano was first mapped with side-scan sonar in 1999 and water column temperature and chemistry in the summit crater suggested active hydrothermal venting. A short seismic monitoring experiment in 2000 showed Vailulu'u to be actively deforming, and a return cruise in 2005 discovered a 300 meter volcanic dome (technically a pillow volcano) in the crater of Vailulu'u that was not present in the 1999-2001 expeditions (Fig. 2). Furthermore, NOAA personnel mapped the crater area in 2006 and implied further growth might have occurred. Therefore, the actual eruption occurred between expeditions from 2001 and 2005 and may be ongoing, and the growth rate inferred for this volcanic dome suggests that it would reach sea level in decades if the documented growth rate persisted. T he new volcanic dome in Vailulu'u crater was found to host hydrothermal

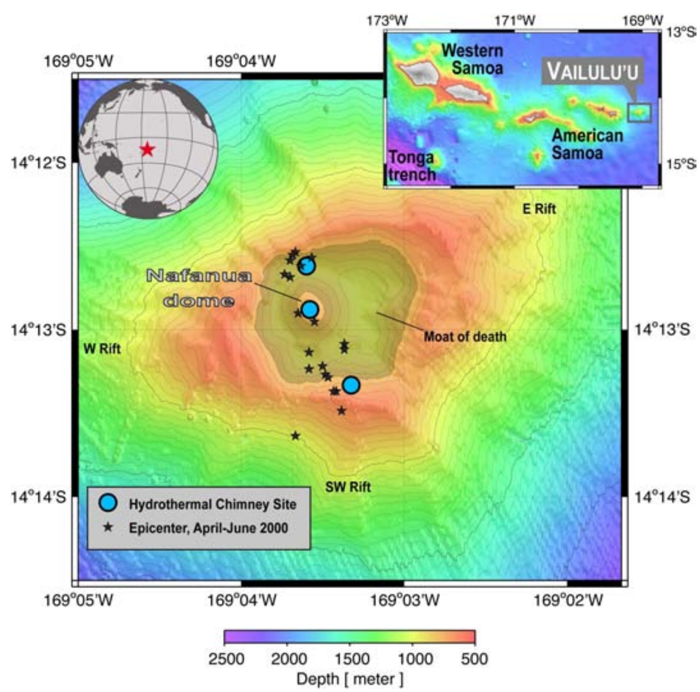

Fig.1. Bathymetric map of Vailulu'u crater and the recently constructed Nafanua dome. Map shows locations of hydrothermal centers that were previously detected and epicenter locations that were located with a small temporary monitoring experiment. Area in the crater around the dome was found to contain life forms affected by volcanic activity, and it is referred to as the moat of death. Sites where the rift zones emerge from the crater are indicated. Insets show location of the Samoan volcanic chain in the Pacific Ocean Basin, and the location of Vailulu'u within the Samoan volcanic chain.

fields that host surprising biological diversity that took hold in the year following the dome's eruption, suggesting rapid colonization of hydrothermally-active volcanic features. Similarly, the eruption's impact was also devastating to life elsewhere in Vailulu'u crater, where a large swath of the crater floor, termed the "moat of death", was littered with dead metazoans (Fig. 3). Unfortunately, since the discovery of the dome in 2005 (which was less than a year old at the time of discovery; Sims et al., 2008), there has not been a return expedition to the volcano, and thus this unique active volcano goes unmonitored (compared to ongoing efforts at dormant Loihi Seamount, for example). In the 9 years since the discovery of the newlyerupted Vailulu'u dome, significant biological colonization of the dome may have occurred, and a new ecosystem may be taking hold. Alternatively, renewed volcanism at the dome may have sterilized the crater and dome at Vailulu'u, starting the life-cycle anew. Such an active volcano forms the intersection of true interdisciplinary work, where asthenosphere, lithosphere, hydrosphere and biosphere meet: these volcanoes are constructed from lavas reflecting asthenospheric mantle through melt compositions, guided to the surface by stresses in the lithosphere, at its current depth transitioning to explosive eruptions due to the interaction with the hydrosphere, while creating habitats for life to evolve around hydrothermal vents. At the human scale, shallow submarine active volcanism can cause ships to sink and can generate a tsunami that would affect the American territory of American Samoa, Independent Samoa, and potentially Tonga, due to a large eruption or deformationgenerated flank collapse. Such hazards and evolving interactions make Vailulu'u Seamount a unique setting to explore. Exploration, in turn, will allow us to assess the eruptive hazard the volcano poses. We feel the focus of such exploration should be on 1) changes in volcano morphology, 2) continued hydrothermal activity, 3) new hydrothermal or lava effusion activity, and 4) further recovery or renewed disturbance of the ecosystem in the crater. In particular the suggestion from NOAA's mapping activities regarding potential ongoing growth of the dome, suggests a detailed multibeam mapping program is needed. Production of such a map may be accomplished with the EM multibeam system in about 1 day. Subsequently, ROV operations (7 dives) in the volcanically (proven and likely) active areas, will allow for study of a dome-shaped and growing pillow volcano. It will also help discover changes in hydrothermal activity (at existing sites, and identifying new sites), and help establish whether aspects of the ecosystem such as the moat of death and for example early colonizing eels at Nafanua summit are ephemeral features. Lastly, ROV operations will allow for direct sampling of any new volcanic deposits.

Brief Overview of Target Area

Vailulu'u Seamount is located just 45 km east of Ta'u Island, the easternmost Samoan island, at 14°13'S, 169°04'W (Fig. 1). This submarine volcano rises about 4800 m from the seafloor to a water depth of about 600 m along its crater rim (Hart et al., 2000). Thefore, Vailulu'u is a sizeable volcano that reaches shallow enough waters for phreatomagmatic, explosive activity. Based on samples collected in 2005, uranium-series geochronology suggests that it was last active in November 2004 (Sims et al., 2008). T he volcano's morphology is defined by a 2-km-wide, 300 meter-deep crater. It has an east-west elongated shape due to the two primary rift zones that buttress the volcano. Vailulu'u Seamount anchors the eastern active end of the Samoan hotspot

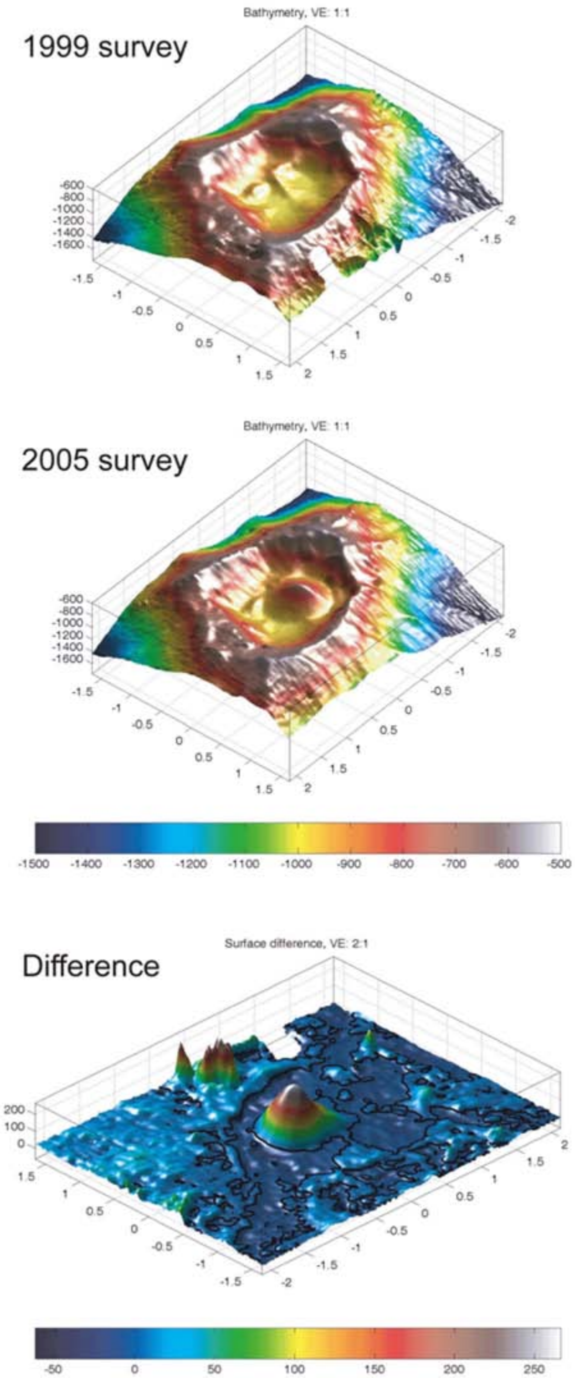

Fig.2. Three dimensional comparison of the bathymetry of Vailulu'u crater before and after the construction of Nafanua dome. Data were collected with two different multibeam systems, but both processed with MB-System, and gridded at the same grid spacing. Bottom figure shows the difference between the two surveys, emphasizing the construction of the dome, and its nearly 300m height. The difference plot also shows some smaller peaks on the rim of the crater that are yet to be explored.

chain of volcanoes. T his chain is unique in its setting, and is located just over 100 km north of the northern terminus of the Tonga Trench, where the north-south oriented trench meets an east-west oriented transform plate boundary. T he proximity to this plate boundary has been suggested to contribute to the volcanism along the Samoan islands (Hart et al., 2004; Konter and Jackson, 2012).

Feasibility of Studying Target Area

We anticipate dramatic changes in the ecosystem developing on Nafanua, which has either diversified since colonization following the extrusion of the volcanic cone, or sterilization due to volcanic activity since 2005. This project would entail about a day of mapping with the multibeam system, followed by several ROV dives. The E/V Nautilus and ROV Hercules are ideally suited for this mission of discovery. The summit, crater floor and volcanic dome are all shallower than 1000 mbsl, and well within the capabilities of Hercules. T he manipulator arms on the ROV are ideal for sampling fresh volcanic material for geochemical analysis, and water sampling capability and sensors aboard the ROV will permit detailed analysis of hydrothermal vents. Bathymetry data is already available from a decade ago, and augmented with new data, this should provide excellent base maps for the dives. In general, ROV dives would focus on an area along the original epicenter locations of the earthquakes, subsequently extended with exploration of the east and west rift zones. The real unknown in this project is what changes have taken place on the volcano since it was last visited. American Samoa has an international airport and a deep water port (Pago Pago), located ~95 nm west of Vailulu'u. T he port affords opportunities for on-loading and off-loading as well as resupply.

Educational and Outreach Potential of Target Area

We anticipate that discovery of evolving ecosystems and renewed volcanic activity on Vailulu'u will generate intense public interest. These types of discoveries by our team have previously generated significant interest from the general public, and they have resulted in featured topics in National Geographic and on Discovery Channel. In addition, some of our work on various Pacific Islands made on-site national newspapers. In addition to general outreach, we have had contact with local schools in Samoa on previous research expeditions, including guest lecturing and tours of the research vessel used. We would exploit our contacts to generate local involvement in the research project. As an example, the name Vailulu'u resulted from a local "competition" we were involved in to replace the original "working names", and was suggested by a local Samoan student. We also anticipate interest in this project in Hawaii, given the significant Samoan population in Hawaii, and we would work on bringing the project to some of the class rooms in Hawaii. We envision this for the K-12 level, consisting of visits prior to the ROV dives, live streaming of the ROV dives, all followed by a question-and-answer session with the students

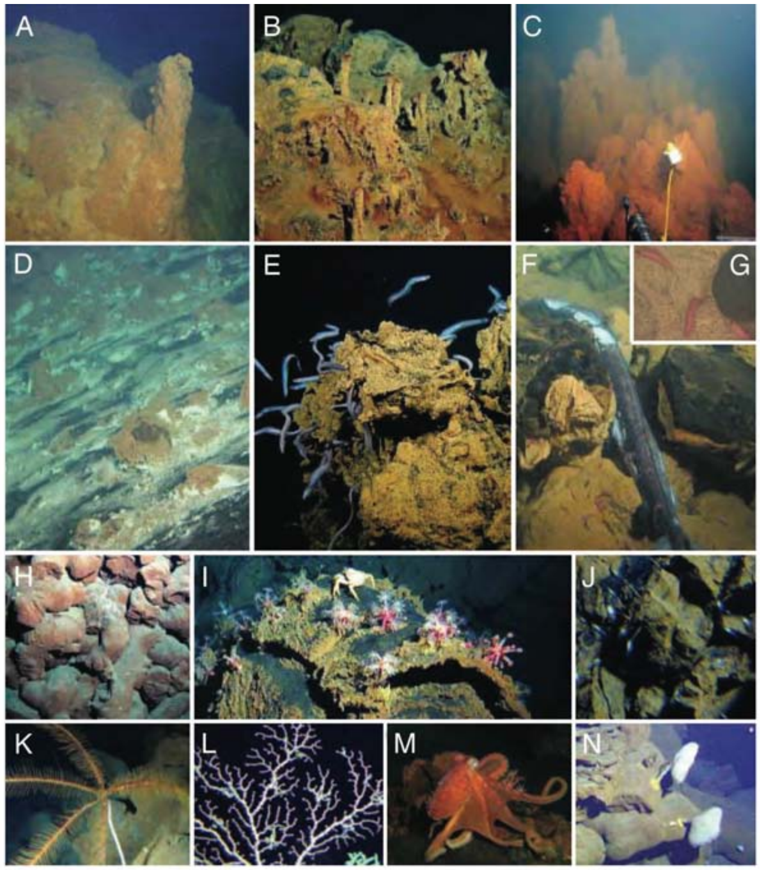

Fig. 3. Photos from Pisces V (Staudigel et al., 2006). (A) Rock pillar on Nafanua Summit (1-m diameter; 700-m water depth) coated with microbial mats. (B) Pencil-sized Fe chimneys from low-temperature hydrothermal vent west of Lefa Summit (760 m). (C) Meter-sized Fe oxide chimneys of the South Wall Hydrothermal Complex (SWHC; 720 m). (D) NMHC vent field (940 m). (E) Eels (≈30 cm and smaller; Dysommina rugosa) swarming near Nafanua Summit (710 m). (F and G) Polychaetes of unknown genus and species in the family Polynoidae, feeding near a meter-sized fish (930 m). (H) Pillow lavas from the western rift. (I) Octocorals, Anthomastus sp., and an unidentified crab on Lefa Summit (580 m). Carapace width on the crab is ≈10 cm. (J) An abundant demosponge, Abyssocladia brunei , on the inside of the crater, downslope from the SW breach (745 m). The sponges are ≈1 cm in diameter and stand on stalks ≈2 cm long. (K) Large isocrinid crinoid, unidentified, from the western rift. (L) Euryalid ophiuroids on a gorgonian from the western rift (1,670 m). (M) Unidentified octopus from Lefa summit (580 m). The diameter is ≈1m, arm tip to arm tip. (N) Large, unidentified hexactinellid sponges, ≈20 cm in diameter, from the western rift (1,650 m).

Active Volcanic Calderas of the Northern Lau Basin

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Region

Tonga/Kermadec Trenches

Rationale for Exploration

The northern Lau Basin is host to a wide variety of submarine volcanic activity, presumably driven by the subduction of the Pacific Plate beneath the Australian Plate along the Tonga-Kermadec Arc. These volcanic centers include the volcanoes of the Tofua Arc, several back-arc spreading centers, and a series of "rear-arc" volcanoes interspersed between the back-arc and the arc proper. Several expeditions to the region have identified several sites of activity, including 2 cases of submarine eruptive activity, and several sites of submarine hydrothermal venting. Among the various volcanic centers are 4 which have clearly-defined volcanic calderas or collapse features, one in the NE Lau Basin, and 3 farther west along the NW Lau Back-arc Spreading system. The Supplementary Attachments show an overview map of the area as well as detailed maps of the 4 calderas of interest. Exploratory work to date has shown that all 4 of these calderas host active hydrothermal venting. However, to date these 4 sites have been explored mainly by water column plume surveys rather than seafloor sampling with manned or un-manned submersibles. Because these calderas represent well-defined localities, extensive mapping or water column plume surveys would not be required in order to locate the sites of hydrothermal venting. Thus these calderas are excellent targets for further seafloor exploration with submersibles .

Brief Overview of Target Area

The northern Lau Basin is bounded on the east and north by the Tonga-Kermadec trench and subduction zone, and on the west by the north Fiji Basin. The rapid subduction of the Pacific Plate under the Australian Plate has resulted in the generation of a string of volcanoes along the Tofua Arc, and also several back-arc spreading centers, which are analogous to mid-ocean ridge spreading centers. From east to west these back-arc centers are the NE Lau Spreading Center (in the northeast), the NW Lau Back-arc spreading center, and the Futuna Spreading Center. The NW Lau back-arc system in turn consists of two different segments, the NW Lau Spreading Center (NWLSC) to the south, and the more complex Rochambeau Rifts (RR) to the north. The NWSC and RR are of particular interest because He, Sr, Nd, and Pb isotopic measurements in the seafloor volcanic rocks indicate an influence from the Samoan hotspot, which has presumably intruded into the northern Lau Basin through a tear in the subducting Pacific Plate. This hotspot influence is unique to the NW Lau system and is not evident in the NE Lau Basin, where the isotopes show a more normal mid-ocean ridge affinity. At their northern end, all three of these back-arc spreading centers dive into deep Tonga Trench, which wraps around the northern Lau Basin and bounds the basin on the north.

The four volcanic calderas of interest consist of Niuatahi in the NE Lau Basin, Southern Caldera and Central Caldera on the NWLSC, and Lobster Caldera on the Rochambeau Rifts. Niuatahi, formerly called Volcano O, is a large volcanic caldera located in the NE Lau Basin at 15.3°S, 174.0°W midway between the Tofua Arc and the NELSC. The caldera is almost perfectly circular and about 8 km in diameter with a flat floor averaging 1400 m depth below the sea surface punctuated by a central cone. The other three calderas of interest are situated on the NWLSC-Rochambeau Rifts spreading system. The NWLSC is a well-defined sinuous ridge extending from about 15.5°S down to 16.3°S where it intersects a long transform fault called the Peggy Ridge. The NWLSC has two caldera collapse features situated on the ridge axis: Southern Caldera at 15.9°S, 177.4°W and Central Caldera at 15.7°S, 177.3°W. Both Southern Caldera and Central Caldera are oblong in shape with the long axis trending SW-NE in alignment with the ridge spreading axis. They have dimensions of about 3 km x 6 km and 5 km x 14 km, respectively, and the caldera floors each lie at about 2100 m depth. In contrast to the NWLSC which has a fairly simple mid-ocean ridge type structure, the Rochambeau Rifts consist of a complex suite of pull apart basins and volcanic centers distributed over a wide area. With the Rochambeau Rifts it is difficult to define the exact center of crustal extension. Lobster Caldera, located at 15.3°S, 176.3°W in the southern part of the Rochambeau Rifts. Lobster is a large volcanic edifice measuring 4 km x 15 km with four rift zones extending away from the summit. At the summit at 1500 m depth is a circular caldera collapse feature about 3 km in diameter. The caldera is breached on the east side but has a steep 100 m high wall on the west.

Brief Summary of What is Known of Target Area

The bathymetric structure of all four of these volcanic calderas has been mapped in detail with high resolution multibeam. The water-column plumes over these four calderas have also been studied with CTD casts and discrete bottle sampling. These studies detected anomalous suspended particle concentrations, helium isotopes and dissolved metals, in each case providing evidence for local hydrothermal input within the caldera walls. Niuatahi (Volcano O) had a strong hydrothermal plume above the caldera when it was first investigated in 2004, and the plume was still present during return visits in 2008, 2010, and 2012. In 2013 a single dive with a remotely-operated-vehicle (ROV) found and sampled 105°C hydrothermal fluid at the summit of the central cone of Niuatahi. There are also active sulfide sites near the southern and northern walls located by Nautilus Minerals Inc. during a submersible dive in 2008, although no water samples were collected and these results are proprietary. No other scientific submersible exploration of this extensive caldera has been completed, and water column studies indicate the presence of other sites of hydrothermal discharge around the caldera perimeter.

The water column plumes over Southern Caldera, Central Caldera, and Lobster Caldera along the NW Lau Back-arc system have been studied with CTD casts during the 2008 voyage of the Australian ship Southern Surveyor. A single cast into Southern Caldera found a low lying plume characterized by excess suspended particles, 3He, and dissolved Mn apparently trapped within the 150 m high caldera walls. This suggests the existence of low temperature venting within Southern Caldera. A suite of 4 CTD casts into Central Caldera in 2008 found even higher concentrations of suspended particles, 3He, and dissolved Mn occupying the bottom 500 m of the water column. The higher rise height of these plumes indicates the existence of high temperature black-smoker-type vents within Central Caldera. Finally, 2 CTD casts lowered into the Lobster Caldera (also in 2008) again found high concentrations of these hydrothermal tracers. In this case the plume appeared to be trapped within the 100 m high caldera walls. Blue Water Metals Ltd. conducted a submersible dive into Lobster Caldera in 2010 although no water samples were collected and these results are proprietary.

The 3 calderas on the NW Lau Back-arc system (Southern Caldera, Central Caldera, and Lobster Caldera) are of particular interest because NWLSC – Rochambeau Rifts spreading zone has evidence of influence from a hotspot in the erupted volcanic rocks. Specifically, the rocks contain elevated 3He/4He ratios distinctly higher than the values normally found along mid-ocean ridges. This has been attributed to intrusion of the Samoan hotspot signal into the northern Lau basin through a tear in the downgoing Pacific Plate. Water column plume studies have also confirmed that these elevated helium isotope ratios are also found in the hydrothermal fluids being vented at all 3 of these calderas. This hotspot influence suggests that the hydrothermal systems along the NW Lau Back-arc might have much different chemical characteristics compared to normal back-arc or mid-ocean ridge spreading centers.

Feasibility of Studying Target Area

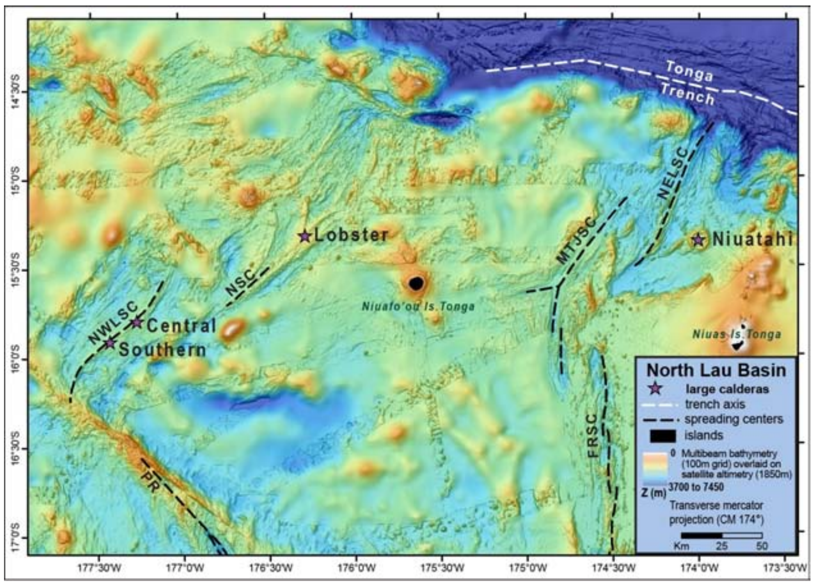
The area is about 1 day's transit from the ports of Apia and Pago Pago in Samoa, and about 2 day's transit from the ports of Nuku'alofa, Tonga, and Suva, Fiji. All four of the calderas of interest lie within the EEZ of the Kingdom of Tonga. In the past the Kingdom of Tonga has been very cooperative in terms of allowing research within their EEZ.

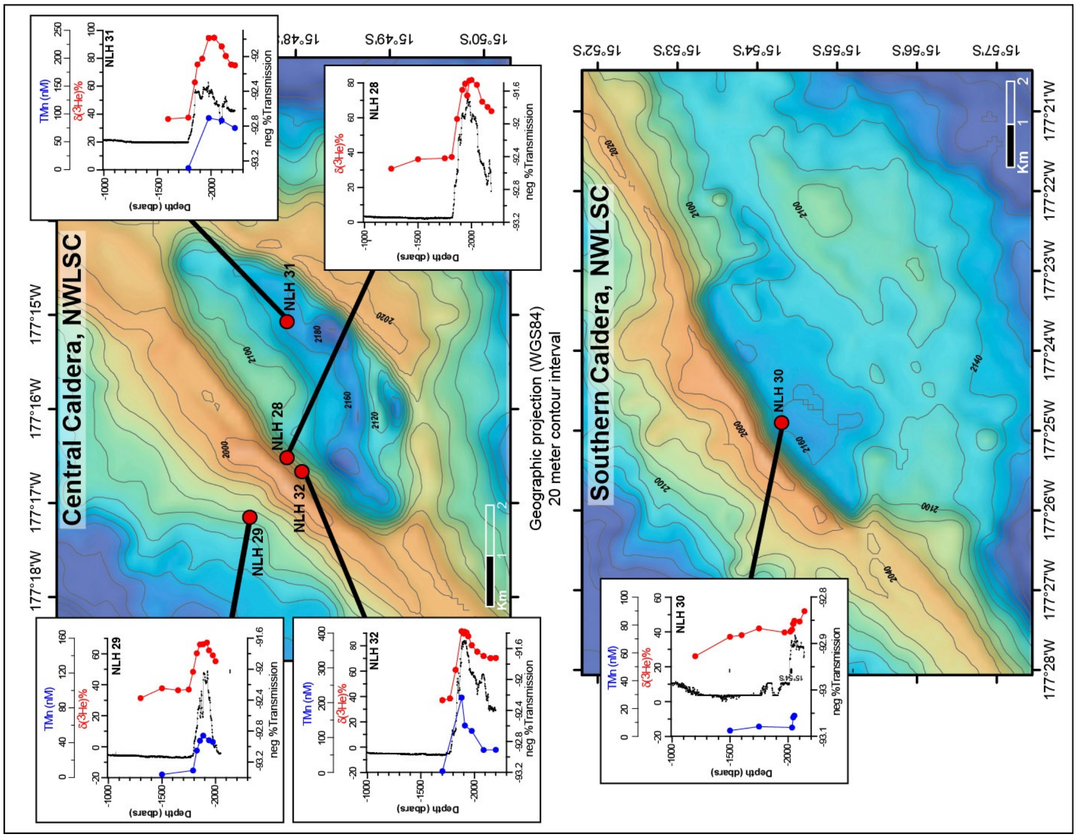
As mentioned above, we have detailed bathymetric maps for all 4 of these volcanic calderas from high resolution multibeam surveys. The water column plume surveys have confirmed that all 4 calderas have hydrothermal activity located somewhere within the caldera walls. Thus these calderas represent well-defined and relatively small target areas for subsequent submersible surveys which would seek to find and directly sample seafloor hydrothermal vents.

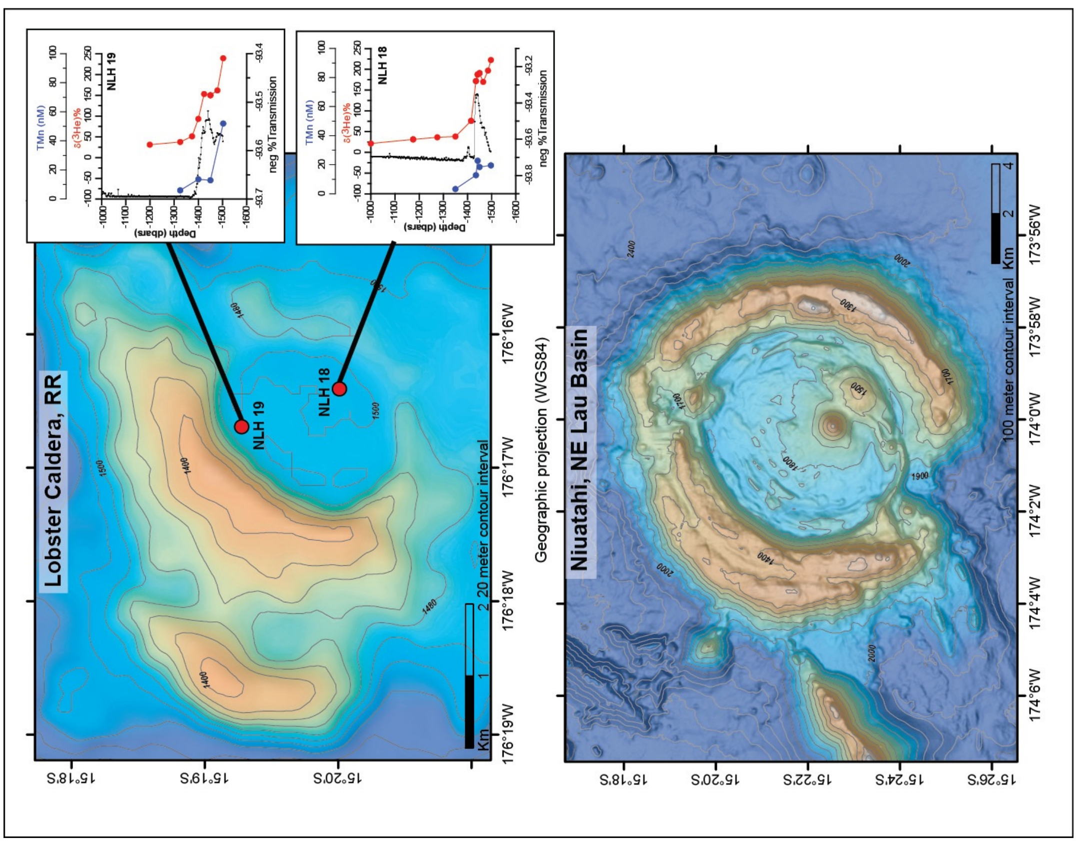
Educational and Outreach Potential of Target Area

The outreach potential for these sites is excellent. The calderas along the NW Lau Back-arc system may have unusual hydrothermal systems due to the hotspot influence

present there. Depending on the connectivity available from the surface ships, the seafloor exploration of these sites with unmanned submersibles could be made available in real time to shorebased audiences. Video clips from manned submersible dives could be shared with shorebased Niuatahi (Volcano O) and Lobster Caldera have both been explored by ocean mineral companies for polymetallic sulfide deposits. It will be important for the public to have knowledge of the chemistry and biology of these sites before mining activities are undertaken.
audiences on a daily basis.




Central Caldera, NWLSC
Southern Caldera, NWLSC
NLH 28
NLH 29
NLH 30
NLH 31
NLH 32
Geographic projection (WGS84)
20 meter contour interval
TMn (nM)
δ(3He)%
neg %Transmission
Depth (dbars)
Km


Lobster Caldera, RR
Niuatahi, NE Lau Basin
NLH 18
NLH 19
Geographic projection (WGS84)
20 meter contour interval
100 meter contour interval
TMn (nM)
δ(3He)%
neg %Transmission
Depth (dbars)
Km

Samoan Clipper (NC16734)

Russ Matthews (TIGHAR)

Collaborators

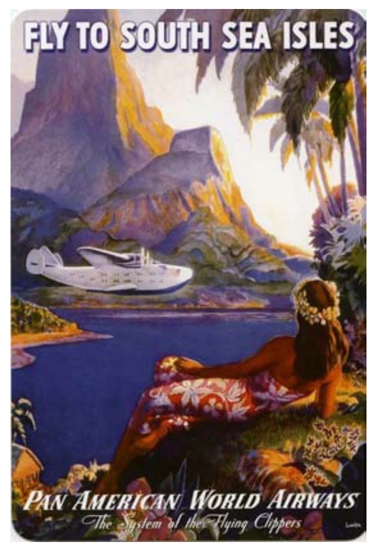
James Delgado (NOAA ONMS Maritime Heritage Program)
Lonnie Schorer (TIGHAR)

Region

Tonga/Kermadec Trenches

Rationale for Exploration

The rationale for exploration in the proposed target area is to locate, identify, and document wreckage of the long lost Pan American Airways plane Samoan Clipper (NC16734) .. and by so doing, determine the last resting place of aviation pioneer Captain Edwin C Musick along with his 6 man crew and collect conclusive evidence as to what lead to their fate. Throughout the 1920s and 30s, Pan Am was at the forefront of an audacious effort to establish aerial links between the United States and the rest of the globe that would ultimately help to define the modern air transport industry. The most challenging and highly romanticized routes were those that stretched across the vast Pacific Ocean and the flying "Clippers" that plied them came to symbolize Aviation's "Golden Age".



Samoan Clipper began life at the Sikorsky Aircraft factory in Bridgeport, Connecticut as the seventh of ten S-42 type flying boats, designed to carry up to 32 passengers over thousands of miles in luxury and sold exclusively to Pan American Airways. Serial number 4207 (as it was then known) would be the first of three S-42 aircraft modified as a "B" model, given added fuel capacity and expanded crew facilities to make special long range survey flights and open yet more new pathways. After delivery in 1936, she was designated with the federal registration (or "tail number") NC16734 and the next year assigned a new task to inaugurate service between Honolulu, Hawaii and Auckland, New Zealand by way of Kingman Reef and Pago Pago, American Samoa. She was also given a new name, Samoan Clipper , appropriate to the region and a new skipper commensurate to the daunting job at hand, Pan Am's legendary Chief Pilot, Edwin C. Musick. Musick had been with Pan American from practically the very beginnings of the airline and was the flier who pioneered most all of its ever expanding routes to the Caribbean, South America and the Pacific. At one time he held more flying records and honors than anyone else in the air, including the 1935 Harmon Trophy which recognized him as "the world's outstanding aviator," a prize previously accorded to only two other Americans (Charles Lindbergh and Wiley Post). Thoroughly professional and scrupulously careful with the people and planes under his care, "Uncle Ed" earned the everlasting respect of his peers as the ideal model of a transport pilot. By January, 1938 Musick and his crew had completed their trailblazing survey from Hawaii to New Zealand and back .. then set out once more on the inaugural commercial Air Mail run to Auckland. At 05:32 on the morning of the 11th, the Samoan Clipper took off from Pago Pago harbor with Musick at the controls for the final, fateful leg of her journey. An hour into the flight, "NC34" (as the Pan Am radio operators would note it) reported an oil leak in the Number 4 engine. Musick elected to shut down the balky motor and return to American Samoa. At 07:59 the plane was sighted 75 miles away over Apia and headed in the direction of Pago Pago. Another radio contact was received starting at 08:27 informing the Pan Am station that Musick was dumping fuel to lighten his now underpowered and still heavily laden ship before attempting to land in the severely restricted waters of Pago Pago harbor just a few miles ahead. After 08:35 all contact was lost with the Samoan Clipper and her crew.

Brief Overview of Target Area

Within hours, reports reached Pago Pago that "native fishermen" had spotted smoke off the NW coast of the island (Tutuila, American Samoa). A US Navy plane was dispatched to search the area and quickly sighted an oil slick that "appeared to be coming from [the] ocean floor." The minesweeper/seaplane tender USS Avocet (AVP-4) sailed from Pago Pago and was vectored to the scene some 12 miles north of the western tip of Tutuila. Shortly after first light on 12 January, her crew spotted the oil slick and followed it until discovering small fragments of debris floating on the surface. A small boat was launched to collect what they could. The recovered items were comprised mainly of small, charred pieces of "flooring, partitioning, books, papers, interior wall parts and the navigator's drift target tray." Most telling and heartbreaking of all was a tattered Pan American Airways officer's jacket with its distinctive winged "PAA" logo identified as belonging to the Samoan Clipper's radio officer J.T. Findlay. The position of these finds was recorded and preserved in a Bureau of Air Commerce accident report (dated 1 April 1938) that concluded the loss of the Samoan Clipper was probably due to "fire and explosion associated with the dumping of fuel, the precise cause of ignition being undeterminable." Speculation focused on a static charge, engine exhaust or a spark from the electrically driven flap actuators as they were engaged prior to landing, but without an opportunity to closely examine the main body of wreckage, the exact reason for the destruction of NC16734 was reluctantly left a mystery. In the days following the accident, inquiries were made with an eye toward recovering the plane and the bodies of her crew. Divers were considered as well as an idea to drag for the wreckage from a US Navy cruiser in the area or perhaps hiring a cable laying/repair vessel for the task. However, soundings taken by USS Avocet showed water depth at the wreck site to be 1,000 fathoms, placing Samoan Clipper far beyond the reach of any technology available at that time.

Brief Summary of What is Known of Target Area

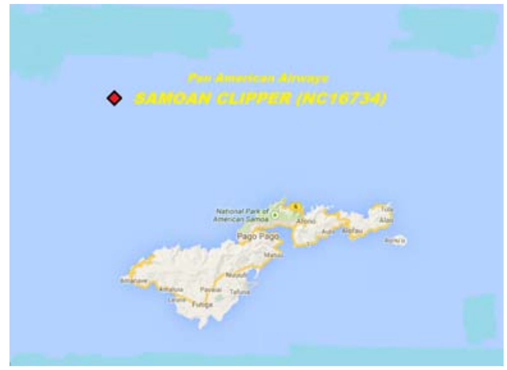
Unfortunately little is known for sure about the geophysical characteristics of the target area, aside from the 6,000 foot depth measurement recorded in 1938. Tutuila and the islands of the Samoan group, like main others throughout the Pacific, are the result of ancient volcanic activity. The wreck of Samoan Clipper , several miles offshore, likely rests on the approach slopes of the submerged mountainside, but precisely how gentle or rough the terrain is in the primary target area has yet to be determined. Some clues to the potential condition of the lost plane can be found again in the BAC report filed less than three months after the accident. Investigators analyzed the evidence collected at the scene by Avocet and realized nearly all of the items came from the Clipper 's navigation compartment, located immediately forward of the fuselage-mounted auxiliary fuel tanks where the explosion almost certainly occurred. Furthermore, the small size and relative scarcity of debris, coupled with one eyewitness account, suggested to them that the plane had gone into the water at low speed and low altitude, as if Musick had detected the fire and "started and at least almost completed" an emergency landing of his stricken craft.

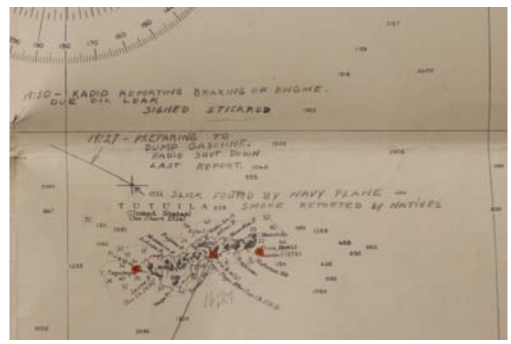
The investigators went on to state that it is possible the general wreckage "being mostly metal, held together sufficiently to sink completely." It is therefore reasonable to imagine that the remains of the Samoan Clipper comprise a relatively tight concentration of substantial and recognizable aircraft components. The great depth at the site should have shielded it from natural forces such as wave or storm action and the lack of light ought to have inhibited the growth of coral or other marine organisms from adversely affecting the historic structure. Similarly, it is unlikely to have suffered from human interaction, inadvertent or otherwise, such as commercial fishing or salvage attempts, etc. Today the Samoan Clipper probably lays undisturbed where she fell more than 76 years ago.

Feasibility of Studying Target Area

Very high. The target area was quickly and conclusively identified within mere hours of Samoan Clipper 's loss. And while 6,000 feet of ocean utterly frustrated efforts to find the sunken airliner at the time, it is well within the capabilities of assets that may be deployed in the region next year. The location is within an easy half day's steam from the American port of Pago Pago, which would make an excellent home base for a Samoan Clipper survey effort, allowing for replenishment/refueling of the research vessel and even swapping out of personnel and equipment. It is also a Convenient waypoint for any other operations planned for that remote area of the Pacific.

Initial bathymetric data, establishing the underwater "lay of the land" could be collected with a depth sounder/AUV which might also be employed to characterize the surrounding region in relation to the recently (2012) expanded American Samoa National Marine Sanctuary, now the largest such preserve in the US system. Close follow on examination of the area utilizing towed side scan sonar would seem the logical next step to identify potential anomalies of interest. According to the witness cited by BAC investigators in their accident report, the wings of the airplane remained intact following the crash as they "appeared to be visible for an appreciable interval before sinking from sight." The wing of the Sikorsky S-42 was immensely strong, described in a company specification booklet as being "made up completely in one piece" with "two spar stressed skin construction." Fully intact, as the evidence appears to indicate, it would measure 118 feet long and 13 feet wide. Such a large all metal structure, along with the four half-ton Pratt & Whitney radial engines arrayed along its leading edge, should make for a very good potential sonar target. A camera-equipped ROV could be sent down to check out the most promising leads in real-time. If aircraft wreckage is discovered, there are a wide variety of distinguishing markings known to have adorned Samoan Clipper (name, registration number, PAA livery, etc) with which to make a positive identification. As a comparison, the remains of the Marshall Mars , a large US Navy flying boat that burned and sank off Oahu after WWII, was discovered in 1,400 of water by the Hawaii Undersea Research Lab (HURL) in 2004 with the paint of its name and insignia still legible. However, even in the absence of an answer literally "spelled out" for the explorers, they should still be able to definitively recognize Samoan Clipper by locating one of the many structural features unique to the Sikorsky S-42 as no other planes of this type were lost in the region.





Finally, given Ed Musick's stature among aviation pioneers and the romance associated with the Pan American "clippers" (very few traces of which survive at present above the surface), a project like the one outlined above would seem to stand a good chance of garnering significant widespread support among individuals and corporations in the aerospace and air transport community.

Educational and Outreach Potential of Target Area

Extremely high. The story of the Samoan Clipper is one of exploration, tragedy and the wonder of flight with a distinctly human dimension. It can engage and educate all ages, the science, technology, engineering and math behind how this special plane was built, flown, lost, and perhaps found again. What's more, the public, and by extension the media, loves a mystery and craves to see it solved. To prove this point, one need look no further than last March when it seemed the entire world was transfixed by the sad fate of Malaysian Airlines flight MH370 which disappeared somewhere over the Pacific. Even now people await news of the latest progress from the still ongoing search and families of the lost wait for the closure that can only come from finding the resting place of their loved ones. Much the same was true 76 years ago for the Samoan Clipper and her crew. However, in this case, the time may finally have arrived when the old resolve and evidence can be combined with new technologies undreamt of in 1938 .. and just maybe yield the long sought answers.

Survey of the South Pacific Gyre

Tim O'Hara (Museum Victoria, Australia)

Region

East Pacific Rise
SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise
W Central Pacific/Line Islands
S Pacific Basin

Rationale for Exploration

For the past 2 years I have lead a working group of the INDEEP network of Deep Sea scientists dedicated to constructing a global biogeography of seafloor fauna. This project compiled distributional material for several major marine invertebrate groups through validating online datasets, identifying selected survey material in various museums and institutes, and digitising scientific literature. A map of the sample sites is given as an attachment to this proposal. We are currently analysing this data with the view to producing global maps of assemblage structure, species richness and beta-diversity for selected groups of seafloor fauna. This exercise usefully databased survey effort for the worlds oceans. T his identified the bathyal/abyssal areas along the mid-oceanic ridges and subtropical gyres as being among the most poorly surveyed areas of the oceans. Consequently, we are interested in any proposals to visit these unexplored regions. We are primarily interested in specimen collections, as we don't yet understand the deepsea fauna enough to be able to identify species from images, and we require specimens to assess connectivity and evolutionary patterns in the deep-sea.

Brief Overview of Target Area

We would be happy to collaborate with any proposals to survey bathyal (200-3500m) and abyssal (3500-6500 m) zones in the southern Pacific Ocean, particularly in the South Pacific gyre and the SE Pacific Ocean. Seamounts south of Hawaii are also of interest as these will be targeted by mining companies seeking to exploit the mineral resources.

Brief Summary of What is Known of Target Area

See above and attached map.

Feasibility of Studying Target Area

Remote surveys will be technically complex, however, the INDEEP community have appropriate collection gear that could be used for such a survey.

Educational and Outreach Potential of Target Area

People engage readily in deep-sea exploration, discovery of new species and large-scale biological patterns. Any proposal would include a full time outreach coordinator to document the progress.

Palmyra Atoll and Kingman Reef

Emil Petruncio (U.S. Naval Academy)

Collaborators

Jennifer Caselle (UC Santa Barbara)
Rob Dunbar (Stanford University)
Kevin Lafferty (USGS and UC Santa Barbara)
Laurie Moore (The Nature Conservancy)

Region

W Central Pacific/Line Islands

Rationale for Exploration

Palmyra Atoll is a remote and pristine National Wildlife Refuge, rich in biodiversity. The shallow reefs and the lagoon have been well explored, but very little is known about the deeper habitats. The flanks of the atoll are steep and rugged, dropping off rapidly to depths of 3000m over a horizontal distance of 10 km, and numerous seamounts are situated within 30 km of the north, west, and southern shores. Vast areas to the northeast and southwest of Palmyra Atoll remain to be mapped, including two potential seamounts (based on analysis of satellite altimetry data) within 50 nm of the Atoll. There are oral history reports of WWII aircraft wrecks in the area, but none have been located to date. The potential to gain new knowledge about deepwater ecosystems and energy exchange between deep and shallow water habitats, map and image interesting geological formations, and discover wrecks of historical interest make Palmyra Atoll an ideal target for telepresence-enabled exploration. Nearby Kingman Reef (61 km / 33 nm to the north) is another exceptionally attractive target for ocean exploration. In a report of the 2005 and 2007 National Geographic Pristine Seas expeditions, Kingman Reef is described as “an ecosystem that has survived in an almost pure state of nature”.

Brief Overview of Target Area

Palmyra is located at 5°52′N 162°6′W, approximately 1700 km (918 nm) southwest of Hawaii, 61 km (33 nm) southeast of Kingman Reef, 652 km (352 nm) north of the Equator, in the center of the Line Island chain. Palmyra’s administrative status is unique in that it is owned by a private organization, The Nature Conservancy, and the U.S. Fish and Wildlife Service, but administered by the Office of Insular Affairs, DOI. It is the only remaining uninhabited atoll in the northern Line Islands chain. Palmyra Atoll has the largest land mass of the six islands of the central U.S. Pacific Remote Island Area. It is comprised of 2.75 km2 of emergent land and 63 km2 of submerged reefs and aquamarine lagoons. The Nature Conservancy purchased most of the land area from private owners in 2000. In January of 2001, the USFWS extended further protection to Palmyra when it designated 450 acres of land and 480,647 acres of lagoons, coral reefs and submerged lands and waters as a National Wildlife Refuge. In 2004, a group of universities and the USGS formed the Palmyra Atoll Research Consortium in collaboration with The Nature Conservancy. They funded and constructed a small research station in 2005. In 2009, Palmyra was included in the establishment of the Pacific Remote Islands Marine National Monument. The boundaries of the monument extend 50 nm from the mean low water line of the atoll. The Proclamation prohibits commercial fishing within the monument, but gives the Secretary of Commerce, through the National Oceanic and Atmospheric Administration, primary responsibility for managing fishery-related activities from 12 to 50 nautical miles from the islands.

Brief Summary of What is Known of Target Area

Palmyra is a relatively large atoll with extensive reef and 54 islets and bars. The atoll encompasses 12 sq km with two shallow interior lagoons. In 2006, the Pacific Islands Benthic Habitat Mapping Center completed multibeam bathymetric maps of the island (Figure 1 in the supplementary uploads) that reveal steep flanks on all sides outside of the lagoon and a small secondary rise to ~1000 m depth approximately 11 km (6 nm) to the west of the atoll. Because it has never been densely inhabited other than a brief U.S. military presence during WWII, Palmyra Atoll has experienced virtually no sustained fishing or extractive pressure and as such, has a relatively intact marine food web (DeMartini et al., 2008, Sandin et al., 2008, Stevenson et al., 2007,). The shallow, SCUBA-accessible reefs are well studied, but little is known about the deep reef environment (below 30 m), aside from data gathered by Stanford University using the Hawaii Undersea Research Lab's submersibles Pisces IV and Pisces V in 2005 (Houlbrèque et al., 2010, Guilderson et al., 2013, and HURL 2005 Cruise Report) and a recent study in collaboration with National Geographic using deepwater drop cameras. The submersible dives reveal the existence of vertical walls extending from about 250 meters to over 600 meters along Palmyra's western, northern, and eastern margins. 3 Large (100's of meters) caverns in these walls mean that significant areas of Palmyra's forereef and reef crest are undercut. Large pinnacles reminiscent of karst terrains on land are also common. These environments support a unique and abundant community of deep sea corals. In 2005, grey reef sharks were observed diving from shallow waters to feed on slow-moving chimaera fish in very cold waters at ~600 meters, suggesting the possibility of an interesting mechanism of returning biomass (and energy) from the deep sea to the photic zone. Unlike neighboring inhabited islands in which overfishing has largely removed top predators from the system, but similar to nearby Kingman Reef, the fish biomass of Palmyra is dominated by apex predators (Sandin et al., 2008; DeMartini et al., 2008; Friedlander et al., 2010). This apex predator community consists largely of sharks and snappers, and these species comprise up to 85% of the biomass of large predatory fishes on Palmyra's forereefs (Stevenson et al, 2007, Sandin et al., 2008; Papastamatiou et al., 2009 a, b, in review; McCauley et al., 2012). Palmyra reefs are also home to a large number of threatened or rare species including manta rays, green and hawksbill sea turtles, humphead wrasse, and bumphead parrotfishes (Sterling et al., 2013; Papastamatiou et al. 2012). Finally, with over 180 coral species identified to date, Palmyra Atoll's reefs support five times as many coral species as the Florida Keys and three times as many as Hawaii and the Caribbean (Williams et al., 2008). According to the Naval Oceanographic Office, satellite altimetry data indicates the presence of two gravity anomalies within 50 nm of Palmyra Atoll that may be seamounts, but have not been mapped by sonar:
Location 1: 5° 57' N, 162° 00' W
Location 2: 6° 24' N, 162° 34' W

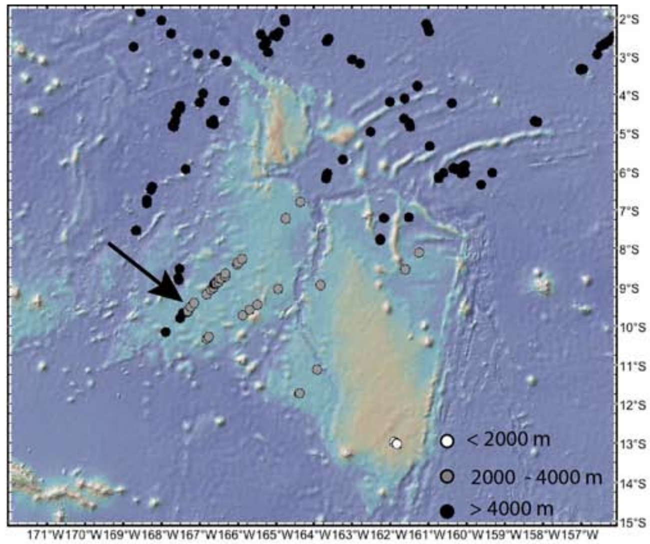
Multibeam mapping of these locations could contribute to improved safety of navigation.

Feasibility of Studying Target Area

Of the few remaining pristine coral reefs in the world, Palmyra Atoll is perhaps the only one that allows for regular access for scientific study. The Nature Conservancy established a scientific research station at Palmyra in 2005 with accommodations for up to 25 researchers at a time. It maintains an air strip which can accommodate small jets and C-130s for travel from Hawaii. The sea conditions are generally good, allowing regular access to locations surrounding the atoll. In addition, Palmyra has a deepwater lagoon with a dredged channel that allows access to flat water for large vessels, making exploration safe and efficient. Despite the presence of the field station, limitations on boating and diving have largely restricted scientific study to relatively shallow forereef and backreef sites.

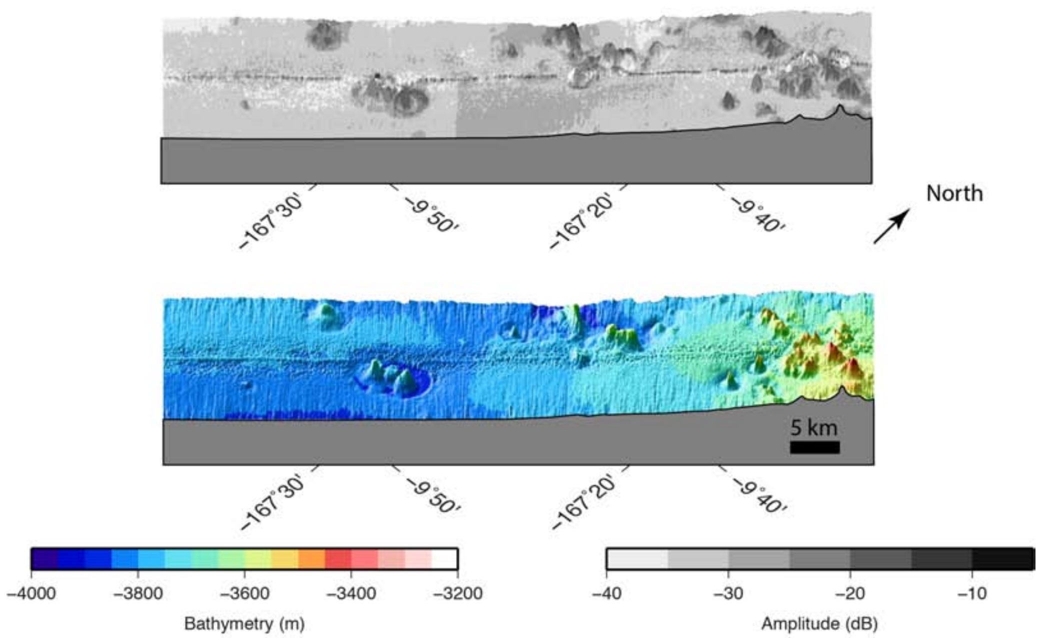
Educational and Outreach Potential of Target Area

Exploration of the flanks of the atoll would yield striking images of steep ridges and canyons, carbonate pillars, and deep water coral communities. A recent pilot study recorded the presence of at least 5 species of deepwater sharks not previously seen at Palmyra Atoll, and deep water corals have also been observed. These discoveries would be studied and shared with a broader audience by the Palmyra Atoll Research Consortium, a collaborative partnership of universities, museums, and conservation organizations that conducts innovative, interdisciplinary work on the natural systems of Palmyra Atoll and the central Pacific. The consortium members include UC Santa Barbara, Stanford University, Scripps Institution of Oceanography, USGS, The American Museum of Natural History, The Nature Conservancy, and others.



Above: Location of seamount moats (filled circles with depth range) on and around the Manihiki Plateau. Arrow indicates location of bathymetry and backscatter plots shown below.

Below: Multibeam bathymetry and backscatter draped on bathymetry for representative seamount moatson the Manihiki Plateau. Backscatter data has been corrected for cross-track decay and topographic slopes.



Manihiki Plateau Seamount Moats

Robert Pockalny (URI GSO)

Collaborators

Robert Harris (OSU)
Art Spivack (URI GSO)
Steven D'Hondt (URI GSO)
David Smith (URI GSO)

Region

W Central Pacific/Line Islands
Tuamoto Archipelago/Austral (Tubuai) Island/Cook Islands

Rationale for Exploration

Rationale

Brief Overview of Target Area

The primary target shown in Attachment 1 is near 167:30˚E and 9:45˚S, on ~120 Ma basement created during the formation of the Ontong Java, Manihiki and Hikurangi large igneous province during the mid-Cretaceous (~120 Ma). Bathymetry in the region ranges from 3400 – 4200 m with numerous small seamounts (< 500 m) located on top of the plateau. Several small seamounts in the region are surrounded by 50-200 meter depressions that are about 1 km wide. T he target area is located in the Cook Island/ New Z ealand territorial waters and about a 3-day transit (680 nm @ 10 kts) from Puntarenas, Costa Rica or a The target area is located in international waters and about a 2- day transit (400 nm @ 10 kts) from either Apia, Samoa or Pago Pago, American Samoa.

Brief Summary of What is Known of Target Area

The moats in the Manihiki Plateau target area are located on a large igneous province created during the mid-Cretaceous at about 120 Ma. The actual age of the basement or volcanic plateau is not well constrained due to the lack of correlateable magnetic anomalies during the mid- Cretaceous Superchron (~84-120 Ma). The seafloor in the region is imaged by numerous ship tracks of multibeam data with a SW-NE heading. Sediment thickness in the region ranges from 100 – 150 m (Divins, 2006), but a nearby single-channel seismic line (RC1305) indicates sediment thickness ranging from 100-250 m. T he biogenic component of sediments is highly variable in the region and ranges from 5 to 60% (Archer, 2003). T he target area is located about 580 km westnorthwest of DSDP site 317. HYCOM ocean circulation models indicate maximum abyssal current speeds of < 5 cm/s in the immediate vicinity of the target area and < 20 cm/s over a broader region of the Manihiki Plateau (see Attachment 2).

Feasibility of Studying Target Area

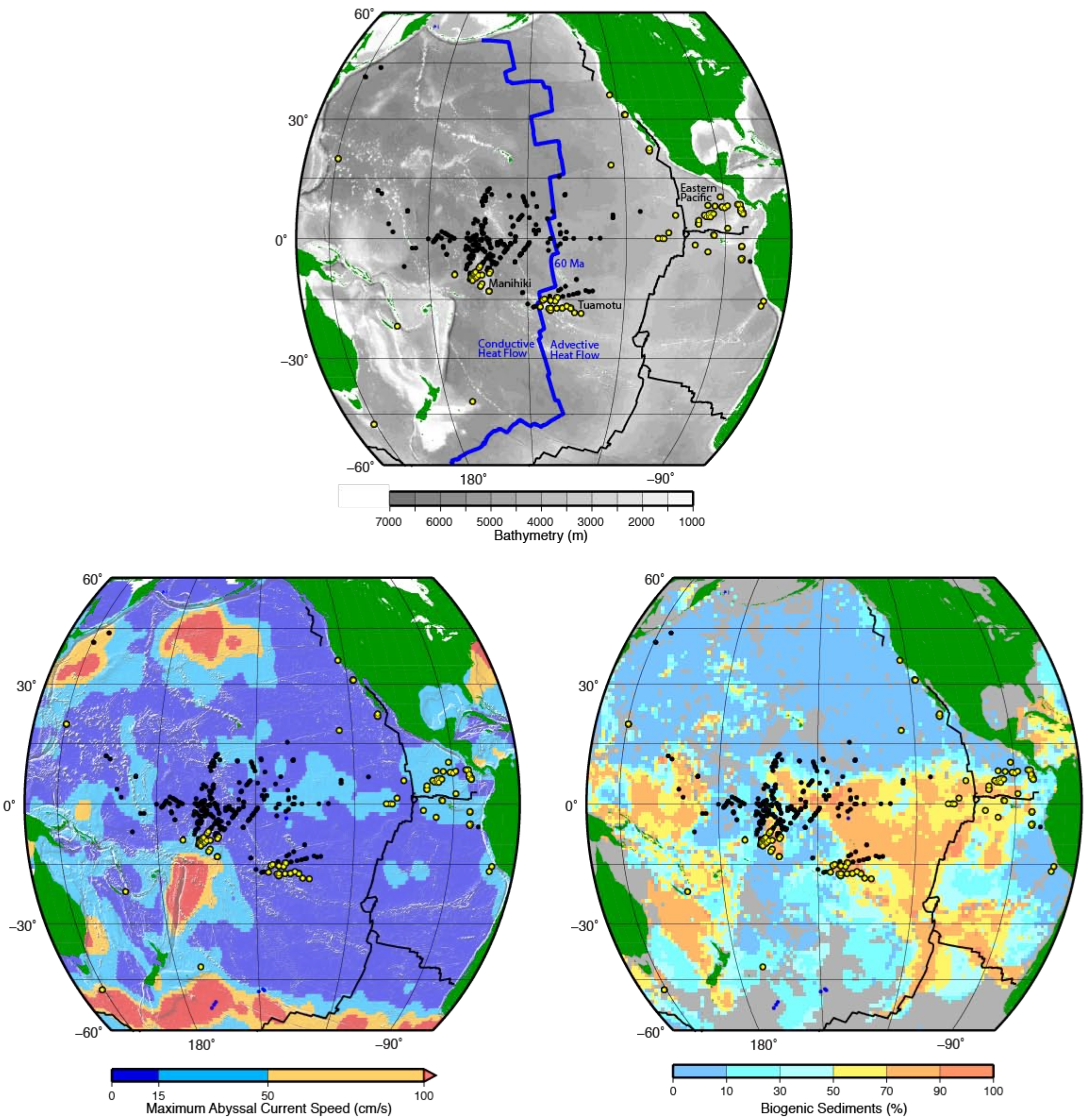
The geographic location of the target area is within the Cook Islands/New Zealand territorial waters, but we have had no prior issues gaining access to these waters. Easy access to nearby deep water ports include Apia, Samoa and Pago Pago, American

Samoa. The bathymetry is less than 4000 m for the targeted seamount moats so the multibeam, Chirp and ROV systems will be able to reach the proposed targets. This project would benefit significantly from heat flow measurements that can be obtained from an ROV (with some adaptations that have been successfully employed with Alvin an Jason) or from conventional overboard probes deployed from the ship.

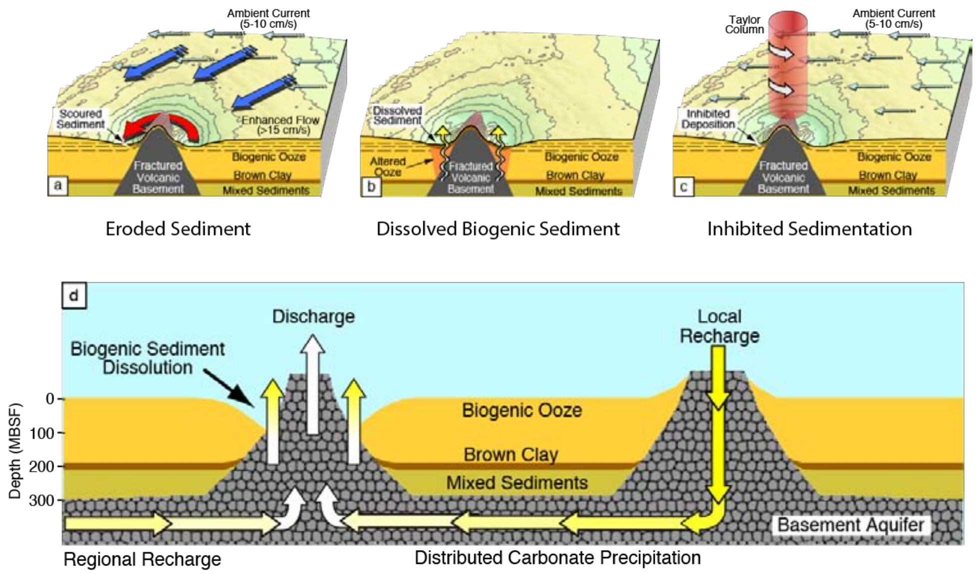
Educational and Outreach Potential of Target Area

The proposed target investigation would involve an array of activities ranging from seafloor mapping, nearbottom measurements, and sampling that would provide a varied experience for students or the on-line public. This expedition is truly exploratory since the only prior study of these features (in other regions of the Pacific) include two survey programs with Deep-Tow on older seafloor (40 and 100 Ma) and at higher latitudes [Normark and Spiess, 1976; Mayer, 1981]. Two gravity cores of other moats and a pit do exist, but the moat cores have only been visually inspected.

The proponents also have extensive experience engaging Middle and High School students and teachers in their programs by taking teachers to sea or visiting classrooms in Rhode Island and rural Upstate New York. The lead proponent has also collaborated with a local environmental reporter (Cherelle Jackson) from Apia, Samoa for news articles and presentations in the Samao Observer newspaper, so there is a possibility to renew the collaboration.

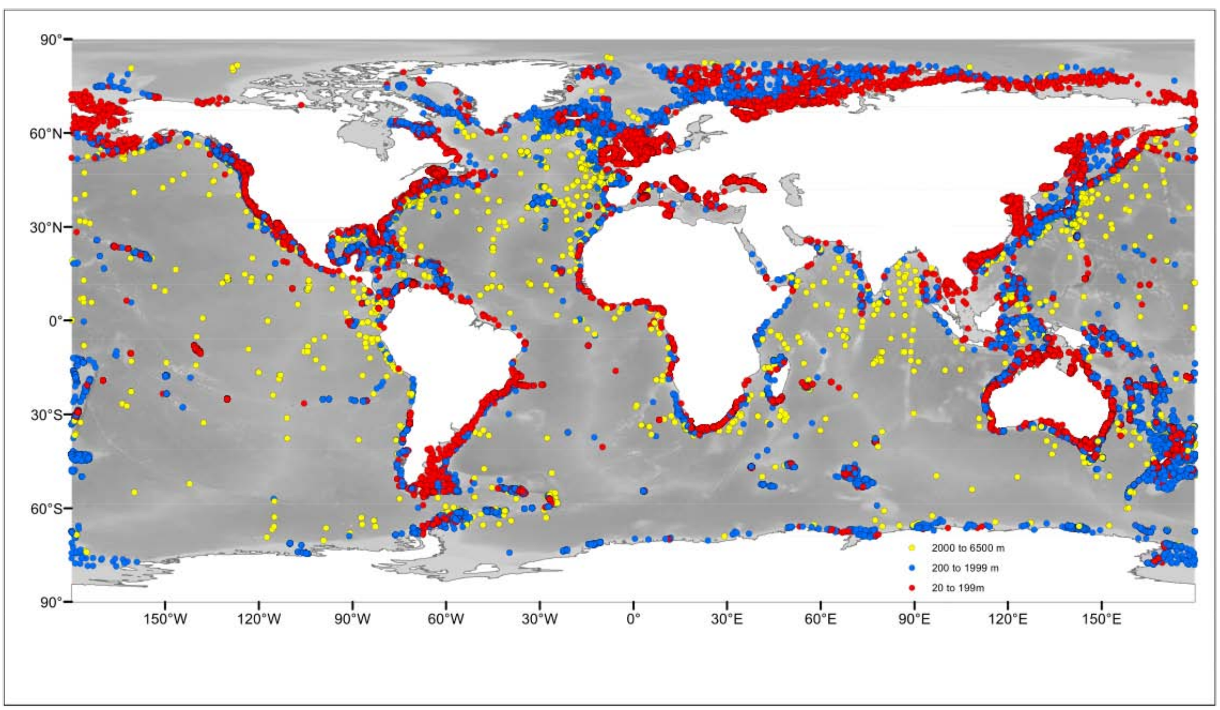


Top: Bathymetry map of the Pacific Ocean showing the location of catalogued seamount moats from available transit multibeam data. The location of oceanic plate boundaries are shown (black line), and the 60 Ma basement isochron (blue line) indicate the canonical age limit of hydrothermal circulation. Black circles are moats located deeper than 4000 m and the yellow cirsles are moats shallower than 400 m.
Left: Location of moats overlain on a map of maximum abyssal currents obtained from the HYCOM global circulation model.
Right: Location of moats overlain on a map of the percentage of biogenics contained in surface sediments (after Archer, 199; 2003).



Top: Series of 3D ocean crust cut-aways illustrating the three most viable models of seamount moat fomration: a) eroded sediment by enhanced abyssal currents, b) dissolved biogenic sediments, and c) inhibited sedimentation related to Taylor Colum formation.

Bottom: Conceptual model for how the biogenic sediment dissolution model would occur. Seawater inters the crust through sediment-free fractured basement exposures and warms. The warming and retrograde solubility of carbonates will cause precipitation of dissolved carbonates in the ocean ic basement. As the water exits the basement through small seamounts, the undersaturated water dissolves the overlying biogenic sediment (both siliceous and carbonate sediments) near the basement -sediment interface, which creates the local moat-shaped depressions.



Pacific Remote Islands Marine National Monument

Brendan Roark (TAMU)

Collaborators

Robert Dunbar (Stanford)
Thomas Guilderson (UC Santa Cruz)

Region

W Central Pacific/Line Islands

Rationale for Exploration

In 2009, President Bush established the Pacific Remote Islands Marine National Monument (PRIMNM). Included in this mostly unexplored national treasure are a series of seven distinct carbonate capped volcanic atolls and coral islands (Baker, Howland, and Jarvis Islands, Johnston, Palmyra, and Wake Atoll and Kingman Reed). If one includes Rose Atoll in American Samoa to the southwest of the PRIMNM, a latitudinal transect from ~17°N across the equator to 14°S is possible. The rational for exploring this large area would be an interdisciplinary (ecology, taxonomy, geochemistry, oceanography, and climate science) exploration of the deep-sea in order to describe deep sea coral communities and their associated macrofauna over a depth range of 250 to 4000 meters and to collect specimens to be used for paleoenvironmental reconstruction of the ocean interior, taxonomitic studies, and genetic studies. These sites cross major ocean interior gradients in temperature, pH, alkalinity, water mass age, and oxygen concentration and they are largely unexplored below 200 m. As a consequence such a program can begin to address some of the many questions that were identified at a recent Pacific Islands Deep-Sea Coral Research Needs Workshop sponsored by the NOAA Deep Sea Coral Research and Technology Program such as;

1)Are there biogeographic boundaries to the distribution of different species of deep-sea corals associated with or governed by currents and/or environmental factors;
2)What is the depth distribution, especially beyond 1000 m, of different species of deep-sea corals;
3) What is the genetic connectivity within the region and to other regions such as the Hawaiian Islands;
4)What is the basic biology and ecology of deep-sea corals within the region, and how does that information compare to other regions? More specific questions include what are the habitat forming corals, what are the associated species, how are the deep-sea coral reproducing, what are the age and growth rates of deep-sea corals?

From an oceanographic and paleoenvironmental standpoint we are interested in whether the chemical and environmental changes in the overlying water column have an impact on the nature of carbonate and non-carbonate deep sea corals and associated macrofauna, with a view towards understanding possible trajectories of change in the deep sea as the ocean takes up anthropogenic CO_2. We would plan to collect specimens of deep-sea corals that are known to record environmental conditions in the deep sea over periods of centuries to millennia with goal to better understand decadal to centennial variability in the South Pacific Gyre as well as changes in the strength and intensity of the equatorial upwelling system.

We have several working hypotheses that we can bring into finer focus as part of the planning process. They include:

1) Thermocline variability is greater in the Southern Hemisphere (than in the north) over decadal-centennial timescales, reflecting large scale changes in the South Pacific Gyre linked to variability in the westerly wind field,

2) Deep-sea coral community structure is organized at least in part by changes in carbon system chemistry across the equatorial upwelling region. We are also interested in the relationship between substrate type and slope and the kinds of corals that occur and will collect observations that allow us to further develop, and possibly, test an appropriate hypothesis as well as coral habitat models.

Brief Overview of Target Area

We propose a series of ROV transects at Johnston Atoll (16°45′N 169°31′W), Palmyra Atoll (5°53 ′N 162°05′W), Kingman Reef (6°23′N 162°25′W), Jarvis Island (0°23′S 160°01′W), Rose Atoll (14°32′S, 168°9′W), and American Samoa as primary targets with Howland (0°48’N 176°36′W) and Baker (0°13’N 176°31′W) islands as secondary targets (if cruise track and timing permit). These are remote refuges that contain some of the most widespread marine protected areas on earth under one governing authority which sustain many endemic species of corals, fish, birds, marine mammals, shell fish not found in other areas. In addition there is a rich history associated with the area ranging from early explorations, colonization, World War II to present day resource management and protection plans. For example both Johnston and Palmyra Atoll have a ‘unique’ utilization history with the surface expression of the Atolls being com pletely restructured during WWII. In addition to being a naval aviation resupply point during WWII, Johnston was a nuclear weapons test-site and a storage and incineration location for chem ical weapons. Am elia Earhart disappeared on her way to Howland Island as a refueling stop during her around the world flight in 1937.

The purpose is to describe deep-sea coral communities over a depth range of 250 to 4000 meters and to collect specimens to be used for paleoenvironmental reconstruction of the ocean interior, taxonomic studies, and genetic studies at each site. Based on existing bathymetric maps and additional mapping to be done during the cruise/s, coral habitat prediction models, and environmental parameters a series of dives along a depth transect would be conducted at each site. Ideally multiple transects on different sites of each island/atoll/reef would be possible but we recognize the limitations of working in remote areas. The primary focus of the transects will be to define the nature, extent, and im portance of deep-sea coral com m unities along the flanks of each site and to assess the trophic interactions and level of ende ism .

Brief Summary of What is Known of Target Area

This proposed target area (PRIMNM and American Samoa) builds on work that several researchers have completed (largely through the Hawaii Undersea Research Laboratory -HURL) in the Hawaiian Islands and Cross Seamount, the Northwest Hawaiian Islands, and the northern Line Islands (Palmyra and Kingman Atoll), (Supplementary Figure 1).

These sites extend from 24°N to 6°N and cross from the central North Pacific Gyre into the equatorial “trough”, illustrated most clearly in supplemental figure 1 as the upwelling-associated depression in temperature and water column

Radiocarbon content at depth. The proposed target sites (white circles) extend from the equatorial trough into the South Pacific Gyre. Above 400 meters, the South Pacific Gyre contains substantially more stored heat compared with the North Pacific (supplementary Figure 1a shows areas of T>15°C at 300 meters depth as an example). This results from a greater depression of the Permanent thermocline in the southern gyre, particular in the water column east of the dateline. Deep sea corals are abundant at depths between 300 and 700 meters and we propose to use them to examine thermocline variability along a cross-equatorial transect, specifically as tracers of deep heat storage as well as equatorial upwelling and deep water entrainment (Supplementary Figure 1b). Both processes have the potential to significantly influence Pacific Basin climate, and the El Nino system over decadal to centennial timescales. Most information about oceanic involvement in Pacific-region climate change, both instrumental and paleo-proxy-derived, currently comes from the northern hemisphere. These proposed target areas offer the possibility of extending a deeptime view into the Southern Hemisphere where the gradients in temperature and amounts of thermocline heat storage are arguably greater than in the north. In terms of previous work we are aware of a single HURL expedition to the region in 2005 resulting in ~12 submersible dives in PRIMNM and ~18 dives in America Samoa (only 1 at Rosa Atoll). Note all three proponents (Dunbar, Guilderson and Roark) participated in one leg of this expedition. Accordingly, we consider the proposed depth transect dives to be first-look, quantitative assessments of the deep ocean marine living resources within the target areas.

Feasibility of Studying Target Area

We know that the different species of deep-sea corals needed to address the climate and paleo-ecology hypotheses have been found during HURL dives at Palmyra Atoll, Kingman Reef and Jarvis Atoll in 2005. Broader biogeographic and depth boundaries are inherent to the region proposed. There are no other limitations we can identify.

Educational and Outreach Potential of Target Area

There are a couple of factors that make this target area rich in terms of educational and outreach potential. 1) The target area is truly unexplored and as consequence one can expect many new discoveries ranging from new species, expanding ranges of species, to new paradigms in deep-sea coral and their associates distribution. 2) The target area includes the oldest continually growing marine organism (Savalia – gold coral and Leiopathes – deep-water black coral) known which always holds great interest to the public. 3) The proposed target site requires an interdisciplinary team of scientist that lends it self to a broad and far reaching education program across multiple subject areas. 4) The rich history of the region will easily capture the public imagination and aid the Outreach.

Active Submarine Volcanoes of the Central Pacific

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Collaborators

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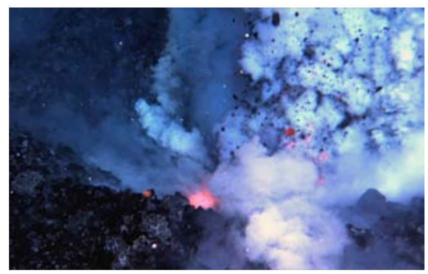
Robert Embley (NOAA PMEL/OSU)
Timothy Shank (SHOI)
Scott White (U. South Carolina)
Adam Soule (WHOI)

Region

W Central Pacific/Line Islands
Tuamoto Archipelago/Austral (Tubuai) Island/Cook Islands
Other

Rationale for Exploration



Submarine volcanism is the dominant form of volcanic activity on the planet, and yet study of active submarine volcanoes is in its infancy, especially for deep sea volcanoes (e.g., Rubin et al., 2012). Every time we explore an active or recently active submarine volcano, we learn something new and see many unexpected things about the style, processes, controlling factors, manifestations, and ecological impacts of submarine volcanism. Yet the number of sites we have explored with in situ methods (e.g., ROV) is tiny and even fewer have been visited more than once.

This white paper advocates a multi-target - area study to visit and explore several active, non-mid-ocean ridge submarine volcanoes in the central Pacific to dive, discover, learn and share about volcanism in Earth's last frontier. These sites are interesting from many perspectives, not the least of which are the styles and products of still poorly understood active submarine volcanic processes, but also including their interplays with hydrothermal, oceanographic and biological systems. For instance, study of the dynamic ecosystems of active volcanic sites provides invaluable information about recruitment, colonization, community stresses, and succession at these sites, and species and gene flow between them.

The active volcano sites include (a) West Mata (NE Lau Basin, last erupted 2008-2010), (b) Vailulu'u (Samoa, last erupted mid-2005),(c) Monowai (Kermadec Arc, last confirmed eruption in 2011), (d) Macdonald Seamount (Austral Cook Islands, last confirmed eruption 1989) and (e) Teahitia (French Polynesia, last known eruption, 1985). Please see location and depth information in the attached spreadsheet. All of these sites have been visited before, several by submersible, although some, such as Teahitia and Macdonald not since the 80's). Even at highly active sites, like W. Mata, there is much to learn from site revisits, such as dramatic differences in activity and state of the volcano at its summit in 2009 (Resing et al., 2011) and 2011 (Embley et al., in review), plus none of these volcanoes has been investigated in detail throughout the edifice, so that again, using W. Mata as an example, we have not visited any of the non-summit eruption sites discovered from the last decade of repeat bathymetric surveys. The gas rich and extremely rare boninite composition magma erupts at the W. Mata summit in a very dynamic style; exploring recent eruption deposits at 500-1500m deeper on the rift zones will provide critical information on how water pressure affects explosivity and lava morphology, eruption and deposit styles, and the degree of connectivity in magmatic plumbing system at a small, youthful volcano. We have selected the target volcanoes on the basis of their geographic spread and depth ranges, recent activity, and range of eruptive styles. The more sites we visit, the more we will learn, by comparing and contrasting activity, deposits, hydrothermal systems and ecosystems, and through comparison to what was observed in prior studies at each site. Yet even if OET can only visit one of these sites with Nautilus and Hercules in 2015, or if some site visits happen in other years, there is much we will learn and it is a sure thing that the public will be excited by these investigations, based on feedback from our prior NOAA-OE live telepresence activities (e.g., 2011 explorations of NE Lau Basin volcanoes and hydrothermal systems, RR1211, using the QUEST 4000 ROV).

Brief Overview of Target Area

Each of these volcanoes has had confirmed eruptive activity in the since the 1980s, some as recently as the last 5 years. West Mata (15.1°S 173.75°W) is an elongate composite volcano in the NE Lau basin (Tofua rea arc) with a summit depth of 1176 m and a basal contour at about 2800m. It was discovered on a NOAA Vents Program expedition by water column anomalies in 2008 and visited while it was eruption by a group of us using NSF and NOAA funds using the ROV Jason in 2009 (e.g., Resing et al., 2011) and mapped by AUV o the same expedition Caress et al., 2010). We have visited it on 3 other cruises without ROVs (see http://www.pmel.noaa.gov/eoi/laubasin.html). It has experienced several recent eruptions on the summit and flanks and a recent pit crater formation at the summit (Embley et al., in review). Ly the summit eruption site have been visited and sampled. They are a rarely erupted magma type called boninite, a gas rich high T ultramafic magma that show very unusual chemistries and ranges of compositions (Rubin et al., in prep.). See also Embley et al. OET White paper for regional details. Vailulu'u (14°13′ S 169° 4' W) is the active expression of the Samoa hot spot, east of the easternmost islands of American Samoa (e.g., see http://www.tos.org/oceanography/archive/23-1_koppers2.pdf). It rises from >4000, depth to about 590m depth. Originally discovered after a seismic swarm in 1973, it has also experienced intense seismicity in 1995 and 2000 (Hart et al., 2000). A volcanic cone named Nafanua grew inside the summit crater from 2001-2004 (e.g., Koppers, et al., 2010). The crater and cone has an interesting biological community produced by by volcanic fluid inputs below the sill, depth in the summit crater and infrequent ventilation. Macdonald seamount (28.98°S 140.25°W) was discovered hydroacoustically in 1967 and first visited in 1987 by Craig et al., on the R/V Melville, when it erupted and gas rich volcanic bombs floated to the surface (Rubin et al., 1989). It is the likely active location of one of the hotspots that feed the Austral-Cook Islands chain. Macdonald seamount has a shallow summit below sea level, at average 40m deep and a deeper summit platform (~100m depth) and flanks descending to >4000m). It experienced a second eruption in 1989 and has not been visited recently. He nearest land mass is Rapa Iti island. Teahitia (17.57°S 148.85°W) is a submarine volcano in the Society Islands, whose summit reaches to within 1400 m of the surface, located 40 km NE of Tahiti.

Several seismic swarms were detected from 1982 to 1985 including volcanic tremor that may have resulted from a submarine eruption (Talandier and Opal, 1984). Rocks dredged from the volcano in 1986 were very gas rich. There are two known low-temperature hydrothermal fields that were discovered on the flanks of the volcano during submersible dives in 1986 and 1989. It has recently been visited for hydrographic surveys and water sampling, which confirmed hydrothermal activity is ongoing (German and Resing, pers. Com. – see German OET White paper). Monowai (25.887°S 177.188°W) is a Kermadec Arc volcano discovered in the 1940s by an aerial survey. It last erupted in 2012. The summit is quite shallow (just 132m depth), which is why it was not explored by HOV Pisces V as part of a NOAA/PMEL OE "Ring of Fire" cruise in 2005. Depth changes at the summit and flank indicate that it is quite active in places, although also supports a stable edifice with a 1.5 km deep caldera and hydrothermal activity (e.g., summit's position and depth changed between 1998 and 2004, due to mass wasting and eruptive regrowth; e.g., Chadwick et al., 2008; Wright et al., 2008; Watts et al., 2012). It is clearly a dynamic setting with much to explore even if the shallowest portions of the summit are avoided by the OET expedition. Note about: Havre Volcano (Kermadec Arc): This volcano, which is near to Monowai, would be another interesting target. It erupted explosively in 2012 and sent a large pumice raft around the W. Pacific. We have not included it in our targets because NSF has recently funded several investigators (Soule, Carrey, Houghton) to investigate this volcano in 2015.

Brief Summary of What is Known of Target Area

Some of the relevant details are given in the prior section. West Mata has been visited in one form or another on 6 expeditions by the NOOA vents group and collaborators. Rubin has been on 5 of these expeditions (e.g., see http://www.pmel.noaa.gov/eoi/laubasin.html). I has been mapped repeatedly by hull mounted multi-beam, once by AUV, sampled at the summit for microbiology, macrobiology, hydrothermal fluids, and rocks, and yet primarily only at the summit. Bathymetric changes indicate ongoing or recent volcanic activity. Our visits in 2009 with ROV Jason captured the first images of active deep sea (>1 km depth) volcanism.

Vailulu'u has been visited several times by colleagues at WHOI and SIO (Staudigel, Hart and others), once using the HOV Pisces V and NOAA-HURL funds. Here is good multi-beam coverage of the volcano Macdonald seamount was visited several times in the late 1980s. We are not aware of recent expeditions there, although we will follow-up with a more extensive literature search if it is chose as a target site. Teahitia was visited and dredge several times in the 1980s and has recently been visited for hydrographic work. Here is complete multi-beam data for the edifice. Monowai has been visited frequently in the 2000s by several groups, including NOAA/Vents personnel, GNS colleagues (New Zealand), and colleagues at GeoMar and in the UK. It has been mapped in detail by surface ship multiple times.

Feasibility of Studying Target Area

Each of these study sites is near a major port (at most 3 days sail, but in many cases <1 day sail – e.g., see W. Mata logistics section of Embley et al. white paper). Permissions for study at these sites is easily attainable from the respective countries who control these EEZs (US, Samoa, Tonga, New Zealand, France). Each target is within the depth range of the OET ROV capability, each has excellent bathymetric maps available, and each has a range of interesting features to study. We hope that one or more will be erupting when we visit. Deep water active volcanoes can studied up close because of the high confining pressure and the viscosity of the sea water, which greatly attenuates the velocity and transport distance of pyroclasts relative to subaeiral eruptions. Our experiences at NW Rota volcano (Mariana arc) and W. Mata are that it is safe to move the vehicle quite close to the active vents, after they has been surveyed from a distance and the range and extent of activity at the moment determined.

In the event that one or another of the shallow volcanoes (Macdonald and Monowai) is actively erupting, we propose that the summit areas be approached only cautiously, and instead our exploration be focused on deeper sites at those volcanoes. If they are not erupting, we suggest that visits to the summit vents would be fascinating and educational.

Educational and Outreach Potential of Target Area

Submarine volcanism is exciting, engaging, enticing, and yet still poorly understood. They represent one of, if not the, most dynamic environment in Earth's last frontier, the deep sea. The public is demonstrable excited about submarine volcanism and about learning how and where it occurs. On our 2009 W. Mata cruise, we piped images from the ROV Jason throughout the ship and no matter what time of day or night it was, one would find crew members and scientists alike starring fixedly at the monitors to revel in the exciting and at that time, unprecedented views. Yet besides the active volcanism, in our experience, the unique flora and fauna and volcanic landforms at these sites present uniquely enticing images with which to educate students and the public about geology of the ocean depths and life in extreme environments. Rubin teaches a multidisciplinary deep sea volcanism course at Univ. of Hawaii every couple of years and demand is very high even from non-geologists, because the subject matter is just that cool and approachable by just about everyone. It combines the out-of-this-world element of planetary exploration with the dynamics of actively changing systems, which makes people want to watch and engage while the expeditions are happening, rather than just look at a few stills after the fact (i.e., like the Mars rover missions). See also http://laueruptions.blogspot.com/

Deep Sea Minerals

Alison Swaddling (Secretariat of the Pacific Community)

Collaborators

Akuila Tawake (Secretariat of the Pacific Community)

Rationale for Exploration

Deep Sea Minerals (DSM) is an emerging global industry and many Pacific Island countries have potential DSM resources. This prospective new economic revenue stream has potential to address economic vulnerability and is attractive to developing Pacific Islands. This industry must be balanced against other imperatives including to protect and preserve the marine environment. It is therefore important to have an understanding of the deep sea floor environment and the potential resources Pacific Islands may have. The Deep Sea Minerals Project is working with Pacific Island Countries to develop national policy, law, and fiscal regimes, and to build technical capacity in-country to regulate DSM mining activities, however these countries also need assistance with obtaining data about their resources to enable well informed decision making.

Brief Overview of Target Area

The DSM Project works with 15 Pacific countries: Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor Leste, Tonga, Tuvalu and Vanuatu.

Brief Summary of What is Known of Target Area

Three deep sea mineral types are known to occur in the Pacific Region: Seafloor Massive Sulphides, Cobalt Rich Crusts, and Manganese Nodules. Some Pacific Islands have already begun issuing commercial exploration licenses (PNG, Vanuatu, Tonga, Fiji, Solomon Islands) and are receiving data on their resources. Other countries have limited information provided to them through marine scientific research or no data.

Feasibility of Studying Target Area

It would be ideal to have a dedicated sampling expedition for studying and sampling marine minerals, however samples may also be obtained during other expeditions that visit appropriate areas. The DSM Project is willing to collaborate with other researchers to help Pacific countries fill the data gaps in their DSM knowledge.

Educational and Outreach Potential of Target Area

The DSM Project is looking for capacity building opportunities for Pacific Island Nationals to participate in offshore expeditions to gain introduction to, and understanding of, the processes involved in marine research and exploration.

Line Islands Area

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Collaborators

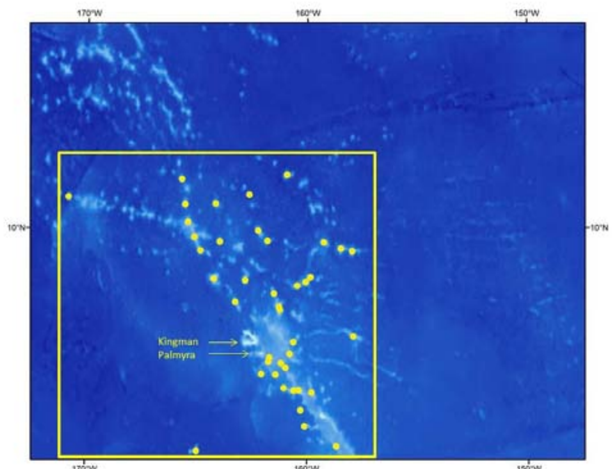
Christopher Kelly (UH)
Scott France (University of Louisiana Lafayette)

Region

W Central Pacific/Line Islands

Rationale for Exploration

The seamounts in this area are remote and in a zone of latitudinal currents. T hat means that currents run W to E whereas the seamount group is arranged N to S. There is some evidence of a bathyal depth biogeographic boundary in this area. The bathyal fauna is also limited at its upper depth limit by the oxygen minimum zone, which is very strong in this area and extends to about 1000 m depth.



41 seamounts with summits shallower than 1500 m

Brief Overview of Target Area

The northern part of the Line Islands portion of the Pacific Remote Islands Marine National Monument is populated with more than 40 seamounts whose summits are about 1500 m water depth or shallower, so will provide a diversity of sizes and shapes for comparison of attached megafauna and seamount-associated fish.

Brief Summary of What is Known of Target Area

Very little is known about the deep water fauna of the target area, at least so far as what is published. While only two species of deep coral have been identified from this area, the photo archive at HURL contains a number of unknown species. None of those were collected however so it is not possible to know what the species are. And, if this area is like the Hawaiian Ridge, it will contain a vast number of new species. For the Hawaiian Ridge, which is pretty well studied and more than 100 species of deep octocorals are known, we still have between 30 and 50 new species yet to describe.

Feasibility of Studying Target Area

This area is about a 3 day transit from Hawaii and lies either in international water or within waters of US jurisdiction. Permits will need to be obtained because some of the seamounts are within the national monument.

Educational and Outreach Potential of Target Area

This is one of the more remote areas of the Pacific, and so could be the focus of outreach questions about how did the species found get there. Lots of potential regenetic connectivity, larval duration and travel, how to remote populations maintain themselves (or do they depend on larvae from elsewhere all the time)?

EASTERN PACIFIC

Benthic fauna of the seamounts surrounding Easter Island and Sala y Gomez Island

Diva Amon (University of Hawaii at Manoa)

Collaborators

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Javier Sellanes (Universidad Catolica del Norte)
Erin Easton (Universidad Catolica del Norte)

Region

East Pacific Rise

Rationale for Exploration

Seamounts are widespread topographic features numbering in the 20,000s worldwide (Clark et al., 2010). Seamounts are thought to have higher benthic-invertebrate richness and abundance than surrounding deep-sea areas as a result of the 'oasis hypothesis' (Samadi et al., 2006; Rowden et al., 2010). This may result from topography-currents interactions that enhance local biomass by mixing nutrients into the euphotic zone, and by increasing particle flux to suspension feeders (Rogers, 1994; Samadi et al., 2006). Seamounts are often targeted by the fishing industry because pelagic and demersal fishes aggregate around seamounts due to enhanced food availability, as well as orientation structure.Another prevailing theory has been that seamount fauna are, in general, characterized by high levels of endemism as a result of the geographic isolation of clusters of seamounts (Richer de Forges et al., 2000). This view has, however, been challenged in the last decade (McClain, 2007; Clark et al., 2010). Benthic assemblages on seamounts differ across multiple spatial scales, ranging from compositional differences on a single seamount to extreme variation in faunal assemblages between seamounts on different ridges and ocean basins. Some of the main environmental factors that may determine seamount biota include light levels; the productivity of the overlying water; the hydrodynamic regime; the chemical nature of the water column; the geomorphology of the seamount; geological origin and age, which can dictate substratum type; and volcanic and hydrothermal venting activity. Some of these factors are related to water depth, which is thought to be responsible for some differences in faunal composition between seamounts (e.g. O'Hara, 2007).

Overview of Target Area

Most of the Chilean seamounts are concentrated along the Nazca Ridge and Sala y Gomez Ridge. There are over 400 seamounts of at least 200 m height in this area (Rappaport et al., 1997). The fauna inhabiting these seamounts are particularly poorly known, with the main source of information derived from scientific reports of Soviet expeditions along the Nazca-Ridge seamounts (e.g. Parin et al., 1997). Deep-sea trawl fishing has been banned on all of Chile's seamounts and a no-take zone established around the island of Sala y Gomez (Motu Motiro Hiva marine protected area), but this was not before some Chilean seamounts were negatively impacted by fishing activity, potentially providing an opportunity for comparative studies of anthropogenic impacts on seamounts in this area.

Brief Overview of What is Known About this Area

Despite being the site of geological investigations (Rappaport et al., 1997), very little is known concerning the biology of the seamounts of Easter Island and the Sala y Gomez Ridge. Fish populations were studied on 22 seamounts in this area by Parin (1991) and he concluded that there was a total of 173 fish species from 66 families. These samples were accumulated as the result of Soviet expeditions between 1979 and 1987. 192 species of benthopelagic and benthic invertebrates were also sampled from these seamounts, 150 of which were new to science (Parin et al., 1997). Benthic invertebrate communities of the seamount summits were said to be characterized by strong dominance of a few species (Parin et al., 1997). The vast majority of fish and invertebrate species were more closely related to the Indo-West Pacific fauna than the fauna on submarine ridges and coasts of South America. Parin et al. (1997) also concluded that there was a high degree of endemism at the species level (51% among identified bottom invertebrates, 44% among fishes), although it was not clear whether this could have been due to undersampling.

Feasibility of Studying this Target Area

Access to the study sites should be possible from ports in Peru (Callao) or Chile (Valparaiso, Coquimbo), as well as a port on Easter Island (Hanga Roa). We will collaborate with biologists/ecologists from Chile (Javier Sellanes, Martin Thiel, Carlos Gaymer and Guillermo Luna-Jorquera) from the newly-created program, Ecology and Sustainable Management of Oceanic Islands (ESMOI), funded by the Chilean government for the next three years. This new centre is based at Universidad Catolica del Norte, campus Guayacán at Coquimbo.

Education & Outreach Potential for Exploration at this Target Area

One of the most important research lines of ESMOI is based in citizen science, thus a major focus of the centre is devoted to educational and outreach activities with local people from Easter Island as well as with people of the continent. Furthermore, the UCN Aquarium and Museum (currently managed by Javier Sellanes), receives thousands of visitors each year from a broad spectrum, including pre-kindergarten to K-12 students, local residents, national and international authorities, tourists, as well as local and visiting scientists, to mention a few. All environmental and (eventual) biological data collected during the project will be included in public access databases. Examples are the Chilean National Oceanographic Data Centre (Centro Nacional de Datos Oceanograficos de Chile, CENDOC), Global Biodiversity information Facility (GBIF) and the Ocean Biogeographic Information System (OBIS). Inclusion of data to GBIF will be through the Biological Collection of UCN (CBUCN, http://grbio.org/cool/pkv3-7ant).

Deep-sea fauna inhabiting Chilean canyons

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Collaborators

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Region

SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise

Rationale for Exploration

Submarine canyons are ubiquitous features of the world's coastlines that can be intense hotspots of productivity and biodiversity, and yet they are some of the least explored marine habitats. Studies suggest that there could be up to 5800 submarine canyons worldwide (Harris & Whiteway, 2011), but there have been less than approximately 50 canyons studied to evaluate faunal diversity and community structure, and even fewer addressing overall productivity (De Leo et al., 2012). Canyons are sinks for particulate materials, including macrophytic debris and organic-rich sediments. These horizontal food subsidies from marine and terrestrial production often enhance benthic biomass and productivity in canyons at shelf and slope depths, resulting in elevated abundances from benthic invertebrates up to whales (Vetter, 1994; Vetter & Dayton, 1998, 1999; Vetter et al., 2010; de Leo et al., 2010, 2012, 2013). In some instances, canyon benthos can reach biomasses 100x higher than other detritus-based deep-sea habitats (De Leo et al., 2010). The strength of this ''canyon effect'' of enhanced faunal abundance varies with depth (Houston & Haedrich, 1984), and appears to be most intense in canyon heads (Vetter & Dayton, 1998) and at slope depths (Duineveld et al., 2001; Escobar-Briones et al., 2008). In canyon systems fueled largely by organic detritus from the coast, the enhancement of canyon benthos may decrease exponentially with depth as organic material is consumed downslope (Vetter & Dayton, 1998).

Alternatively, when canyons are large enough to extend far onto the continental slope, primary production over the outer shelf/slope may be enhanced by canyon-hosted mesoscale eddies, yielding mid-depth peaks in canyon organic carbon flux and benthic community abundance (Duineveld et al., 2001; Escobar-Briones et al., 2008). Canyon fauna is also likely to be influenced by the amounts and types of coastally-derived organic detritus entering the canyon, which is in turn affected by the terrestrial ecology, e.g., land-use patterns (forests, farmlands, etc.), around the input source. The role of canyons as biodiversity hotspots is even less well understood. Studies have demonstrated that the complex circulation patterns and elevated habitat heterogeneity (e.g. various substrate types and keystone features) of canyons may yield higher species richness than seamounts, often known as biodiversity oases (Schlacher et al., 2007). In conclusion, since only ~0.8% of all submarine canyons worldwide have been studied with some level of detail, it is likely that there are many more biomass and biodiversity hotspots waiting to be discovered worldwide.

Overview of Target Area

The coastline of Chile is replete with submarine canyons, all of which are poorly explored. The very narrow shelf and steep Chilean slope suggest that these submarine canyons will entrain substantial amounts of coastal and terrestrial organic detritus, yielding highly productive canyon systems. There are at least six canyons off the Torres Del Paine fjord area in southern Chile (-52.224, - 75.972), eight larger canyons off mid-Chile between 42 and 36º South latitude and six canyons in northern Chile between 29 and -35ºS. All of these canyons have heads near the coastline with the furthest canyon head being approximately 85 km offshore. These canyons have varying types of land use adjacent to the canyon heads, with some being near heavily forested areas (mid Chile), some near scrubland (southern Chile) and some adjacent to densely populated cities (Valparaiso and Concepcion).

Feasibility of Studying this Target Area

Access to the study sites should be possible from ports in Peru (Callao) or Chile (Valparaiso, Coquimbo). We will collaborate with biologists/biogeochemists from Chile (Javier Sellanes and Praxedes Munoz, Universidad Catolica del Norte, UCN), and Juan Diaz (Pontificia Universidad Catolica de Valparaiso, PUCV). Furthermore, we foresee a strong interaction with the newly created Millennium Institute of Oceanography (IMO), funded by the Chilean Government for the next ten years. Director and Deputy Director of this centre are Dr. Osvaldo Ulloa and Dr. Rubén Escribano, respectively, from the University of Concepción.

Education & Outreach Potential for Exploration at this Target Area

The UCN Aquarium and Museum (currently managed by Javier Sellanes) receives thousands of visitors each year drawn from diverse backgrounds, including pre-kindergarten to K-12 students, local residents, national and international authorities, tourists, as well as local and visiting scientists.

All environmental and (eventual) biological data collected during the project will be included in public access databases. Examples are the Chilean National Oceanographic Data Centre (Centro Nacional de Datos Oceanograficos de Chile, CENDOC), Global Biodiversity information Facility (GBIF) and the Ocean Biogeographic Information System (OBIS). Inclusion of data to GBIF will be through the Biological Collection of UCN (CBUCN, http://grbio.org/cool/pkv3-7ant).

Isla de Coco and Seamounts Marine Management Area

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Collaborators

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Region

Galapagos/Cocos Ridge

Rationale for Exploration

Detailed maps of the landscape and faunal sampling that links diversity to landscape features are critical elements for developing a fundamental understanding of drivers that mediate the distribution and abundance of species and the communities in which they occur, as well form the basis for conservation strategies. Limited studies using the human occupied submersible DeepSee and remotely operated vehicle Hela, at sites around Isla del Coco and Las Gemelas Seamount to about 300 m depth, demonstrated that both invertebrates and fishes are influenced by both mesoscale and microscale topography (Starr et al. 2012 a, b, Auster, in prep). For example, observations at Las Gemelas suggest that remnants of volcanic activity, in the form of vents, lava tubes and sheet flows exhibit differential densities of fish species with abrupt topographies like vents supporting highest densities of prey fish and associated predators. In contrast low relief lava tubes were dominated by muraenid piscivores and had proportionally fewer groupers and prey fish. New species are commonly discovered at depths beyond scuba in the Eastern Tropical Pacific (e.g., Breedy and Cortés 2008, McCosker and Rosenblatt 2010) and such knowledge will contribute significantly to the conservation and management of the Park and focus additional conservation actions in the Seamounts Marine Management Area. The deeper waters of the Park and Seamounts Marine Management Area (SMMA) hold promise for discovery of new species and ecological relationships in an area relatively unimpacted by direct human activities.

Overview of Target Area

Isla del Coco (Cocos Island) is approximately 500 km south southwest of mainland Costa Rica and is a UNESCO World Heritage Site. A marine national park extends 12 nautical miles from the island and encompasses 1,989 km2 in area. In 2011 President Laura Chinchilla expanded conservation beyond the park in a newly designated Seamounts Marine Management Area (SMMA) that adds an additional 9,640 km2. The undersea landscape around Isla del Coco consists primarily of a near summit platform that drops off into precipitous volcanic topography at around 200 m (Lizano 2012), where standard towed gears like trawls and dredges to determine the composition and patterns of biological diversity are ineffective. Direct observation of seafloor communities and collections using divers or submersible vehicles is the principal way in which such ecological exploration is most efficiently conducted, but to date this work in the Eastern Tropical Pacific has been extremely limited. While much is known about the diversity and distribution of shallow species within the Isla de Coco National Park (Cortés 2012), little is known about the biology or meso-scale geology beyond the platform boundary (but see, for example, Starr et al. 2012a, b and Cortés et al. 2012).

Brief Overview of What is Known About this Area

Auster, P.J., J. Cortés, S. Blum, A. Sánchez-Jiménez,A. Rodríguez-Arrieta,A. Quesada and C. Pérez. In preparation. A preliminary catalog of facilitative interactions between deepwater piscivores at Isla de Coco National Park and Las Gemelas Seamount, Costa Rica. Rev. Biol. Trop.

Breedy, O. and J. Cortés. 2008. Octocorals (Coelenterata: Anthozoa: Octocorallia) of Isla del Coco, Costa Rica. Rev. Biol. Trop. 56 (Suppl. 2): 71-77.

Cortés, J. 2012. Marine biodiversity of an Eastern Tropical Pacific oceanic island, Isla del Coco, Costa Rica. Rev. Biol. Trop. 60 (Suppl. 3): 131-185.

Lizano, O.G. 2012. Rasgos morfológicos alrededor de la Isla del Coco y de sus montes submarinos vecinos, Pacífico de Costa Rica. Rev. Biol. Trop. 60 (Suppl. 3): 43-51.

McCosker, J.E. and R.H. Rosenblatt. 2010. The fishes of the Galapagos Archipelago. 3 Proc. Cal.Acad. Sci. Ser. 4. 61(Supplement II; No. 11):167-195.

Starr, R.M., K. Green & E. Sala. 2012. Deepwater fish assemblages at Isla del Coco National Park and Las Gemelas Seamount, Costa Rica. Rev. Biol. Trop. 60 (Suppl. 3): 347-362.

Starr, R.M., J. Cortés, C.L. Barnes, K. Green & O. Breedy. 2012. Characterization of deepwater invertebrates at Isla del Coco National Park and Las Gemelas Seamounts, Costa Rica. Rev. Biol. Trop. 60 (Suppl. 3): 303-319.

Feasibility of Studying this Target Area

We propose use of the EV Nautilus multibeam sonar to map the fine scale volcanic features around the park and use the Hercules ROV to image biological communities associated with particular features. A multibeam survey strategy will depend upon available days at sea for this activity.

Education & Outreach Potential for Exploration at this Target Area

We suggest that education and outreach potential for this target is extremely high. Recovery and management of the fauna in the Isla de Coco National Park has been extremely successful and effects appear to stretch into deep water. Use of ROV imagery and associated multibeam sonar maps of seafloor features can illustrate the diverse volcanic landscape and how such variation influences species distributions and interactions. Diverse invertebrate communities and apex predators are common and visually impactful. Live broadcast of the expedition via th web can reach broadly across Costa Rica and other Latin American countries. The results of this work, beyond contributions to the scholarly literature, will be communicated to National Park personnel and used to determine additional areas for greater conservation needs, inform stakeholders of the unique biodiversity contained within the Park 4 and SMMA. This information is crucial and can influence zoning of the new SMMA.

Oceanographic processes and plankton community structure in the Salas y Gomez seamount chain in the SE Pacific

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Region

East Pacific Rise
SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise

Rationale for Exploration

In the South Pacific region between the South American coast and the South Pacific Gyre exists one of the greatest productivity gradients on Earth, from the high productivity in the coastal waters of the Humboldt Current System (HCS) to the very low productivity waters in the ultra-oligotrophic waters of the subtropical gyre (REF???). Some of the most relevant oceanographic characteristics in this region include:

- the occurrence of coastal upwelling and high fish production,
- the presence of an intense and relatively shallow oxygen minimum zone (OMZ) and associated biogeochemical peculiarities,
- relatively high level of mesoscale eddy-activity with the potential of strongly connecting the coastal and the open ocean,
- the remote influence of climatic processes (e.g. El Niño) upon the structure and dynamics of regional ecosystems.
- the presence of several topographic features in the open ocean, including oceanic islands, seamounts, rises, and a narrow, deep trench - the Atacama.

Knowledge on these points has been advanced during the last decade except for the latter point which remains relatively unexplored. On the other hand, the oceanic islands (e.g. Easter Island, Salas y Gomez, Juan Fernandez Archipelago) and seamounts around them have been recognized as high priority regions for conservation based on specific scientific criteria (e.g. Clarke et al., 2014) but no scientific programs for studying and monitoring them have been established yet.At the same time, the international experience on seamounts in particular is still scant and several issues remain to be scientifically evaluated (review in Rowden et al., 2010). Moreover, most of the focus on seamount studies has been on benthic ecosystems or communities and much less attention given to pelagic ecosystems or communities (Rowden et al., 2010; Santos et al., 2013), including the oceanographic processes (from basin scale to (sub) mesoscale), the planktonic communities (from viruses to macroplankton), and the potential trophic link or biogeochemical flux between pelagic and benthic systems in seamounts.

Seamount ecosystems are topographic features which can create a complex pattern of currents and which can also enhance (sub-) mesoscale activity by generating eddies or vortices or they can represent a barrier for their propagation or a decay zone for eddies arriving close to seamounts (Sokolovskiy et al., 2013). In some cases, these physical processes can create localized regions of upwelling, injecting nutrients into the photic or mixed layer and thereby can enhance phytoplankton biomass and/or production (REF). In the same line, local increases in primary production of phytoplankton can lead to local increases in organic particle flux which can fuel suspension feeders in the benthic system (e.g. Samadi et al., 2006).Also, pelagic and demersal fishes aggregate around seamounts (Parin et al., 1997), probably due to enhanced food availability, and this has been exploited by the fishing industry until recently. Nevertheless, seamounts remain as one of the least known habitats on earth (Wessel, 2 2007) and part of the paradigms about them appear to be fiction based on big gaps in knowledge (Rowden et al., 2010). On this framework, our group would like to explore some of the following scientific questions applicable to the seamounts in the SE Pacific region, focused on the Salas y Gomez Seamount chain:

- how seamounts influence the current patterns in the area and in their vicinity and what is the effect of a chain of seamounts on these patterns?
- what is the extent of sub- and mesoscale activity around different types of seamount in the chain and do eddies/vortices generated within their area produce upwelling of nutrient-rich waters?
- what type of response develops the phytoplankton in connection with the (sub-)mesoscale activity in the area and vicinity of seamounts
- what is the structure and spatial coherence of microorganism communities (taxonomic and molecular) inhabiting seamount ecosystems and how different are they from the communities in the areas not influenced by them?.
- what is the structure and spatial coherence of meso- and macroplanktonic, as well as micro-nektonic, communities (taxonomic and molecular) inhabiting seamount ecosystems and how different are they from the communities in the areas not influenced by them?.
- What types of links exists between the pelagic and the benthic communities in the areas of seamounts (e.g. passive sinking of pelagic components/production, active transport, etc.)?

Brief Overview of Target Area

Most of the seamounts are concentrated along the Sala y Gomez ridge and Nazca Ridge. There are over 400 seamounts of at least 200 m height in this area (Rappaport et al., 1997). Seamounts have a major influence on the physical structure of the water column.At a large scale they may deflect major ocean currents. Smaller-scale effects include the formation of trapped waves, the reflection, amplification and distortion of internal waves and amplification of tidal currents. One of the most common effects of potential biological significance is the Taylor Columns formation. Taylor Columns are associated with upwelling of nutrient rich water from the deep ocean and may lead to increased productivity in the upper waters above or downstream of seamounts. These structures may be temporary, seasonal or semi-permanent and their role in seamount biology is poorly understood. Plankton biomass may be increased over seamounts as a result of local enhancement of productivity. In consequence, they form a food source for larger, commercially valuable species 3 of pelagic fish such as sharks, rays, tuna and swordfish. The association of such commercially valuable fish species with seamounts is well known and therefore these habitats and the waters overlying them are subject to trawling and long lining throughout the world's oceans.

Feasibility of Studying this Target Area

During the present year, the Chilean government provided 10-y funding for the creation of the "Instituto Milenio de Oceanografía" (IMO), presented by a multidisciplinary group of 8 researchers from 3 different universities in Chile: U. de Concepcion, P. U. Católica, and P. U. Católica de Valparaíso, and to which today pertain about 20 scientists and several postdocs, graduate and undergraduate students. IMO main themes involve the exploration of the open seas in the South Pacific, including islands, seamounts, rises, and the Atacama Trench. Therefore, we can provide a series of services/consumables and appropriate equipment/technology to undertake a multidisciplinary study in the region. At the same time, we are prepared to collaborate with other groups which are interested in seamounts; in Chile, they include biologists/ecologists focused on benthic fauna (Drs. Javier Sellanes, Martin Thiel, Carlos Gaymer and Guillermo Luna-Jorquera) and belong to the newly-created program, Ecology and Sustainable Management of Oceanic Islands (ESMOI), based at the U. Católica del Norte. Since last year, Chile has also a new oceanographic platform for open ocean exploration, the R/V "Cabo de Hornos" (e.g. http://www.ship-technology.com/projects/rv-cabo-de-hornos/) and it could be considered for this type of studies.Access to the study sites should be possible from ports in Chile (Coquimbo, 4 Valparaiso) and in Easter Island.

Education & Outreach Potential for Exploration at this Target Area

IMO formally includes educational and outreach activities, under the coordination of our colleague Pablo Rosenblatt (http://www.cienciavida.org/pablo-rosenblatt/), a film producer and specialized in scientific contents and in the creation of scientific material for the use in K12 education. IMO is seeking to contribute with appropriate technologies to make accessible to the public the knowledge generated by us. We will also directly collaborate with the UCN Aquarium and Museum (current Director: Dr. J. Sellanes). It is our policy that data, documents, and scientific products generated by IMO should made available to the public whenever this is possible. Besides this, we are requested to formally provide our cruise data to the Chilean National Oceanographic Data Centre (Centro Nacional de Datos Oceanográficos de Chile, CENDOC) and we also collaborate with information to the Ocean Biogeographic Information System (OBIS).

We will coordinate a meeting with the Chilean oceanographic data system (CENDOC and the Service of Hydrography and Oceanography of the Navy, SHOA) to inquire about bathymetry and oceanographic data in the region but at present there is little information available.

The Revillagigedo Archipelago and Mathematician Ridge

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Collaborators

Claus Siebe (Institute of Geophysics, UNAM)

Region

East Pacific Rise
E Equatorial Pacific

Rationale for Exploration

Shallow submarine volcanism that produces large floating lava balloons is one of the most peculiar and rarely observed eruption styles on Earth (Kueppers et al., 2012). Eruptive conditions that generate these products are not well understood due to their rare occurrence and paucity of direct submarine observations. This has led to debate as to the style of submarine eruptions that produce these unique deposits. There have been only five cases where lava balloons have been observed on the surface during submarine eruptions. One these, the 1891 eruption of Foerstner volcano northwest of Pantelleria island (Butler, 1892; Washington, 1909), was studied by the E/V Nautilus in 2012 during cruise NA018 in the Straits of Sicily (Carey et al., 2012). A more recent example occurred in 1993 during an eruption near Socorro Island (Mexico), in the Eastern Pacific (Siebe et al. 1995). No submarine investigations of this 1993 event have been carried out and this provides an excellent opportunity to explore the nature of this unusual eruption style at another well-documented site. Soccorro island is part of the Revillagigedo Archipelago located near the northern part of the ancient Mathematician Ridge spreading center. It is an area of active subaerial and submarine volcanism with several historic eruptions taking place during the last century. The production of highly evolved alkaline magmas in this area coupled with the recent submarine/subaerial activity also makes this an interesting area to explore in relation to hydrothermal activity that is likely to be unique compared to the nearby fast-spreading East Pacific Rise.

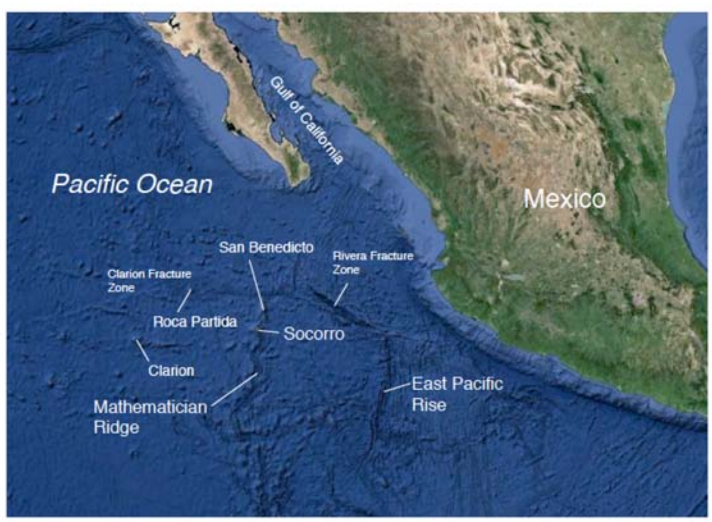


Figure 1. Location of the Revillagigedo islands (Soccorro, Clarion, San Benedicto and Roca Partida) in the eastern Pacific Ocean.

Brief Overview of Target Area

The Revillagigedo Archipelago in the eastern Pacific consists of the islands of Socorro, Clarion, San Benedicto, and Roca Partida (Fig. 1). Socorro is the largest of the group with an area of 120 km2 and a single summit of 1050 m occupied by Mt. Evermann (Seibe et al., 1995). It is a large basaltic shield volcano with a volume of 2500 km3 based on a radius of 24 km at 3000 m water depth. The islands are located at the northern end of the north-trending Mathematician Ridge near the intersection with the Clarion Fracture Zone and just to the southwest of the Rivera Fracture Zone (Fig. 2). Marine geological studies of the Mathematician Ridge indicate that it was an active spreading center from 6.5 to 3.9 Ma B.P., but was then abandoned during plate reorganization and establishment of the present East Pacific Rise about 500 km to the east (Mammerickx et al., 1982; 1988). Despite the abandonment there has been active volcanism in this area up to recent times. On Socorro island eruptive events occurred in 1848, 1896, 1951 and 1993. In 1953 a spectacular eruption of Isla San Benedicto produced a new volcano, Barcena, that grew violently from the sea and developed into a tuff cone 400 m high in only two weeks (Williams, 1952).

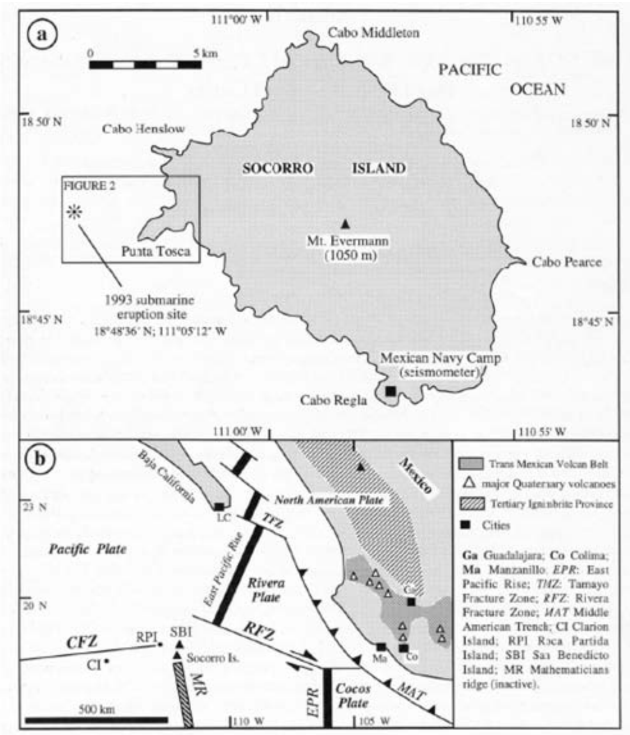


Figure 2. a) Map of Socorro Island showing the location of the 1993 submarine eruption off west coast of the island. b) Map showing the location of the Revillagigedo islands in relation to the major plate boundaries of the eastern Pacific. Figure from Seibe et al. (1995).

A distinctive feature of the volcanism in the Revillagigedo islands is the alkaline and evolved nature of the magmas being erupted, including alkali basalts, peralkaline trachytes, pantellerites and rhyolites (Bohrson and Reid,1995; 1997). Along the Mathematician Ridge dredge rocks also exhibit an alkaline character with volatile-rich hawaiites and trachytes being recovered near the intersection with the Clarion Fracture Zone (Batiza and Vanko, 1985). The alkaline and evolved nature of the volcanism in this region is consistent with spreading center abandonment and late stage alkaline volcanism as seen in other extensional geological environments and large oceanic islands.

Bathymetric data near the northern part of the Mathematician Ridge, just to the south of Socorro island, indicates the presence of numerous small cone-shaped seamounts. This is reminiscent of the occurrence of many similar cone-shaped structures located just offshore of Pantelleria island in the Straits of Sicily where an 1891 eruption also produced floating lava balloons (Carey et al., 2012).

Brief Summary of What is Known of Target Area

A prime area of interest is the site of the 1993 submarine eruption that produced basaltic lava balloons on the sea surface near the island of Socorro (Fig. 2). Indications of a submarine eruption were first detected by SOFAR hydrophones near Hawaii and Haiti. Ten days later on January 29, 1993 floating lava balloons were observed on the surface (Siebe et al., 1995). The balloons gave off steam and eventually broke into pieces and often were propelled laterally by vigorous steam jets. An area up to 6000 m2 was covered by floating lava balloons that remained on the surface for up to 15 surface for up to 15 minutes before sinking. The activity lasted intermittently for at least 15 months. Lava balloons appeared to be generated from two areas in water depths of 30 and 210 m (Seibe et al., 1995). A bathymetric survey taken two months after the start of the eruption revealed the presence of two submarine vents along a steep irregularly-shaped ridge that trended in a NE-SW direction off the coast of Socorro island (Fig. 3). The vents, especially the deeper one at 210 m are likely constructional features formed by the accumulation of eruptive products during several months of activity. Samples of meter-sized lava balloons collected on the surface consisted of highly vesicular homogenous alkali olivine basalt with relatively few crystals (Siebe et al., 1995). Some clasts consist of reticulite, an extremely vesicular magmatic foam that is produced only by high levels of CO2 degassing (Fig. 4). It has been proposed that the balloons were formed by intermittent submarine lava fountaining at fixed vents caused by changes in eruption velocity induced by fluctuating magmatic gas contents (Siebe et al., 1995). In particular, the formation of reticulite requires a high magma ascent rate and a rather narrow conduit to prevent gas escape. Much can be learned about the eruptive mechanisms of these types of eruptions by detailed mapping and ROV studies of the vent areas and the eruptive products on the seafloor as was done during cruise NA018 of the E/V *Nautilus* (Kelley et al, 2014).

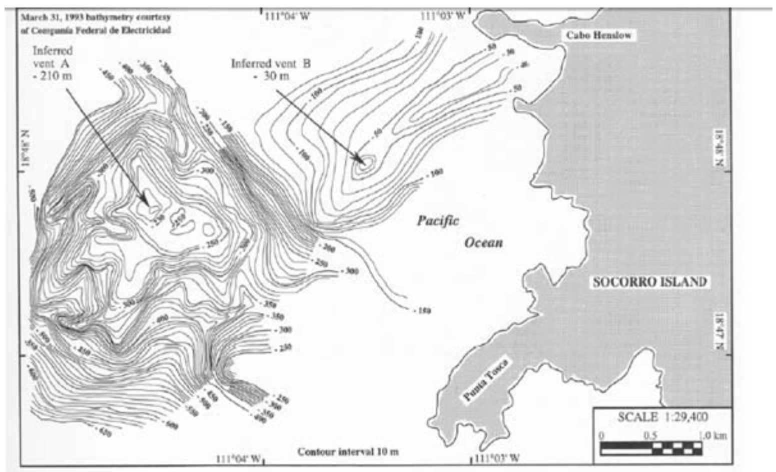


Figure 3. Bathymetric map of the proposed vents sites (A and B) for the 1993 submarine lava balloon eruption off the coast of Socorro Island. Figure from Seibe et al. (1995).

A second area of interest encompasses parts of the Mathematician Ridge that lies to the north and south of Socorro island. Dredging of volcanic rocks along the ridge have recovered fresh samples indicating recent eruptive activity.

Educational and Outreach Potential for Exploration of Target Area

The Revillagigedo Archipelago and Mathematician Ridge of the eastern Pacific is an interesting area for education and outreach activities because of the potential for discovery in a variety of areas. First, from a geological perspective there is the theme of submarine eruptions and lava balloon formation; a fascinating process to explore and try to understand. Excellent video footage of a recent lava balloon eruption in the Canary islands is available and could be used to engage students and the public in the nature of the problem (http://www.youtube.com/watch?v=9kCUFWmqsR8&feature=related).

There is also a strong possibility that there will be hydrothermal venting and biological communities associated with the young volcanic activity of the area. These aspects are typically of great interest to students and the general public owing to the exotic organisms that thrive at vents and the extreme conditions under which they live.

The islands also have a great interest to biologists as they are one of the main wintering grounds of Pacific humpback whales and little is known about their summer feeding grounds (Lagerquist et al., 2008). In addition, like the Galapagos islands the Revillagigedos also host a number of endemic bird, reptiles, and insects (e.g. Rodriguez-Estrella et al., 1996; Arnaud et al., 1993) that make for unique ecosystems that are in need of conservation.

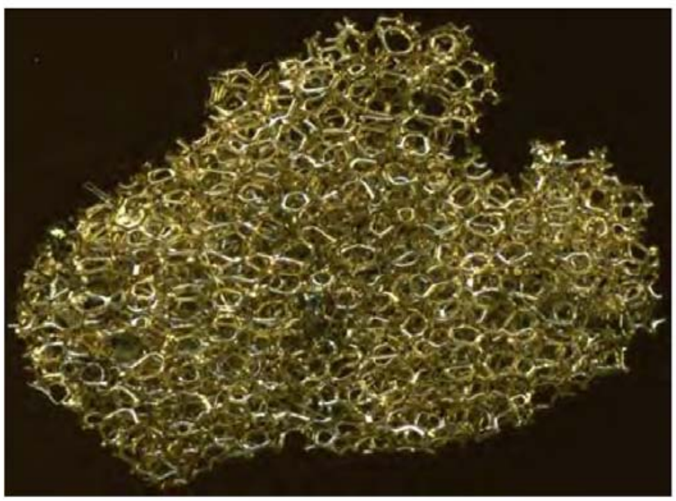


Figure 4. Sample of basaltic reticulite produced at Kilauea volcano, Hawaii.

Pito Deep, EPR

Mike Cheadle (University of Wyoming)

Collaborators

Christopher German (WHOI)
Jeffrey Gee (Scripps)
Barbara John (University of Wyoming)
Laurence Coogan (University of Victoria)
Katherine Gillis (University of Victoria)

Region

Galapagos/Cocos Ridge
East Pacific Rise
SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise

Rationale for Exploration

i. To understand the geological context of, and explore and sample, the black smoker hydrothermal vent system at Pito Seamount (23° 19.65'S, 111° 38.41'W at a depth of 2270m). Pito Seamount lies at the southeastern end of Pito Deep and is interpreted to be the focal point for a developing/new ridge axis propagating to the NW along Pito Deep (Naar et al., 1991). The seamount is large with an anomalous 7.5km by 5km dome sitting at its summit, and its origin is unknown. The vent system was discovered in 1993 during a single Nautile Dive (Naar et al., 2004), along with relict, extinct chimneys and shimmering water in a few places along the single track (supplementary figure). No temperature probe measurements, vent fluid or biological samples were taken. We propose to explore the geological setting of this new vent system, map the vents in detail, and collect fluid and biological samples to fully characterize the vent system and examine how the vent-site and it's biological community has evolved since the only previous visit in 1993. It should be possible to use the biological samples for genetic studies to compare with species collected elsewhere along the EPR in this region to test for barriers to larval dispersal.

ii. To explore/sample the dike-gabbro transition of superfast ocean crust exposed along unexplored fault scarps at Pito Deep (5980m, ~22° 55'S, 111° 40'W). Superfast spreading ridges are the most volcanically active plate boundaries and consequently they host more hydrothermal activity than anywhere else on the Earth. However, the lavas produced by the volcanism ubiquitously cover, and make direct observations of, the frozen magma chambers that fed the lavas and their associated hydrothermal plumbing systems very difficult. Pito Deep is one of the few places in the Pacific where a tectonic window exposes the dike gabbro transition and hydrothermal plumbing system to submersible exploration. The fault scarps of the Pito Deep Rift, located near the NE corner of the Easter microplate have >3km of relief and expose sections of crust created at the East Pacific Rise (EPR) at a "superfast" spreading rate of >140 mm/yr (Francheteau et al., 1988; Hekinian et al., 1996; Karson et al., 2005). Nautile and Jason II/Alvin have visited the westernmost scarps, however the Nautile dives were reconnaissance dives and the Jason II/Alvin dives focused on the upper dike-basalt section. Here we propose to map and sample the previously un-explored eastern scarps (supplementary figure). Exposures along the eastern scarps at Pito Deep offer the possibility to systematically sample superfast-spread oceanic crust at deeper structural levels than previously, and address outstanding questions regarding hydrothermal circulation, the width and the temporal evolution of axial magma chambers.

iii. To carry out a night time CTD program using towed sensors to explore for previously undetected hydrothermal plumes along the ridge NW from Pito Seamount into and along the Pito Deep Rift. SeaBeam bathymetry and one Nautile dive confirms the presence of volcanoes at the bottom of the Deep. Is this ridge/rift an active seafloor spreading center with previously unrecognized active hydrothermal vents?

Brief Overview of Target Area

Pito Deep is located at ~23°S at the northeast corner of the Easter microplate and marks the northernmost tip of the propagating East Rift of the southern EPR (Francheteau et al, 1988, Hey et al, 1995; Karson et al, 2005). Pito Seamount lies at the SE end of Pito Deep and marks the transition from the more N-S oriented East Rift of the EPR to the NW-SE oriented Pito Deep. Pito Seamount is a young and recently active volcanic seamount with an active black smoker vent site at its summit (Naar et al., 2004). The NE side of Pito Deep consists of a series of NW-SE trending extensional fault blocks (Naar et al., 1991) that provide >3km deep sections through the uppermost ocean crust. These scarps formed at a rate of ~10 mm/yr when the lithosphere was rifted apart <1 Mya. Although the present morphology is the result of recent slow tectonic extension, the exposed crustal structure along the scarps was formed by normal superfast seafloor spreading (>140 mm/yr) approximately 3 million years ago at the EPR. The scarps cut the abyssal hill fabric at a very high angle in an ideal orientation perpendicular to spreading-related structures, creating a natural and relatively unexplored cross-section through superfast spread crust. These scarps also expose crust formed over multiple geomagnetic reversals and mapping these magnetic boundaries provides important constraints on the thermal structure of crust.

Brief Summary of What is Known of Target Area

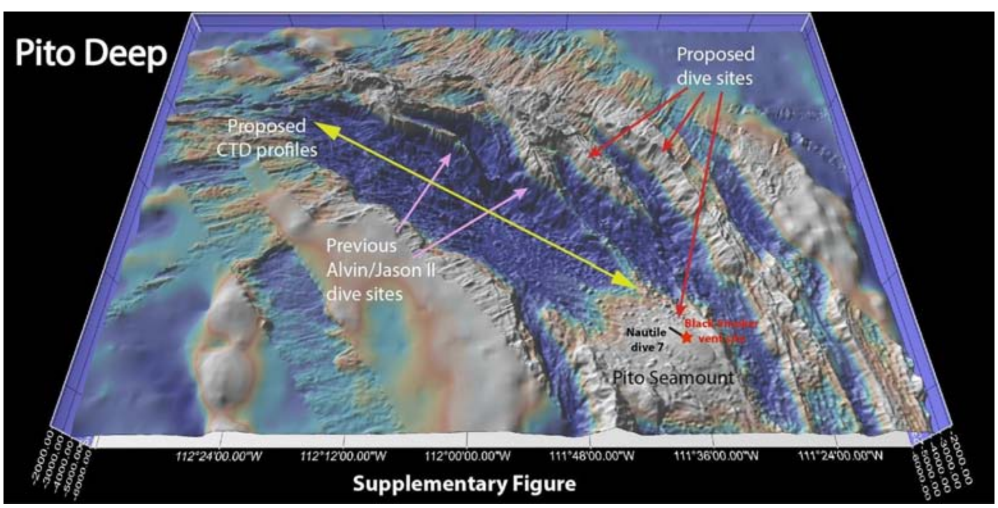
The target area has been previously mapped by SeaBeam and SeaMARC II and by a magnetometer survey. Two submersible dive programs have been carried out in the area (one Nautile - Francheteau et al., 1994; and one Alvin/Jason II - Karson et al., 2005). These dive programs show that the gabbro/dike/basalt transition and >1km of the gabbro section is exposed in the westernmost scarps. However the similar sized easternmost scarps remain unexplored. There has only been one single Nautile dive on Pito Seamount, which discovered the black smoker vent system with a fauna of alvinellid, bythograeid, bythitid fish, alvinocaridid shrimp, but no vestimentiferan tubeworms (Naar et al., 2004). However there has been no fluid or biology sampling. There is little sediment cover on the Seamount suggesting that it was recently volcanically active. SeaBeam bathymetry shows a large anomalous, elongate dome lying at the top of the seamount (supplementary figure), and the origin of the seamount itself, is unknown.A CTD program has not been previously carried out along Pito Deep, although a small volcano was discovered during one Nautile dive to the bottom of Pito Deep at ~5500m, suggesting the rift is active and hydrothermal vents may be present.

Feasibility of Studying Target Area

The Pito Deep rift is comparatively young and previous cruises have recognized abundant outcrop. Pito Seamount is relatively shallow at 2270m and is easily accessible to Hercules, providing an opportunity to investigate a new vent system (and biological activity) hosted in this unusual environment. The gabbro-dike transition has been recognized at ~3500m in the western scarps and from structural arguments is likely to be at ~2500m in the easternmost scarps. Therefore up to 1500m of the gabbro section should be accessible by Hercules. The exploration of the gabbro-dike section, perhaps the critical boundary within the oceanic crust, would involve detailed mapping and sampling to provide a unique and unprecedented sample-set to further investigate the interlinked magmatic and hydrothermal processes involved in the formation of fast-spread oceanic crust at a ridge segment center.

Educational and Outreach Potential of Target Area

The proposal is multidisciplinary (geology, biology, chemistry) and currently involves proponents from four universities/institutions (University of Wyoming, WHOI, Scripps and the University of Victoria) from two countries (USA and Canada). The University of Wyoming (UW) has previously been involved in one NOAA Ocean Exploration (2011) cruise and one Ocean Exploration Trust (2013) cruise, both to the mid-Cayman Spreading Centre; the most recent cruise (NA-034) involved a team of 6 UW undergraduate and graduate students as observers and data collectors on a 24-hour rotation. One graduate student is currently investigating samples recovered from this expedition for his Masters degree. We and the other proponents would envisage involving both undergraduate and graduate students during the dive program, and organizing live public events at our respective universities/institutions (for example a live video feed to the Birch Aquarium at Scripps and the University of Wyoming Geological Museum). The samples collected would form the basis for graduate student research.



Supplementary Figure

Costa Rica Margin

Erik Cordes (Temple University)

Collaborators

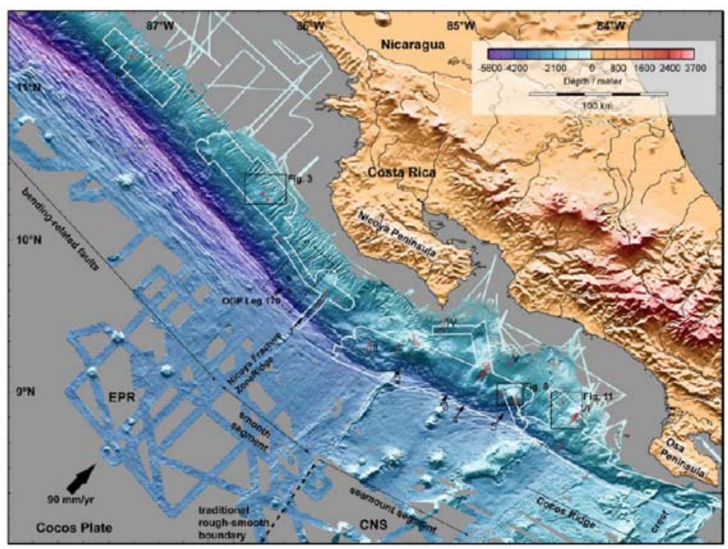
Lisa Levin (Scripps Institution of Oceanography)
Greg Rouse (Scripps Institution of Oceanography)

Region

Galapagos/Cocos Ridge

Rationale for Exploration

We propose to further explore the hydrothermal seeps of the understudied Pacific Margin of Costa Rica, an unusual location where warm hydrothermal venting and methane seeps coincide and support diverse chemosynthetic communities. These hydrothermal seeps are caused by the rare geological process of seamount subduction and subsequent deformation and landslides along the slope toe. We have begun to reach the stage of deep-sea exploration where we can ask questions about the global connectivity of marine populations and communities, and these sites potentially contain some of the answers. Large- scale models of deep-sea biogeography have been developed and regions of interest were prioritized as part of the International Census of Marine Life. One of these regions was the "Atlantic Equatorial Belt", stretching from the Gulf of Mexico through the Caribbean, over the Mid-Atlantic Ridge, and across to the Atlantic margin of Africa. Recent work on the Pacific margin of Costa Rica suggests that the "hydrothermal seeps" may also lie within this biogeographic province, and also overlap with some of the nearby hydrothermal vent communities of the East Pacific Rise, Galapagos Rift, and Guaymas Basin.



Brief Overview of Target Area

The Pacific Margin of Costa Rica includes an active subduction zone where the Cocos plate slides beneath the Caribbean plate. This results in episodic and rapid flux of sub-surface fluids through permeable conduits to venting sites on the seafloor (Kahn et al 1996). Although initially believed to be a result of sediment dewatering resulting from accretionary processes along the lower slope, it has been shown that the warm seeping fluids are derived from the rare process of seamount subduction (Bohrmann et al. 2002). This process leads to the indentation of the overriding slope by the seamounts causing mound formation, faulting, and seafloor instability causing frequent landslides and potentially tsunamis (von Huene et al. 2004). The surface expression of these processes includes gas venting with some mud volcanism, and numerous patches of authigenic carbonates on the large mounds, and exposed sediments associated with the faults, scars, and landslides (Sahling et al. 2008). Where active seepage and authigenic carbonates coincide, there are typically dense chemosynthetic communities, which vary with depth (Levin et al. 2012). The shallowest seep sites between approximately 250 and 550 m depth within the oxygen minimum zone (Bohrmann et al. 2002), there are gigantic bacterial mats covering large areas of the seafloor. Deeper than this, there is sufficient oxygen in the seawater to support chemosynthetic communities at active sites and deep-water coral communities on inactive carbonates. These sites typically occur between 20 and 40 km from the edge of the subduction zone where the seamounts have caused the most landward deformation, fracturing in the overlying mound, and sediment collapse on the seaward edge. Although many of these areas have been previously explored, there are over 100 mounds and other anomalies that have not yet been directly observed.

Brief Summary of What is Known of Target Area

Of particular interest in this area are the chemosynthetic communities at the hydrothermal seeps and their connectivity with the surrounding cold seeps and hydrothermal vents. There are numerous similarities between the fauna of the Costa Rica seeps and the seeps of the Gulf of Mexico, even though the deep-water connection between the Pacific and the Caribbean was closed as early as 13-21 million years ago (Stiller et al 2013), owing to the rising of the Isthmus of Panama. There are additional affinities with both the other seeps of the Pacific along the west coast of the US and extending down to Peru and Chile, as well as the notable presence of the yeti crabs (Kiwa puravida) (Thurber et al. 2011). Of the smaller macrofauna, many of these share affinities with the nearby vents fauna of the East Pacific Rise, Galapagos Rift, and Guaymas Basin (Cordes, Levin, Rouse unpublished data). Biogeographic patterns of microbial diversity within seafloor reducing environments are also emerging, although the similarities in these patterns at different scales of biological organization remain unexplored.Although these seep communities have been described at a basic level (Levin at al. 2012), more complete quantitative sampling and genetic identifications are necessary to truly understand their placement in the global biogeographic context and the relative uniqueness of this system.

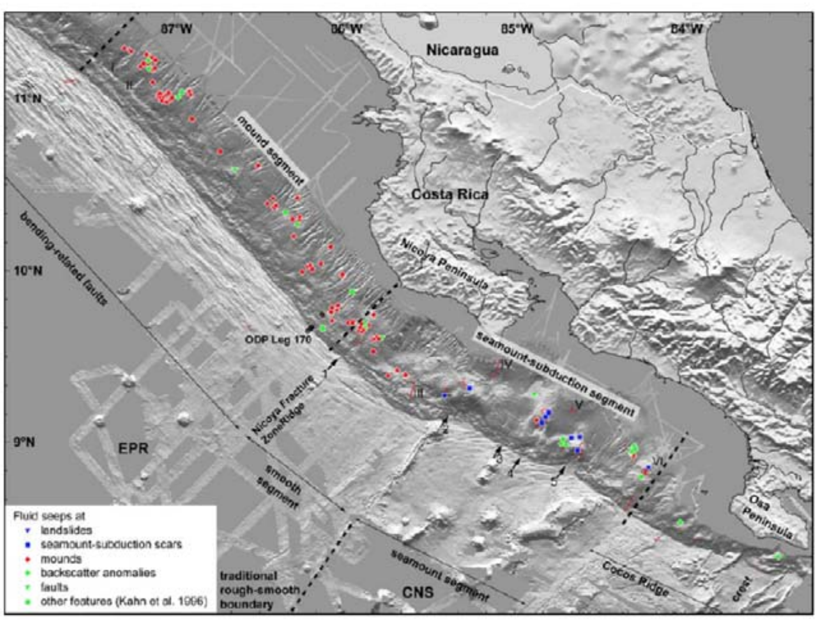
There is even less information on the deep-water coral communities of the region. However, numerous corals were observed during the Alvin dives in 2009 and 2010 with one species described from these samples to date (Opresko & Breedy, 2010). Targeted and limited coral collections will augment our current work in the Gulf of Mexico, and will help determine connectivity patterns and whether the Isthmus of Panama served as a vicariance event leading to the formation of incipient species in the deep sea. We will also collect discrete water samples adjacent to the corals we discover in order to characterize the current state of ocean acidification for the first time in this region. It is likely to be similar to the other nearby areas of the eastern Pacific, which are near or below the aragonite saturation horizon. If deep-water scleractinian (reef-forming) corals are discovered, they may be surviving under the most adverse conditions ever recorded.

Feasibility of Studying Target Area

This proposal fits in with the larger field season linked to the proposals for the Pacific by the co-PIs and other collaborators. Levin has established collaborations with scientists from Costa Rica. We will include them in the cruise and vouchers from our physical collections will be deposited in their museums in order to ensure proper permitting to work within Costa Rica waters. We will depart and return to Puntarenas, Costa Rica. The sites are within a 12 hour steam from port. There are many known seep sites, extending from 400 m to a maximum depth of nearly 2000 m. We plan 2 days of work at strategically selected sites on subducting seamounts and their associated seepage features, for a total of approximately 20 days at sea.

Education and Outreach Potential of Target Area

The goals of this proposal are to utilize the state-of-the-art research platform of the EV Nautilus and Argus-Hercules to complete the surveys and the sampling necessary for our inter-disciplinary team to fully understand this complex ecosystem at all levels of biological organization. We will communicate the findings immediately through the use of telepresence technology. Our group has had extensive experience with telepresence, and we are actively engaged in educating the public about the deep sea while we discuss our findings. We will also cultivate an interactive web-based following of our existing network of personal and professional contacts through both Scripps' internet infrastructure and our own social media resources. We will bring local Costa Rican scientists on the cruise with us, as we have before, to ensure that their institutions are involved and samples are transferred to local repositories, and also to facilitate communications within Costa Rica and throughout Central America. Through these outlets, we will broadly and rapidly communicate our findings to both scientists and the general public alike.



Petit Spot Volcanism off the Coast of Chile

Fred Davis (Smithsonian Institution)

Collaborators

Katherine Kelley (University of Rhode Island)
Elizabeth Cottrell (Smithsonian Institution)

Region

SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise

Rationale for Exploration

In 2001, the discovery of small (1-2 km dia.), young (<1 Ma.) basaltic volcanoes oceanward of the Japan trench was announced. These volcanoes, dubbed "petit spots", represent a new type of previously unknown and unexpected oceanic volcanism, although the origin of the Japanese petit spots is still uncertain. They are not located near a mid-ocean ridge and are on the passive side of a subduction zone, so they did not form due to a response by the mantle to plate tectonic processes, and there are no mantle hotspots in the vicinity of the petit spots. The chemistry of the petit spot lavas suggests that they formed in the mantle at depths below the lithosphere-asthenosphere boundary. They may thus form due to brittle fracturing of the oceanic plate in response to compressional stresses associated with subduction at the Japan trench. If so, then petit spot volcanoes may be ubiquitous features of subducting oceanic plates globally. We propose an exploration of the region near the outer rise of the Chile trench with the goal of sampling young basalts from petit spot volcanoes.

Direct, in situ observation of petit spot volcanoes is essential to understanding their place in the Earth system. Age constraints, paired with observed volcanic stratigraphy and measurements of the water properties around these volcanoes and in the overlying water column, will reveal the timing of eruption and longevity of these systems. Do they represent instantaneous geological events, or do these volcanoes have an extended lifetime of volcanic and/or hydrothermal activity? Moreover, sampling petit spots on the Nazca plate would be invaluable to our understanding of mantle composition and dynamics. If this new category of volcano is not unique to Japan, it promises the opportunity to sample low degree melts of the "ambient" upper mantle globally. The geochemical information that these basalts would provide cannot be found in other types of oceanic volcanism. Unlike high-degree melts from ridges, petit spots should not obscure small-scale heterogeneities in mantle composition. Unlike low-degree melts from mantle plumes, petit spots should not tap unusual mantle depths, compositions, or thermal anomalies. Furthermore, Japanese petit spots also carried with them numerous mantle xenoliths, so it may be possible for petit spots near Chile to provide direct samples of the mantle in this region. The potential discovery of petit spots near Chile would also provide constraints on the strength of the oceanic lithosphere and the depth of fracture networks near subduction zones. Recently erupted volcanoes with low sediment cover, distal from active hydrothermal systems near ridges, might provide a unique biological habitat that is totally unknown to science. Enrichment of basalt in potential nutrients such as phosphorus may be conducive to supporting biota.

Brief Overview of Target Area

We have selected an area near the outer rise west of the Chile trench (Figure 1). Petit spot volcanoes are thought to form where the lithosphere fractures oceanward of the outer rise, and then the volcanic edifices are carried along with the plate towards the trench. This means that the outer rise itself should host quiescent, but recently active petit spot volcanoes. Apparent faulting west of the rise suggests a stress-state and rheology of the plate that is conducive to petit spot volcanism, and the several small seamounts of approximately the expected scale of petit spots are visible in the bathymetric data on the rise. The whole outer rise area in this region is at a depth shallower than 4000 m, which will allow sampling by ROV. We want to avoid areas associated with known mantle hotspots to limit ambiguity as to the origin of any basaltic volcanoes that are discovered. The target region is comfortably south of the Easter Island seamount track and north of the San Felix hotspot track.

Brief Overview of What is Known of Target Area

Three cruises have traveled across the target region between 2000 and 2002. COOK02MV, DANA03RR, VANC03MV collected multibeam bathymetric data that reveal the presence of small seamounts (1-3 km dia.) in the target area. As the target area is approached from the west, the seafloor is relatively free of seamounts until about 150 km west of the outer rise. Small seamounts, similar in height and diameter to the Japanese petit spots, are common from about 150 km west of the rise to the Chile trench. Trench-parallel linear features are common in the area, which may suggest faulting that could provide fracture networks for melt transport. A cruise in the broader Chile-trench region returned relatively young basalts (6-10 Ma.) from near the trench at roughly 73°W and 33°S that were interpreted to be erupted by petit spot volcanoes; however, this sampling site is coincident with the Juan Fernandez hotspot track, and the origin of these basalts is ambiguous.

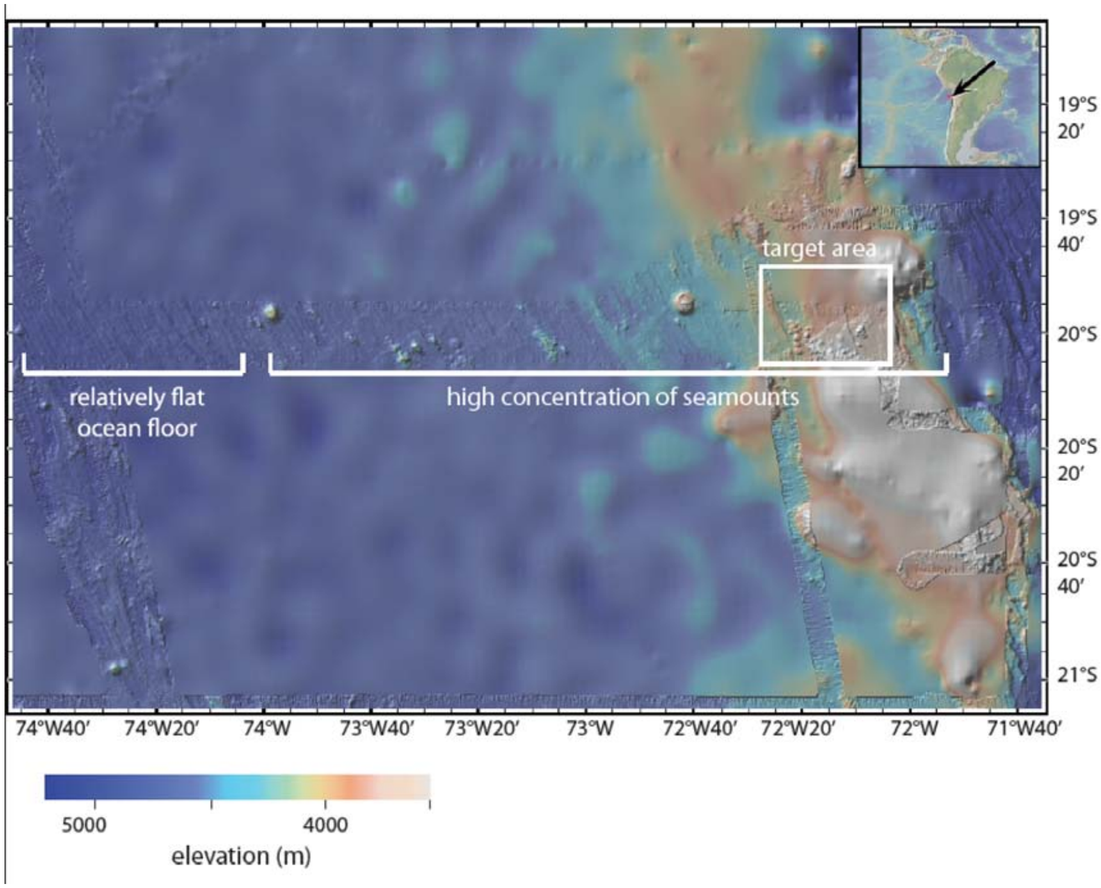
Feasibility of Studying Target Area

The target area is approximately 260 km from the Port of Arica and 1450 km from Valparaiso. The target could be reached within 14 to 78 hours of departure depending on the port of origin. Depth to the seafloor in the target area is well within the 4000 m depth limit of ROV Hercules.

Education and Outreach Potential of Target Area

The National Museum of Natural History (NMNH), Smithsonian Institution, offers unparalleled opportunities to engage public audiences in ocean exploration. Potential vehicles for public engagement include “Live from Q?rius” webcasts (customized to align with middle school Earth Science curricula) and exhibition of retrieved materials and multi-media footage in NMMH’s new Sant Ocean Hall or new public outreach hall, Q?rius. Meet-the-scientist engagement events, public lectures, and online and social media experiences accessed through Smithsonian’s popular “Ocean Portal” (http://ocean.si.edu/) or iTunes University series could all be leveraged. ROV footage of volcanic edifices and basalt sampling could be paired with interviews with members of the scientific team for Nautilus Live and archived and broadcast online (e.g. the Ocean

Portal's "Vents and Volcanoes" pages) or for in-house events. By taking advantage of these existing structures we have the potential to bring the Nautilus experience to tens of thousands of school children and members of the lay public (domestic and international).



Chile Rise

Brian Dreyer (University of California, Santa Cruz)

Region

NE Pacific Basin
Galapagos/Cocos Ridge
East Pacific Rise
SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise
E Equatorial Pacific

Rationale for Exploration

The Chile Ridge was ranked in the top 5 (out of 40) ridge segments in need of exploration, and the only one in the Pacific basin (InterRidge Long-Range Exploration working group, 2010). It is a type-example of a Trench-Trench-Ridge triple junction. Young lithosphere created at Chile Ridge subducts obliquely beneath South America plate. It is a natural laboratory for the study of myriad processes interacting within and beneath the sea. This area is ripe for exploration using advanced deep-sea tools.

Recent large-scale bathymetric mapping has revealed many compelling questions regarding the interplay of magmatic and tectonic processes. In general, the morphology and structure of the Chile ridge axis likely reflects complex relationship between local magma plumbing, ridge-transform forces, and regional "plate-edge" factors associated with oblique subduction of the Nazca plate (e.g., age-dependent lithosphere buoyancy and mechanical resistance to subduction) that affect mantle flow, melting, and detailed kinematics (summarized after Blackman et al., 2012).

The petrology and geochemistry of the Chile Ridge basalts is also intriguing because it is the only known location where 1) a mid-ocean ridge is subducting beneath a continental arc and 2) where mid-ocean ridge basalts have "subduction zone" geochemical affinities (Karsten et al., 1995). Issues of geochemical "feedstock" are compounded by largely unconstrained effects of plate bending on mid-ocean ridge magma generation process (InterRidge's Long-range Exploration WG, 2010). For example, recent volcanic activity is oblique to axial trends and cannot be explained by simple models of ridge-transform intersection forces (Blackman et al., 2012). Further information on the geochemistry, occurrence, and morphology of young Chile Ridge lava may clarify their unique petrological underpinnings, including whether there is a slab window where the subducted plate "unzips" along the ridge axis and modifies shallow mantle flow. Continental slope sediments overlie the southeastern part of the Segment 1 of the Chile ridge. Recently, Lizarralde et al (2010) explored how "sedimented ridges" act to defocus magmatic activity at the base of the lithosphere, resulting in broad zones of shallow magma emplacement into carbon-rich sediments. Consequently, young sedimented ridges are be potential source of CO_2 to the ocean. Furthermore, it is likely that sedimentary components are incorporated into hydrothermal fluid circulation pathways, and therefore are interconnected with diverse ridge biological communities (German et al., 2010).Active hydrothermal vents may be discovered with further exploration of the bottom guided by existing bathymetric data and plume signals detected in the water column. The biogeography of hot vents near to whale falls, cold seeps, etc. is also compelling (InterRidge's Long-range Exploration Working Group, 2010). Volcanic edifices are also built upon the sediment fill shed from the continent, but little is known about geological relationships and interactions. Consequently, direct observation and sampling on the seafloor in this vicinity can provide important clues to understanding the nature of magmatic emplacement into or onto the sedimented seafloor at ≥2900 mbsf.

Brief Overview of Target Area

Three tectonic plates intersect in this region (Nazca, Antarctic, South American), and the Chile Ridge spreading center subducts obliquely beneath continental crust of the western margin of South America, creating the Andes volcanic arc. Earthquakes in the vicinity of the triple junction are rarely larger than M6, but historical earthquakes >M7 have occurred within 800km associated with plate convergent and pose an extreme hazard to human life and infrastructure. Segments 1 to 4 of the Chile Ridge (stepping outward from the continent) are offset by transform faults of subequal length, generally elongating away from the trench. The axial morphology of these segments has recently been described (Blackman et al., 2012), but only dredges and wax-core samples have been collected to date (originally collected in 1993). Early work showed that the Chile Ridge has petrology and geochemistry unlike any mid-ocean ridge on the globe (Klein and Karsten, 1995). Targeted ROV observations and sampling of the seafloor from Segments 1 and 2 are necessary to sufficiently characterize the relationships between petrology, axial morphology and structure, and magma-sediment interactions, and volcanological parameters. Southwestern-most Segment 1 is subducting beneath the continental margin and it partially buried by sediment derived from the continental slope. Segment 2 is offset ~50km and has a nodal deep (~4000m) as is typically associated with at ridge-transform intersection RTI (Blackman et al., 2012).

Brief Summary of What is Known of Target Area

The Chile Ridge spreads at a ~31 mm/yr (half-rate; Cande et al., 1987), an intermediate rate at which axial structure is most sensitive to variations in magmatic and tectonic conditions. Sediments derived from the slope produce methane and are deposited in the axial zone of segment 1 (southernmost, intersects with the trench). Our most detailed and recent knowledge comes largely from the 2010 and 2012 (INSPIRE) R/V Melville cruises. Simrad EM122 to generate ~100m multi-beam bathymetry (and backscatter?) of segments 1-4 axial zones (Blackman et al., 2012), dredge and wax-core samples (none by submersibles) of volcanic rocks, CTD water column sampling, sediment multicores, bottom photography and video (TowCam), trawls, etc.

Feasibility of Studying Target Area

Water depth range in axis from ~2500 to ~4500 mbsl. Port in Puerto Montt or Valparaiso, Chile. Expeditions have been completed recently.

Education and Outreach Potential of Target Area

Public outreach of topics such as active ridge volcanism, ridge subduction, association of plate subduction with volcanic arc (plate tectonic theory), volcanic and seismic hazards, vent life, science career profiles, life at sea, technology at sea.

Southern Gulf of California

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Collaborators

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James Head (Brown University)
Jay Dickson (Brown University)
Nathan Daczko (Macquarie University)
Danielle Sumy (USGS)
Brandi Reese (USC)

Region

NE Pacific Basin
Galapagos/Cocos Ridge
East Pacific Rise
SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise

Rationale for Exploration

The Gulf of California (GoC) region is amultilayered crossroads. Diverse geographic, geological, oceanographic, and biological realms intersect in this area, home to 8 million, and a critical resource for the 120 million citizens of Mexico. From south to north within the GoC, tectonism transitions from classic seafloor spreading near the mouth of the gulf (at the the East Pacific Rise terminus) to increasingly strike-slip towards the Salton Trough. Lavas compositions evolve from normal Pacific-MORB to those compositions affected by the adjacent continental lithosphere (Baja and mainland Mexico). Sedimentation rates increase drastically northward where volcanism occurs as sills emplaced within sediments rather than as surface extrusions. Contrasts in the biological community are generally associated with oceanographic transport: large-scale open ocean (along the continental margin) vs. restricted basin in the GoC. A multidisciplinary study of the southern GoC would provide rich information on the dynamic environment of a young, diverse, and evolving ocean basin. Links between basin evolution, sediment, and microbiology in the Southern GoC:

Numerous submarine canyons supply abundant continentally-derived sediment into basins along the length of the GoC and are opportune for examination of a range of processes. A few examples are introduced here. Sediment deposited near the mouth of the GoC adjacent to the Tamayo Seamount chain has been poorly studied and would contain a record of the transition from continental rifting to oceanic spreading at ~ 3.5 Ma (DeMets 1995; DeMets and Traylen 2000).

Just to the north, the concurrence of ridge magmatism and abundant sedimentation in the Gulf leads to a distinctive setting called a “sedimented ridge.” One

of the better spreading ridge segments studied is Guaymas Basin, between 27°-27°30’N. There, magma intrudes into thick deposits of sediment and solidifies as broad tabular sills, rather than erupting onto the seafloor as is typical for ridges (i.e., Lizarralde et al., 2007). Thermogenic decomposition of organic-rich sediments strongly influences the composition of hydrothermal solutions (Von Damm et al., 1985), and copious amounts of hydrocarbons are released into the ocean (e.g., Simoneit et al., 1988). We expect that the ridge segments between Guaymas and Alarcon are also sedimented but to an unknown extent. The deep basins at ridge-transform intersections within the GoC are important sediment depocenters that would provide a detailed record of continental margin unzipping.

Microbial community diversity at active hydrothermal vents (known from the Guaymas and Alarcon segments) enable exploration of the thermal limits of life at the shallow seafloor and facilitate the isolation and comparison of extremophiles associated with sedimented and sediment-starved ridge segments. Microbial distributions would also provide valuable context for an existing IODP pre-proposal (Teske et al., proposal #833, "Guaymas Basin &

Sonora Margin:

Feedbacks between continental rifting, magmatism, sedimentation, climate history, thermal alteration of organic matter, and microbial activity") that combines continental rifting, thermal alteration of organic matter, and microbial activity and diversity along a transect within the Guaymas Basin. Tamayo Seamount Lithostratig raphy and

Petrology:

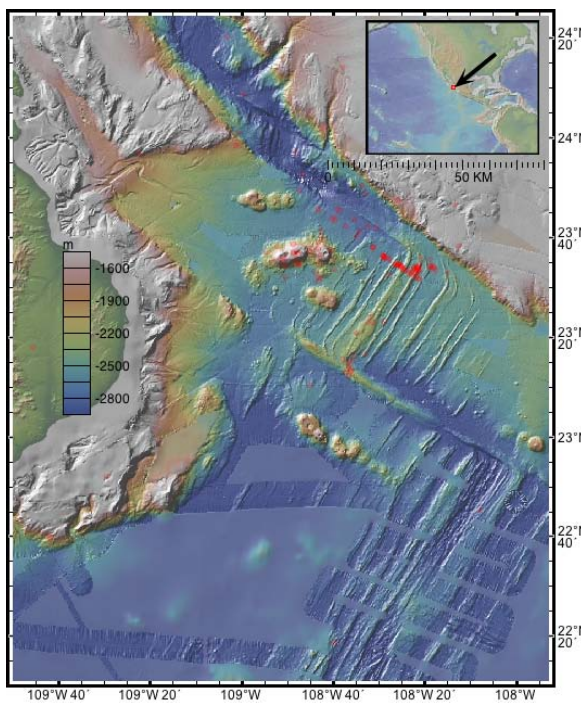
Combined mapping and sampling efforts using multibeam and ROV systems will provide the framework to collect accurately located samples along a linear seamount chain just west of the Tamayo transform fault, and would complement work now underway at Alarcon Seamounts. Unlike many other near-ride seamount chains studied in the North Pacific (Clague et al., 2000) the Tamayo chain shows a regular decrease in summit height above surrounding seafloor from 1600 to 2600mbsl with proximity to the nearby spreading segment and its attendant magma source. Ongoing work from other North Pacific seamounts (Portner et al. in review) has shown that summits invariably contain a variety of sedimentary and volcaniclastic lithofacies that preserve explosive and non-explosive eruption styles. Variation in eruption styles also seems to be associated with seamount evolution and migration away from a parental magma supply. An advantage of studying clastic lithofacies and accompanying lavas on the Tamayo seamount chain will provide a framework to understand how reduced magma supply, seemingly preserved by decreased volume of seamounts with proximity to spreading segment, affects summit lithofacies characteristics and distributions as well as associated lava chemistry. More detailed multibeam mapping of the Tamayo chain and the seafloor to the southwest may reveal additional seafloor features ripe for exploration. Whereas the Alarcon Seamounts are seismically active but magmatically quiet, the Tamayo Seamount chain is seismically quiet, and to the best of our knowledge, is unsampled outside of a single dredge (station THO0099-012), and therefore, its composition, age, and structure are largely unconstrained. An open question is whether contrasts in magmatic and seismic activity at these near-ridge chains could inform us about rifting in a nascent spreading center and the changing connectivity between ridges and near-ridge seamount chains.

Brief Overview of Target Area

We propose to target an area broadly centered near the Alarcon Rise near the mouth of the Gulf. Our primary targets include sedimentary packages atop multiple ridge segments (Pescadero, Tamayo, northernmost EPR, with the potential to include their bounding transforms) and the Tamayo near-ridge seamount chain. The study we propose is in concert with ongoing work by MBARI along the adjacent AlarconRise and Alarcon Seamount chain. Recent expeditions there leveraged high-resolution (~1m) bathymetric data to discover previously unknown active hydrothermal vent fields and a volcanic dome of extremely rare (rhyolitic) composition atop the axis of Alarcon Rise (centered ~23°30’N), a less-sedimented spreading segment at the mouth of the GoC (Clague et al., in prep; brief summary in Clague et al., 2012; and chronicled at: http://goo.gl/jUdfmQ). However, available high-resolution coverage, and seafloor samples elsewhere to the south is severely lacking.

Brief Summary of What is Known of Target Area

The target area is located ~100 km east of the southern tip of the Baja Peninsula of Mexico. It includes intermediate spreading-rate ridge segments (~50 mm/yr; DeMets 1999) that bridge the extension of the East Pacific Rise (EPR) with the section of an en-echelon array of short-segments and long transforms within the Gulf. This rift array has accommodated opening of the Gulf of California since ca. 12.5 Ma when subduction outboard of the Baja Peninsula ceased (Nagy et al. 1999; Conly et al. 2005; Michaud et al. 2006; Fletcher et al. 2007). Continental-rifting gave way to seafloor-spreading, the opening of nascent ocean basins, and construction of ~6 km thick modern oceanic lithosphere (DeMets 1995; DeMets and Traylen 2000; Lizarralde et al. 2007). Lava compositions from within the GoC are generally Pacific-type normal-MORB (Saunders et al. 1982; Bender et al. 1984; Castillo et al. 2002; Dreyer et al. 2012), but at Guaymas Basin there is a subtle subcontinental or subduction component likely inherited from products of long-lived Cenozoic subduction west of the modern Baja Peninsula (Atwater 1970; Saunders et al. 1982). The extent and nature of the continental signature in ridge basalts is not known for crust between Guaymas and Alarcon.



Focal mechanisms of earthquakes are consistent with right-lateral strike-slip faulting along the Gulf of California (Sumy et al., 2012). Although location accuracy was limited by a lack of comprehensive station configuration, the Alarcon Seamounts were found to be seismically active during the 2005-2006 deployment, suggesting that faulting and deformation of the seamounts is ongoing. Seismic activity along the bounding Pescadero and Tamayo transforms is high and several earthquakes occurred beneath a conspicuously large and presumably young (probably ~100s years or less) sheet flow. In contrast, no seismic activity was detected beneath the Tamayo seamount chain. These seamounts are likely to be on the order of 10's Kyr, and the crust upon which they are built several times older. Much of the most recent relevant work at Alarcon Rise has been carried by MBARI expeditions in 2003 and 2012. While the Alarcon Rise is nearly completely covered by 1m-resolution bathymetry (and expected to be published in 2014), most of the surrounding Gulf is mapped with shipboard multibeam at significantly lower resolution (Figure 1 is gridded at 250m resolution from data collected by SIO; background data are GMRT v2.6 as visualized by GeoMapApp; red dots are earthquakes 2005-2006 from Sumy et al., 2012).

Feasibility of Studying Target Area

Mexican territorial waters will require extensive permitting that would require several months of preparation prior to going to sea. Pichilingue (La Paz) was used successfully for MBARI expeditions in 2003 and 2012. Mazatlan may be an alternative.

Educational and Outreach Potential of Target Area

Public outreach of topics could be centered on as active ridge volcanism, near ridge seamounts, ridge-transform intersection, planetary exploration analogs, explosive submarine volcanism, volcanic and seismic hazards, life at hydrothermal vents, science career profiles, life at sea, technology at sea.

Colleagues Jim Head and Jay Dickson within the Planetary Group at Brown University have expressed interest in involving undergraduate and graduate students in at-sea telepresence. Students would travel to URI's Graduate School of Oceanography to visit the Inner Space Center and participate in the dive series. Such an experience would be comparable to participating in mission control operations by NASA space exploration. Moreover, the students would be exposed to aspects of ocean exploration and marine geology that would add breadth to their training. Nathan Daczko from Macquarie University in Sydney, Australia has expressed similar interest in participating in the telepresence of Ocean Exploration. Daczkois interested in the tectonic and structural elements of the transition from continental rifting to oceanic spreading in the GoC.

Deep Sea Macrobenthos of the Galapagos Archipelago and Rapa Nui

Robert Dunbar (Stanford)

Collaborators

Mary Miller (Exploratorium)
Brendan Roark (Texas A&M)
Thomas Guilderson (UCSC/LLNL)

Region

Galapagos/Cocos Ridge
SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise
E Equatorial Pacific

Rationale for Exploration

Although much is known about shallow water benthic communities in the Galapagos Islands, relatively little is known about life on its deep sea volcanic pedestals. Most deep sea exploration in the Galapagos region has focused on the vent communities of the nearby Galapagos Rift and East Pacific Rise. Observations from deep dives on many 100's of seamounts and volcanic islands throughout the Pacific suggests that hard-bottom benthic environments between 200 and 3000 meters are host to rich epibenthic macrofaunal communities. Often these communities are structured by deep sea corals of both calcareous and proteinaceous composition. Deep sea corals (DSC) can be large (in excess of several meters in height) and often adopt an arboreal growth form, offering shelter and habitat space for many other associated organisms. The extent, species composition, and functioning of these communities (in some cases they can be described as deep sea "forests") are very poorly known. Our work in the Gulf of Alaska, Hawaii, the NWHNM, and the northern Line Islands resulted in the discovery of a significant number of new species and even new genera – of large DSC. Furthermore we have established that great longevity is common in some groups of DSC. We have collected branches from living DSC's that are at least 5,000 years old and have many 10's specimens that are 2,000 to 3,000 years old.

Although we know that DSC are present in the Galapagos region from work at the Galapagos Rift, almost nothing is known about their nature and occurrence on the volcanic pedestals of the Galapagos Islands. This is an area rich with potential for new discoveries. The Eastern Pacific is isolated from most of the known DSC communities of the Pacific Basin by distance and the depth of the intervening seafloor. The impact of the Eastern Pacific Barrier on shallow marine communities is well-studied and was first hypothesized by Darwin. Very little is known about its impact on life below the photic zone in the Galapagos.

Furthermore, surface waters of the Galapagos region exhibit extreme seasonal and interannual variability in temperature and productivity relative to other parts of the Pacific. Since food for all benthic communities ultimately derives from surface waters we ask whether Galapagos DSC communities are influenced by such dramatic forcing.

Finally, because of their great ages and known capacity to record environmental signals we suggest that Galapagos DSC's may provide new and unique long term records of ENSO.

We have added Rapa Nui to this White Paper title as the deep sea environments of Rapa Nui and associated Islands (Pitcairn and Sala y Gomez) remain largely undiscovered. Dredges have recovered stony DSC at Rapa Nui as well as evidence for seemingly vast sponge fields. Rapa Nui is the most isolated island on Earth and we see it as a possible end-member for endemism in certain taxa of DSC and DSC-structured communities.

Our research questions include:

1) What composes and structures DSC's and their associated communities on the flanks of Eastern Pacific Islands?
2) How does the isolation of Eastern Pacific Islands such as the Galapagos and Rapa Nui affect endemism in deep sea macrobenthos?
3) Does the strong upwelling of the Galapagos Region and/or high interannual variability impart a signature on DSC communities?
4) How to Eastern Pacific DSC connect genetically with known communities far to the west?
5) How do DSC communities respond to low oxygen levels of the Eastern Pacific mid-water column?
6) What can Eastern Pacific DSC's teach us about past dramatic changes in climate, in particular the past occurrence and strength of El Ninos and La ninas?

Brief Overview of Target Area

We propose a series of ROV transects at several of the Galapagos Islands, with actual dive locations to be determined following swath mapping. Existing bathymetric charts are sufficient for identifying the approximate dive locations. We have experience in identifying dive sites from many 10's of dives in HOV's (ALVIN, PISCES IV and V) and using ROV's and swath maps of the seafloor at the locations described above. Our goal is to describe deep-sea coral communities over a depth range of 200 to 3000 meters and to collect specimens for analysis of taxonomy, genomics, and paleoclimatology. If the Nautilus ventures into the SE Pacific, we request similar field work at Pitcairn Island, Rapa Nui, and Sala y Gomez Island and associated seamounts. Our focus is on hard substrate environments in the middle to upper water column rather than on hydrothermal vent systems, where much is already known about benthic ecology and life.

Brief Summary of What is Known of Target Area

The Galapagos Archipelago and Rapa Nui are major tourist destinations and have regular air service and significant onshore logistical support for expeditionary work. The Galapagos Archipelago is relatively close to major Pacific ports in the vicinity of the Panama Canal. Rapa Nui, Pitcairn, and Sala y Gomez are extremely remote.

Feasibility of Studying Target Area

The Galapagos Archipelago and Rapa Nui are major tourist destinations and have regular air service and significant onshore logistical support for expeditionary work. The Galapagos Archipelago is relatively close to major Pacific ports in the vicinity of the Panama Canal. Rapa Nui, Pitcairn, and Sala y Gomez are extremely remote.

Educational and Outreach Potential of Target Area

The Galapagos Archipelago has captured the attention (and love) of many millions of school children and adults. The wildlife onshore and in the shallow marine environment is charismatic and unique and will continue to be an extraordinary education and outreach resource as we learn more about it. With this program we aim to introduce the world to a charismatic megafauna to which very few have been exposed – the deep sea macrobenthic communities of the SE Pacific volcanic islands. We will discover large organisms currently unknown to science and learn about unusual deep sea lifestyles. We will link life in the deep sea to life in shallow water and on shore – very likely encountering surprises along the way. Dunbar and Guilderson have worked previously on shallow water corals in the Galapagos (Dunbar appeared in a BBC special on a 400 year-old coral at Urvina Bay as well as in an NPR Radio Expeditions special with Dr. Jerry Wellington). In this case we propose to work closely with Mary Miller of the San Francisco Exploratorium on Education and Outreach. Mary has extensive experience in "reaching out" to classrooms and museums (and the public in general) from remote locations. Dunbar and his lab group at Stanford have worked with Mary on "Ice Stories" from Antarctica and also given talks at the Exploratorium. See:

Home page:
http://icestories.exploratorium.edu/dispatches/
Christina's page:
http://icestories.exploratorium.edu/dispatches/author/christina-riesselman/
Your blogs from Wilkes-Land
http://icestories.exploratorium.edu/dispatches/author/rob-dunbar/

Possibilities under discussion include live shows at the Exploratorium, development of content for the Exploratorium Video Wall, and a larger media-gathering effort for an ongoing collaboration with the Charles Darwin Foundation. We aware of the extensive E&O capacity and accomplishments of the OET and are prepared to fully engage in these activities as well.

Understanding Submarine Volcanism and the Construction of Ocean Islands: Large Deep-Water Lava Flows in the Western Galápagos

Dan Fornari (WHOI)

Collaborators

S.A Soule (WHOI)
M. Kurz (WHOI)
D. Geist (University of Idaho)
K. Harpp (Colgate University)

Region

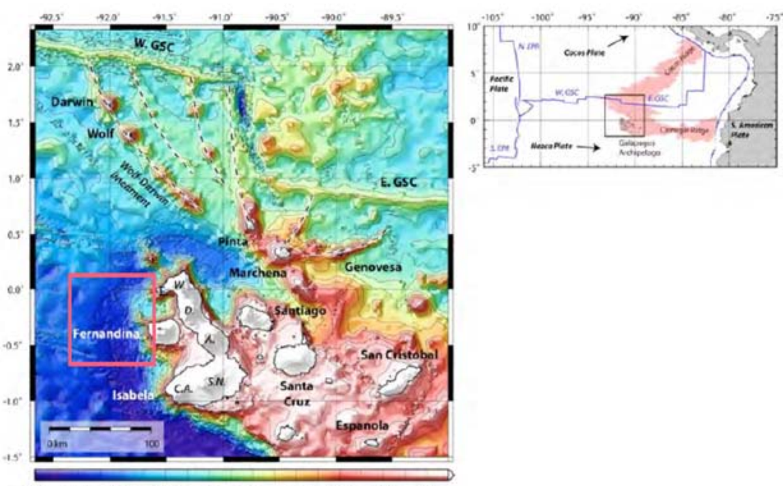
Galapagos

Rationale for Exploration

Submarine eruptions produce the largest volume of volcanic products on Earth [White et al., 2006], but research leading to a holistic and detailed understanding of submarine eruptive processes is still in its infancy [e.g., Rubin et al., 2012]. Mid-ocean ridges (MOR), hotspot-related ocean islands, arc volcanoes, and the large number of seamounts distributed throughout the global ocean basins are typically constructed of thousands of small-volume eruptive units (~<0.1 km3 eruptions (~>1 km3 component of oceanic crustal construction owing to their large volumes (equivalent to tens to hundreds of typical submarine eruptions). Furthermore, these end-member-type eruptions are important because they represent exceptional scales of the physical processes involved in magma accumulation, magma transport through the lithosphere, and lava emplacement relative to typical submarine eruptions. Despite their obvious importance, large-volume submarine eruptions are poorly characterized and even more poorly understood.

We suggest that large-volume lavas make up a significant part of the foundation of many ocean islands provinces and play a critical role in their construction. Knowledge of the early history of submarine volcano and ocean-island development depends mostly on limited exposures of older formations within mass-wasted island flanks, or at the youngest volcanoes in hotspot-formed island chains. Modern examples that provide clues to the eruptive style and nature of nascent island volcanism have proven to be scarce. In models of ocean island growth, the shield-building stage (during which over 90% of the volcano is emplaced) is thought to represent a period of increased magma flux and, by inference, increased eruption frequency [e.g., Walker, 1990]. We suggest, however, that greater eruption size is an equally viable mechanism for volcano growth, a distinction with significant implications for how magmatic systems evolve. There has been considerable research on subaerial volcanic constructional processes that enables us to predict how ocean islands develop once they become emergent, but we are missing the crucial link that can tell us about the initial stages of submarine volcanism and how they lead to the growth of the submarine pedestal of oceanic island volcanoes. A related hypothesis is that large-volume submarine lavas are emplaced in a style similar to that proposed for continental flood basalts and large-volume subaerial sheet flows, by the transport of melt in the interior of a flow via lobe inflation [e.g., Self et al., 1997].

We plan to take advantage of a unique suite of volumetrically large lava flows in the Galápagos Archipelago to address this gap in our understanding. Dozens of spatially extensive (up to 300 km2) lava flows cover the abyssal seafloor at 3400-3600 m depth west of Fernandina Island (Supplement Figs. 1, 2). We refer to these large flows as Galápagos Deep Water Flows (GDWFs). These lava flows are comparable in scale to the largest known eruptive units in the deep sea, including the Hawaiian Arch Volcanics [Clague et al., 1990, 2002], EPR 8°S [Macdonald et al., 1989], Puna Ridge-tip lavas [Holcomb et al., 1988; Clague et al., 1995], and presumably eruptive units within oceanic large igneous provinces [e.g., Coffin and Eldholm, 1994; Greene et al., 2010]. Owing to the patchy, thin sediment cover on the youngest flows and their emplacement on nearly flat sediment-covered seafloor at ~3400 m depth, the GDWFs provide an opportunity to investigate the eruption dynamics and emplacement of large volume submarine lava flows. We hypothesize that the GDWFs constitute the foundation of the Galápagos Platform and thus provide critical insight into the early development of ocean island volcanoes. These studies will also have important implications for characterizing the eruptive behavior of adjacent subaerial volcanoes and their role supplying magma to eruption sites on the deep-sea floor.

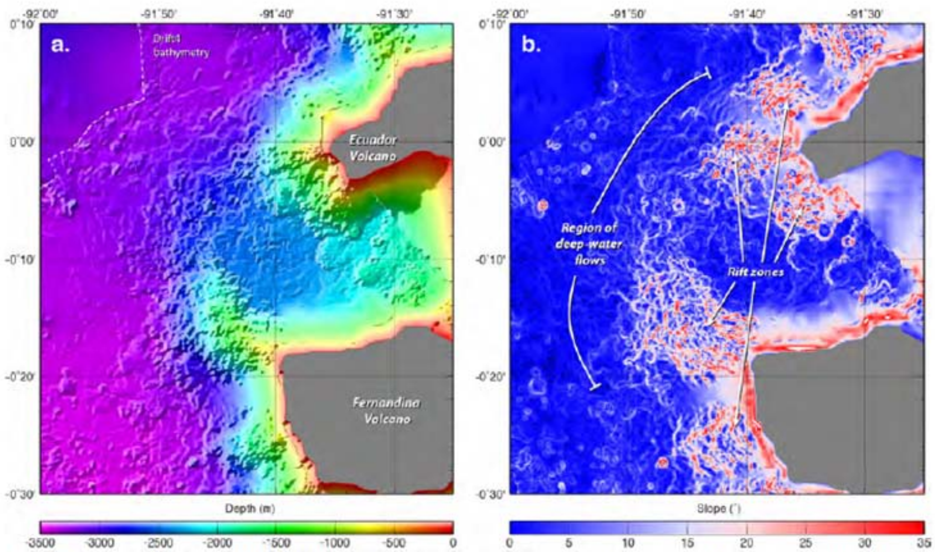


Supplement Figure 1. *Base map of Galápagos Islands region. Red box shows approximate area of Figure 2.*

Brief Overview of Target Area

The Galápagos Archipelago has been constructed over the past ~3 Myr by volcanism related to a mantle plume adjacent to the Galápagos Spreading Center (GSC). The central and western Galápagos volcanoes lie atop a broad submarine volcanic plateau, the Galápagos Platform. Marine studies of the Galápagos hotspot province [e.g., Christie et al., 1992; Graham et al., 1993; Sinton et al., 1996; Harpp and White, 2001;

Harpp et al., 2003; Geist et al., 2005, 2006, 2008; Glass et al., 2007; Kurz and Geist, 1999; Kurz et al., 2009; Mittelstaedt et al., 2012] and study of the subaerial edifices provide a basis for understanding the regional geologic development of the archipelago's platform and emergent volcanoes. The submarine platform is constructed of overlapping large-volume lava flows that stack to form terraces tens of kilometers across. These terraces, which are exposed along the western and southern margin of the platform, are proposed to be the primary architectural units and foundation of the platform [Geist et al., 2008].

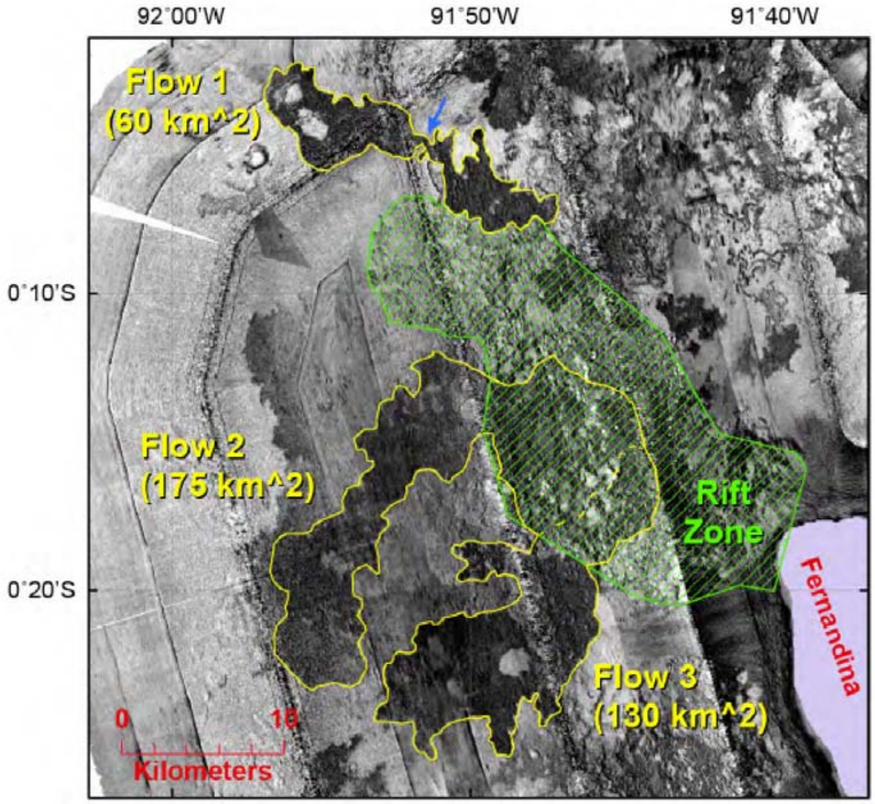


***Supplement Figure 2.** EM120 multibeam bathymetry (left) over the area of the deep-water lava flows and derived slope map (right). The deep water flows are not resolved by the multibeam and are only able to be identified by the MR-1 sidescan sonar imaging carried out on the DRIFT04 cruise (R/V R. Revelle, 2001).*

According to this hypothesis, large-volume (>1 km3 of the hotspot The sequential emplacement and stacking of large-volume, deep-water flows then create submarine terraces, through hundreds of thousands of years of focused magma delivery from the mantle to the crust [Geist et al., 2008]. Over time, as the platform grows upward, magmatism is directed into central volcanoes to create emergent islands. The islands at the leading edge of the hotspot then develop rift zones oriented away from the center of the platform along their un-buttressed flanks [e.g., Geist et al., 2006]. In the Galápagos, the deep-water flows that are the focus of our study are located west of the active rift zones of Ecuador, Cerro Azul, and Fernandina volcanoes (Supplement Fig. 3), consistent with this construction cycle. Although the GDWFs have not yet extended the Galápagos platform westward yet, we propose that they constitute the initial phase of the platform expansion process.

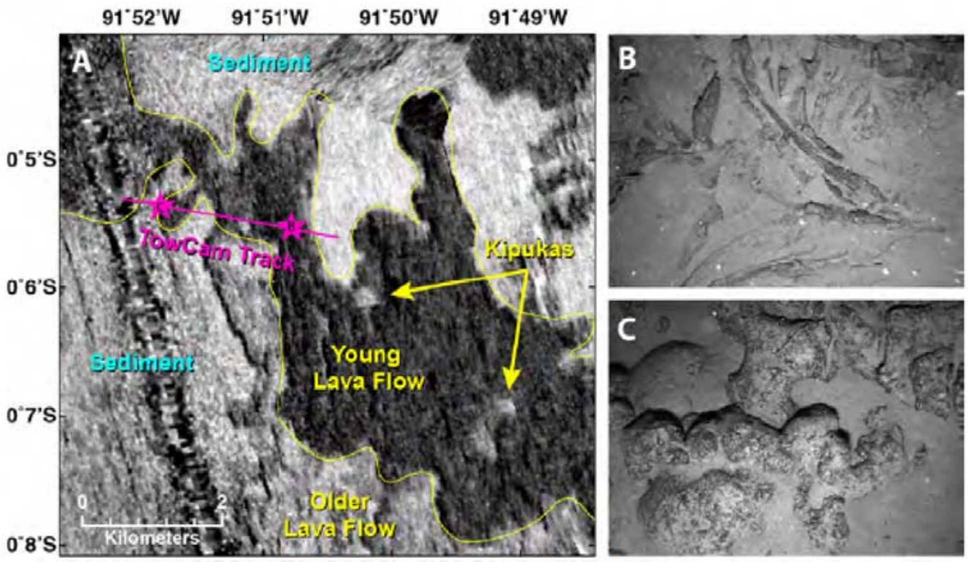
Brief Summary of What is Known of Target Area

Large deep-water lava fields in the western Galápagos were identified in acoustic backscatter imagery from towed MR1 sidescan sonar surveys acquired in 2001 on the



Supplement Figure 3. *MR-1 sidescan sonar imagery for the western Galápagos showing the areas of the deep-water lava flows (dark is high reflectivity). The three main lava flows to be targeted by the field studies have been outlined in yellow. Blue arrow shows location of TowCam traverse of part of Flow #1, shown in Figure 4.*

DRFT04RR cruise (R/V Revelle) [Geist et al., 2006; Glass et al.; 2007] (SupplementFigs. 1-3). Sonar backscatter intensity and direct observation by TowCam (Supplement Fig. 4) indicate a very thin sediment cover (< several cm), enabling detailed field study of fine morphological and textural features. A unique advantage of this setting is that the lavas are emplaced on sediment-covered seafloor instead of other young lava flows, making the delineation of individual eruptive units exceptionally clear (Supplement Fig. 3). They are distinguished from lavas of adjacent rift zones and landslide deposits on the basis of regional slope (<<3˚) and acoustic texture. Individual GDWFs range in area from 9 km2 to 290 km2 of the GDWF are located in water >3000 m (Supplement Fig. 2). Determining the volume of a GDWF requires measurement of flow thicknesses. The existing multibeam bathymetry does not show any abrupt relief across the flow boundaries, which, based on the multibeam vertical resolution, suggests thicknesses <~15-20 m. Estimated thicknesses of low-relief mid-ocean ridge lava flows range from 1.5 m [Soule et al., 2007] to 10 m [Sinton et al., 2002]. The Puna Ridge and South Arch flows in Hawaii are believed to be ~10 m thick on the basis of changes in seafloor depth across inferred flow boundaries [Lipman et al., 1989; Holcomb et al., 1988]. Using a minimum thickness estimate of ~2 m, individual GDWF have volumes of 0.02 to 0.45, comparable to estimates of the largest subaerial eruptions in the Galápagos km3 [Rowland et al., 1996] and subaerial and submarine rift zone eruptions on Kilauea Volcano [Parfitt et al., 2002]. A more realistic thickness estimate may be ~5 m, which would render the flow volumes in the range of ~1 km3 for individual flows.



Supplement Figure 4. *TowCam deep-sea camera track (A) conducted during the 2001 cruise and example bottom photographs (B & C) are the only observational data from this region.*

Feasibility of Studying Target Area

A number of long, deep-water lava flows in the region west of Fernandina display similar characteristics, including: 1) thin (< cm think) sediment cover; 2) great lengths (~18-22 km); and 3) presence of kipukas within the flow, which provide windows into the underlying, older surface. We propose to focus on three lava flows in the Galápagos, which we will map at the meter scale to identify morphological features and sample comprehensively along and across each flow. We propose to collaborate with Dr. C. Roman (URI) and to utilize his near-bottom mapping techniques and system on ROV Hercules to help constrain flow thicknesses of the deep-water flows. Our objective is to evaluate the magmatic and volcanic relationships between volumetrically large submarine lava flows in the western Galápagos Archipelago and the adjacent volcanoes, as well as the processes involved in emplacing and transporting large lava flows in the deep ocean. The data and observations necessary for the study of large submarine lava flows are achievable by applying near-bottom mapping and sampling techniques using the ROV Hercules. Furthermore, if possible, we propose to bring the WHOI-MISO TowCam system, which has real-time imaging capability, to be used on the CTD 0.322" wire during non-ROV diving time to extend our observations (http://www.whoi.edu/page.do?pid=17619). Data collected using these complementary systems have the potential to improve our understanding of oceanic crust construction on a worldwide basis.

Specifically, the study of GDWFs will provide an excellent opportunity to address the following process-oriented questions.

- What are the volumes of deep-water lava flows?
- To what extent does the cooling rate and crystallization during flow control the emplacement and dimensions of large lava flows?
- What is the duration of emplacement of a large submarine lava flow?

Critical to these latter two questions is the assumption that the lava solidified where it has been sampled. All of the PIs have considerable field volcanology experience in both the subaerial and submarine environments, and thus understand the challenges involved inidentifying intact crust that has not been transported by rafting. One of the reasons that this study demands such high-resolution imaging like what can be acquired using the Hercules ROV is to identify intact crusts and detailed field relationships. For example, in our experience, most sheet and lobate lavas have intact crusts because the molten lava is transported endogenously, whereas transported crust is broken and usually spatially associated with lava channels [e.g., Soule et al., 2004]. Consequently, one can presume that continuous (over scales of 10s of meters), unbroken sheet and lobate surfaces have not been rafted, making it possible to identify material that has solidified in situ.

Educational and Outreach Potential of Target Area

The ecosystems of the deep submarine environment around the Galápagos Islands remain virtually unexplored, despite the importance of the archipelago in evolutionary and biogeography studies and the establishment of the Galápagos Marine Reserve, aUNESCO World Heritage Site. We propose to collaborate with the Charles Darwin Research Station (CDRS), based in the Galápagos and the principal organization supporting scientific research in the Galápagos National Park and Marine Reserve. The mission of the CDRS is to perform research that aids in the conservation of the archipelago. We will include CDRS marine biologists in our field expedition, which will provide them with a rare opportunity to explore the ecology and marine life of the western Galápagos waters, otherwise mostly inaccessible to them owing to a lack of research vessels in their organization. Our bathymetric data will be shared with CDRS, as we have done in previous projects, to enhance their resources for studying these otherwise poorly documented regions. Our potential collaboration with the CDRS is facilitated because D. Geist, one of the PIs on this proposal, is President of the Darwin Foundation, the non-profit organization that supports the research efforts in the Galápagos. Furthermore, a scientist from INOCAR, the branch of the Ecuadorian Navy responsible for oceanographic research, and with whom WHOI has an official collaborative relationship (a memorandum of understanding, MOU), will also be invited to participate as the official ‘observer’. As with CDRS, we will provide INOCAR with the newly acquired data, which in the past has facilitated their work in the Marine Reserve significantly. An added advantage to this collaboration is that through the WHOI MOU, we can facilitate research clearances and sample acquisition permits for this work.

From an educational perspective, we propose to involve undergraduate students from our institutions and Ecuadorian universities in the field expeditions and the subsequent research. We have lead two expeditions in the Galápagos region in which undergraduate students have played a critical role in the research mission: the 2001 RV Revelle DRIFT4 and the 2010 RV Melville FLAMINGO cruises. The impact of the experience and the contributions of the students far outweigh their lack of seagoing experience; the hands-on experience and opportunity to do cutting edge research on a team with senior scientists is one of the most effective ways to engage students and encourage them to pursue careers in science. Students from our previous cruises have made more than 15 presentations at international meetings, documenting what they have discovered in post-cruise research; most are co-authors on publications in the peer-reviewed literature, and many have gone on to pursue graduate careers since that time. We would also welcome the opportunity to develop marine geological and volcanology curriculum in collaboration Ocean Exploration Trust education/outreach team.

The Chemosynthetic Ecosystem off Peru and Chile

Victor Ariel Gallardo (Universidad de Concepcion, Departamento de Oceanografia)

Collaborators

Chris McKay (NASAAmes)
Dimitri Gutierreez (IMARPE)

Region

Microbial mats on shelf

Rationale for Exploration

Information needed to define role in the productivity of the Humboldt large ecosystem, Possible analog of extraterrestrial systems such as that of Enceladus ocean.

Brief Overview of Target Area

The area is a sublittoral (benthic) sediment belt on the continental shelf off central Peru to off central Chile.

Brief Summary of What is Known of Target Area

From sporadic and far apart both in time and space samplings it is known that there can be massive microbial mats under the oxygen minimum zone of the region. There is also some knowledge about its biotic composition and the sediment characteristics but much more is needed for a ecological thorough understanding of its function and ecological significance.and for astrobiological applications.

Feasibility of Studying Target Area

The on board and associated equipment should make it very possible. Probably an excellent interdisciplinary team of interested scientist could be put together from various institutions including NASA.

Educational and Outreach Potential of Target Area

I think there is at least in Chile good potential for educational and outreach.

Colombian Pacific

Adriana Gracia (INVEMAR)

Collaborators

Nadia Santodomingo (Natural History Museum, London, UK)
Andrea Polanco (INVEMAR)
Nelson Rangel (INVEMAR)
David Alonso (INVEMAR)

Region

Galapagos/Cocos Ridge
SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise
Eastern Tropical Pacific

Rationale for Exploration

Colombia along with Costa Rica, Panama and Ecuador, are one of the highly productive areas within the Eastern Tropical Pacific (ETP) and one of the most diverse biogeographical provinces of the world due to their special oceanographic and climatic conditions. This region includes the MPA´s Galapagos (Ecuador), Malpelo and Gorgona (Colombia), Coiba (Panama) and Cocos Island (Costa Rica), and five World Heritage sites declared by UNESCO.

Recent explorations along the ETP have identified some strategic sectors of great ecological value and high degree of biological connectivity. The study of the Colombian ETP continental margin is proposed under the framework of a regional initiative for the conservation and sustainable use of biodiversity and coastal and marine resources in the area (NOAA, 2007; Sherman & Hempel, 2008; Conservation International, 2009; In: INVEMAR, 2012). The Colombian Pacific marine areas exhibit a complex geomorphology and conditions in the deep sea. There is a high potential of occurrence of seamounts, cold seeps, deep-water corals, among other marine ecosystems, yet to be discovered. Indirect evidences point to the presence of a large number of seamounts in the ridge along Galapagos, Malpelo and Cocos Islands, which global importance has already been established. Seamounts are the dominant topographic feature of the Pacific Ocean (Carter et al., 2005).

They sustain important ecological communities, determine habitats for fish, and act as obstacles to currents, thus enhancing tidal energy dissipation

and ocean mixing. Furthermore, seamounts exhibit interesting characteristics for studies in disciplines such as geology, oceanography, biology, ecology, and economy, considering future exploitation of mineral resources (Wessel et al., 2010). An important hydrographic feature known throughout the Eastern Pacific is the occurrence of Oxygen Minimum Zones. In other regions of the world, it has been established that oxygen minimum layers are present at intermediate water depths (100-1000 m) and contribute to habitat heterogeneity along continental margins (Guilini et al., 2012). There is still a large information gap about the role that OMZ have in the Colombian Pacific as there are not studies on their dynamics and their particular associated biota.

The Colombian ETP is under intense benthic fisheries exploitation by industrial and artisanal fleets. Most of the fishing fleets target (e.g. Farfantepenaeus brevirostris and Solenocera agassizi) using trawls that sweep the sea bottoms from shallow to deep waters (70-250 m) (Rodríguez et al., 2012). These fisheries have shown an environmental impact on the benthic biodiversity and associated seafloor habitats. These impacts are a result of excessive fishing effort, poor trawl choices, and lack of appropriate management measures based on ecosystem resource assessments (Rodríguez et al.,2012). Regarding marine research offshore, the Colombian Pacific Ocean has historically been less studied than the Colombian Caribbean.

The different intensity of marine research between the two coasts is also reflected on the number of Marine Protected Areas (MPAs) established. The National System of MPAs is represented by 12 coastal-marine areas (8 in the Caribbean, and 4 in the Pacific). This lack of information makes imperative to study this region, primarily the extensive understudied deep ecosystems. In a preliminary identification of conservation targets for the continent, the Seamounts (Guyots) in the Colombian subregion "Oceanic Pacific" have a 100% priority at national level (Chatwin, 2007).

From a biogeographic point of view, the Colombian ETP represents an area of great interest as it contains the Choco biodiversity hotspot. This area is one the wildest regions of Earth and includes a wide variety of habitats, ranging from mangroves, beaches and coastal ecosystems to some of the world's wettest rain forests. In addition, this corner of South America was one of the last connections between the Atlantic and Pacific oceans before the rise of the Panama Isthmus. This geological event had an enormous impact on the Earth's climate and environment and the timing and mechanisms that explain how it happened are currently under intense debate (Bacon et al., 2013; Coates, 2013). Evidence gathered from the Colombian ETP will provide key information to test some of the biological and geological hypotheses related to the closure of the Panama Seaway. In summary, the Colombian ETP is still poorly studied, in particular the deep-water ecosystems of this region. The region hosts a potential high biodiversity as it has proper geomorphological and oceanographic characteristics that favor the presence of significant deep-sea ecosystems yet to be discovered. The exploration and characterization of the Colombian ETP through mapping and deep-sea remote sensing techniques would be a first step towards the identification of seamounts ecosystems, their distribution, habitat composition, and ultimately their role and contribution to the deep sea ecology of the region.

Brief Overview of Target Area

Colombia is the only South American country having coasts on both the Tropical Pacific Ocean and the Caribbean Sea. Because Colombia possesses oceanic islands located far offshore, wide sections of both the ETP and the Southern-central Caribbean are included within the boundaries of its Economic Exclusive Zone (EEZ). The Colombian Pacific Ocean has nearly 1300 km of shoreline and is a component of the Panama

Basin. The Colombian Pacific Basin is located between 01º 30'N to 7º 10'N and between 77º 40'W and 82º 00'W. The basin is bounded on the north by the Gulf of Panama. The coast of Colombia to the east; the Ecuadorian coast and the submarine Carnegie Ridge, to the south; and the Pacific Ocean, EZZ of Panama (30 km) and the Cocos Ridge to the west. The EEZ of the Colombian ETP has 339500 km2, including estuarine, coastal and ocean waters, with depths up to 4000 m. The most important geomorphologic features are Gorgona and Malpelo Islands surrounded by unique coral reef ecosystems (Betancur & Martínez, 2003; Chatwin, 2007; Martínez et al., 2007; Murcia & Giraldo, 2007).

The Colombian Pacific is located in an area of high geological complexity due to the interaction of major tectonic plates: Nazca, Caribbean and South America. Colombia's Pacific coast is characterized by high relief, a narrow platform bordering a deep trench, small drainage basins, and rapid vertical movements. The Colombian ETP is roughly divided into 3 main geomorphological sectors: continental shelf, continental slope (Baudó) and Pacific Rim. The Colombian Pacific continentalshelf has a variable size, mainly due to differential effects of plate tectonics. The shelf is very narrow (between 0 and 3 km) in those places where the compression fronts occur, mainly towards the north, and it reaches its maximum amplitude in the Buenaventura bay off Raposo mouth (51 km) and the Patia River delta (54 km). The slope extends along 700 km from the edge of the shelf to 3000 m depth, including other geoforms such as sand banks, hills and knoll, scarps and plateaus. The northward sector has a diversity of escarps product of high tectonic activity in the area, while in the southern section is cut by numerous canyons and valleys with E-W orientation. The Colombian Pacific Rim presents their major geomorphological features in N-S orientation, among which are the Colombian Trench and the Yaquina Graben, as well as a series of seamounts, hills, and knolls of large area (Molina & Mirmand, 1992; Restrepo et al., 2002; IDEAM et al., 2007: In: INVEMAR 2012). The sediments are mostly biogenic sediments and seasonally controlled by primary productivity, but in the northern and eastern margins consist mainly of terrigenous sediments. The dominant oceanographic dynamics, including waves and currents are controlled from the southwest.

Brief Summary of What is Known of Target Area

Some international expeditions, including Albatross 1904, Velero III 1931-1941, Saint George 1927, and Askoy 1941-1942, carried out a few collections of fauna in localities off the Colombian Pacific coast. Recently, the Marine and Coastal Research Institute of Colombia (INVEMAR) carried out two research cruises, the first in 2002 and the second in 2013, which primary aims were to fill the information gap in the knowledge of the soft-bottom epibenthic macrofauna inhabiting depths of 70 to 1000 m. Biodiversity inventories for the Colombian ETP performed by INVEMAR have offered the first systematic collections of the sea-floor and planktonic biota accompanied by oceanographic and sedimentary characterizations. Geomorphological information was preliminary gathered only off Nariño Province at the southern Colombian Pacific.

Additionally, oceanographic cruises to monitor the El Niño phenomena in the Pacific of Colombia, Ecuador, Peru and Chile have been annually held for more than 40 years. The regional study of El Niño in the Southeastern Pacific (ERFEN cruises) has a network of stations that provide oceanographic information and models. Moreover, biological information (plankton) has been acquired since 2003 from sampling of the water column down to 200 m depth. From these expeditions, information of more than 45 oceanographic stations and 25 biological (plankton) stations in the Colombian ETP and numerous publications are known.

Priority has been focused to the continental offshore. The areas around Malpelo Island remain to be explored. There is a high potential for the discovery of seamounts and related deep-water ecosystems in the Colombian ETP. There is no knowledge of the extent of these habitats, how they are structured, what is species composition, and their relationships with the highly diverse other faunas. Preliminary results of the explorations carried out by INVEMAR found wealth of first species records for the country and new species.

Feasibility of Studying Target Area

Accessibility to the Colombian Pacific Ocean is mostly possible by sea; there are several locations to the north (Department of Choco) with no access by land. The center of greater accessibility to this region by air or land is around Valle del Cauca Department. The main airport is located in the city of Cali. The main harbor is located in Buenaventura bay. Malpelo Island can only be reached by sea from Buenaventura harbor.

Educational and Outreach Potential of Target Area

INVEMAR have coverage and understanding of the research and educational processes in the Pacific coast. Additionally it will be possible to develop strategic alliances with universities and institutes in the region for higher disclosure.

Malpelo Ridge, Colombia

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Region

Galapagos/Cocos Ridge

Rationale for Exploration

Geologic events, such as the closure of the Central American Seaway and the establishment of the Isthmus of Panama, are fundamental drivers of biological diversification. The connection created by the Isthmus, between the South American and North American sub-continents, triggered an exchange of species that drastically altered the biological landscapes on both landmasses. In a similar way, the Isthmus isolated the marine ecosystems of the Eastern Pacific from the Atlantic-Caribbean, separating the evolutionary trajectories and ecological dynamics of both ocean systems (Knowlton & Weigt 1998). Due to its geographic location - not only at the heart of the southern Caribbean, but at the point of formation of the Isthmus of Panama - Colombia is a key piece of the global biogeographic puzzle. Colombia is considered one of the most biodiverse countries in the world, both on land and shallow oceans (Diaz & Acero 2003; Miloslavich et al. 2010; Miloslavich et al. 2011). However, its importance in terms of its contribution to the biodiversity and resources in the deep sea remains unknown. Approximately 45% of the Colombian territory (ca. 928,000 Km2) is ocean and about 9% (ca. 83,000 Km2) of it is considered a Marine Protected Area. However, due the significant technical challenges of working at depths beyond the reach of scuba diving (50-150m), and the lack of appropriate technologies and platforms in the country, a vast extension of deep-sea territory (ca. >800,000Km2) remains largely inaccessible and unexplored. Years of surveys along the Colombian Caribbean continental margin down to

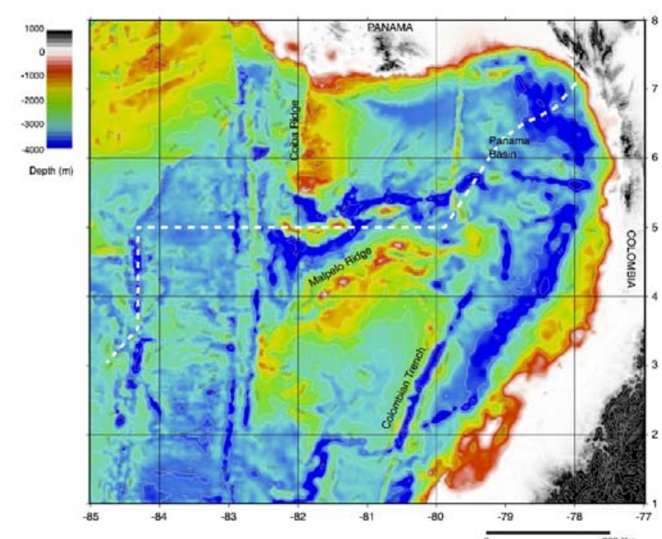

Figure 1. Bathymetry map of the Malpelo Ridge region. Gray lines indicate 500m isobaths. Dotted line indicates the limit of the Colombian EEZ.

1000 m, using tools such as multibeam, CTD, box cores, and trawling nets have discovered over 1600 species (21 endemic to the region) and evidence of deep-sea coral and hydrocarbon-seep ecosystems along areas of low topographic relief (INVEMAR 2010). Much less is known about the geology, biodiversity and kinds of ecosystems that occur on the rich diversity of seafloor features, potential habitats and ecosystems hosted by Colombian Eastern Pacific seafloor, including abyssal plains, cold seeps, hydrothermal vents, and large topographic features like ridges, fracture zones, faults, and seamounts. No visual surveys or targeted sampling of the deep sea has been performed in this area (Miloslavich et al. 2010), making the potential for novel discoveries extremely high.

We propose a program of focused exploration of the seamounts in the Malpelo Ridge region (Fig 1) to address key and fundamental questions through a diverse interdisciplinary team of scientists and stakeholders. For example, what is the degree of connectivity between the deep-sea coral and seep biological communities in the equatorial Eastern Pacific and those found in higher latitudes both north and south? Were the communities in the deep sea Eastern Pacific isolated from the ones in the Caribbean/Atlantic long before the formation of the Isthmus of Panama? Is the equatorial Eastern Pacific a distinct deep-sea biogeographic province? The exploration of the equatorial Eastern Pacific will significantly improve our understanding of the patterns and processes that have shaped the biodiversity in the deep sea, and we anticipate it will lead to the discovery of new species, ecosystems, and ecological interactions.

Brief Overview of Target Area

The Malpelo Ridge is a topographic feature from the Miocene that rises from the abyssal zone to a sub-aerial rocky island and seamounts whose submits range between 300 and 1500 m deep. Malpelo Island (350 ha) is the only sub-aerial island fro this ridge and is located 500 Km off the coast of Colombia. The Malpelo Ridge is considered a biological hotspot characterized by large aggregations of pelagic fauna found on the seamounts and the diverse coral communities found at shallow and mesophotic depths. Part of this region is contained in a marine protected area created in 1995 (Malpelo Fauna and Flora Sanctuary) and was declared world heritage in 2006. Currently, regulations are in place to prevent illegal fishing activities in this area, given that it holds important populations of large predators like hammerhead sharks, silky sharks, whale sharks, and the rare deep-water short-nosed ragged-toothed shark, that is seen in very few places worldwide.

Brief Summary of What is Known of Target Area

To our knowledge there is only one seamount that has been photographically documented in any biological detail between 12°N and 24°S of the equator, in the Eastern Pacific Ocean (Okeanos Explorer GALREX 2011 expedition). The exploration of this seamount, the Paramount Seamount, located north of the Galapagos, revealed extremely abundant and diverse deep-water coral communities (including many potential new species), and a strongly pronounced break in faunal composition with depth. The systematic exploration of the Malpelo Ridge will enable us to build on these preliminary observations to test hypotheses regarding the biogeographic uniqueness and history of the equatorial Eastern Pacific seamount fauna. It will also provide a critical baseline that will enable the identification of potential Vulnerable Marine Ecosystems and inform management and conservation efforts.

Feasibility of Studying Target Area

The proposed area could be one the first targets in the Pacific after the Nautilus crosses the Panama Canal. The Fundación Malpelo has been performing extensive shallow-water work (via scuba) in the area since 1999 with the collaboration of the Natural National Parks of Colombia and the Colombian Navy (permit-granting authorities). Consequently, there is significant experience in obtaining permits to perform expeditions in this area.

Educational and Outreach Potential of Target Area

There is a great interest from science museums in the two largest cities in Colombia, Bogotá (Maloka) and Medellín (Parque Explora), to follow the expedition via telepresence. We plan to set up exploration centers in both of these museums. During the whole expedition these museums will invite (free of charge) a number of schools to visit the exploration centers and interact with scientists both on-shore and on the Nautilus. In addition, the University of the Andes will also set up an exploration center for involving college-level students from Bogotá. We anticipate additional participation from students and scientists in the US through exploration centers in Woods Hole, the Inner Space Center, and Mystic Aquarium, among others.

We propose to make all the outreach materials and communications for this expedition bilingual, in English and Spanish, to reach Hispanic audiences in the US as well as throughout Colombia and Latin America.

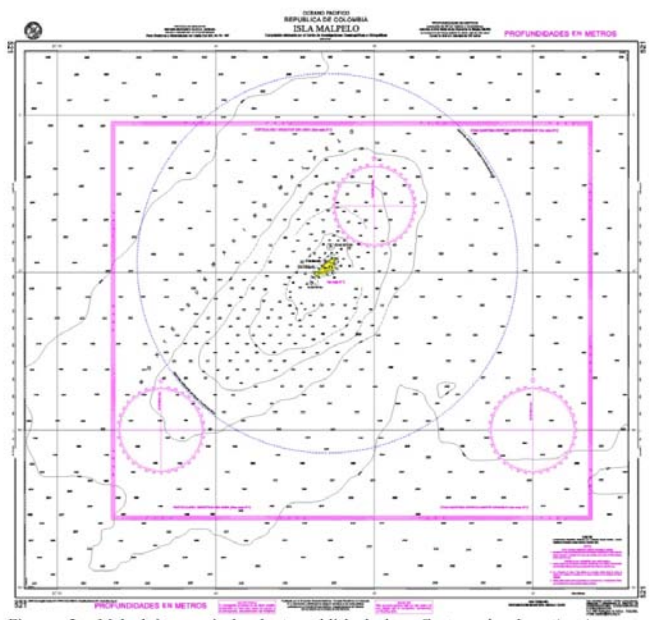

Figure 2. Malpelo´s nautical chart published by *Centro de Investigaciones Oceanográficas e Hidrológicas-CIOH.*

Biodiversity Hotspot Exploration on the Chilean Margin

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Collaborators

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Juan Diaz (Pontificia Universidad Catolica de Valparaiso)

Region

SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise

Rationale for Exploration

The study of the continental margins has become a critical target due to their key roles in biogeochemical cycling and biodiversity support, and their vulnerability to climate change and human-induced disturbances. Increasing economic interest in energy exploitation and mining, as well as expanding fisheries, highlight the need for early exploration of undocumented deep-sea regions to provide relevant baseline knowledge and inform spatial planning and other management decisions. We strongly encourage exploration and characterization of bathyal habitats of the Chilean margin off noth-central Chile, among the poorest-studied areas of the SE Pacific in terms of its deep-water benthic ecosystems. This geologically and seismically active area experiences high upwelling-driven productivity, which sustains many pelagic and benthic fisheries, as well as aquaculture initiatives, while ongoing and planned mining activities pose and increasing anthropogenic threat due to disposal of massive mine tailings in slope areas. We propose to investigate northern-central Chilean habitats, species biodiversity and trophic relationships in order to understand their roles in ecological functioning, ecosystem services, and habitat connectivity.

The Census of Marin Life global biogeography data set for two taxonomic groups (Ophiuroidea and Galatheidae) highlight finding that (a) biogeographic provinces tend to occur in three latitudinal bands separated at approximately 30-35° and 50-60° in both hemispheres and (b) faunas tend to be associated with continents, with one assemblage gradually changing into another in mid-ocean. The situation of Chile is unique because the temperate fauna occurs much further north than in other regions while the Indo-Pacific fauna occurs across most of the Pacific but fail to reach the South American coast. It is unclear whether these patterns are due to temperature or water flow (the cold Humboldt Current), the presence of an oxygen minimum zone (OMZ), or some other ecological or geological factors. In this regard, the coastal morphology forms a “bay system” that seems to play a key role in the primary productivity export to the ocean and bottoms, maintain the fisheries in this region. On the other hand, recently discovered seeps off Concepcion (~36°S), in conjunction with one of the most active upwelling areas and OMZs off Chile, with a well developed OMZ, suggest the presence of biodiversity hotspots, with a potential wealth of species new to science.

Brief Overview of Target Area

We propose to explore and sample the region between ~29°S and 31°S, targeting three transects spanning the shelf break within the OMZ (at 200 m) down to the well-oxygenated mid slope (2000 m), off (1) "Limari seep" (~1000 m), an unexplored seep area associated with the Limari river mouth, (2) "Lengua de Vaca", an active and intense upwelling area also considered to be a sharp biogeographical transition zone, and (3) "Punta de Choros", a hotspot of biodiversity (at shallow and terrestrial levels), including the Marine Reserves "Choros and Damas Islands" and the National Reserve "Humboldt Penguin". Eighty percent of the world's endangered Humboldt penguins breed here, a large population of marine mammals stay here for food (including the bottlenose dolphin, the southern right whale, the humpback whale and the blue whale), as well as the endangered diving petrels. Also, two of the most important fisheries, the Chilean abalone ("loco") and squat lobster ("langostino") are focused around this location.

The overarching hypothesizes that will guide this research is that the hydrological characteristics of the area (intense upwelling and productivity export), and enhanced habitat heterogeneity created by cold seeps presence support a high diversity even within the OMZ . The core of the OMZ potentially supports specific faunal composition, diversity patterns, and feeding modes. Spatial heterogeneity in the structure and function of macro and meiofaunal assemblages occurs at the habitat scale, with the presence of methane seepage, bacterial mats, clam beds, carbonate rocks, and vertically within the sediment. Corals are closely linked to seepage through the use of carbonate substrate once seepage subsides.

Brief Summary of What is Known of Target Area

Along the coast of northern and central Chile, upwelling is localized and its occurrence changes from being mostly continuous (aseasonal) in northern Chile to a more seasonal pattern in southern-central Chile. Furthermore, large-scale climatic events (El Niño Southern Oscillation, ENSO) are superimposed onto this regional pattern, which results in a high spatiotemporal heterogeneity, complicating the prediction of ecological processes along the Chilean coast. Amazingly, El Niño (EN) events in northern Chile do not appear to cause a dramatic decline in primary or zooplankton production but rather a shift in species composition, which affects trophic efficiency of and interactions among higher-level consumers. Studies available from sublittoral soft-bottom communities in northern and central Chile suggest that temporal dynamics in abundance and community composition are driven by inter-annual phenomena (EN and the extent and intensity of the OMZ) rather than by intra-annual (seasonal) patterns. Within the Humboldt Current System (HCS) area, the Coquimbo region (~30˚S) harbors an important coastal upwelling centre, where upwelling occurrence begins to move from continuous to more seasonal. The system of interest is subject of intensive fisheries and eco-tourism. Bifurcated upwelling filaments are thought to be originated at Punta Lengua de Vaca, contributing with cold, nutrient-rich waters to the coastal system. Primary productivity off Coquimbo is 0.5-9.3 g C m-2 d-1 fueling major fisheries, with catches that represent 40% of the annual landings of the HCS. Based on seafloor mapping, ROV imagery and ideally - push coring, rock and biota sampling - we propose characterizing the margin ecosystem and component habitats. In addition, we will explore the potential habitat linkages with commercially important fishery species (i.e. the Patagonian toothfish, Dissostichus eleginoides) and other keystone taxa, and the potential role of cold seeps as nursery sites for marine deep-water predators. First indication of key relationships between fisheries and methane seeps has emerged from studies at the Concepcion Methane Seep Area ~900 km to the south (Sellanes et al., 2012). At one of our target areas, “Limari seep”, tubes of the seep-endemic siboglinid polychaete Lamellibrachia sp. have been collected from ~1000 m depth by long-line fishermen, at a fishing spot known to provide the best catches and largest individuals of D. eleginoides.

Feasibility of Studying Target Area

Access to the study sites should be possible from ports in Peru (Callao) or Chile (Valparaiso, Coquimbo). We will collaborate with biologists from Chile (Javier Sellanes and Praxedes Munoz, UCN), and Juan Diaz (Pontificia Universidad Catolica de Valparaiso, PUCV). Furthermore, we foresee a strong interaction with the newly created excellence centre in oceanography (IMO), funded by the Chilean government for the next ten years. Director and Deputy Director of this centre are Dr. Osvaldo Ulloa and Dr. Rubén Escribano, respectively, from the University of Concepción.

Educational and Outreach Potential of Target Area

The Chile margin will attract the interest of a broad spectrum of students, public and scientists from North, Latin and South America. This project offers an opportunity to convey information about margins, oxygen minimum zones, methane seeps, canyons and deep-sea fisheries. Multiple proposed collaborating scientists all speak fluent Spanish and can engage students from many regions. Outreach activities can be coordinated through the Birch Aquarium, Scripps Institution of Oceanography Communications Office, the UCSD Center for Marine Biodiversity and Conservation and the UCN Aquarium and Museum (currently managed by JS, Co-PI of the present proposal) that receives thousands of visits each year attending a broad spectrum of visitors, including pre-kinder, kinder and K12 scholars, local people, national and international authorities, as well as local and visiting scientists. All environmental and (eventual) biological data collected during the project will be included in public access databases like GBIF, ChEss database (www.soc.soton.ac.uk/chess/database/database.html) and integrated in the Ocean Biogeographic Information System, OBIS (www.iobis.org) through inclusion at the Biological Collection of UCN (CBUCN, http://grbio.org/cool/pkv3-7ant)

Peru Margin Habitat Heterogeneity

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Region

SE Pacific Basin/Peru Basin/Nazca Rise/Chile Rise

Rationale for Exploration

The Peru Margin is highly heterogeneous, with soft OMZ sediments, anoxic basins, phosphorite hardgrounds, numerous deep canyons, and methane seeps that derive from intense upwelling, tectonic activity and subduction. These ecosystems apparently support valuable deep-water fisheries. However few of these habitats have been studied, and the unusual juxtaposition of different settings with OMZ s offers a unique opportunity to understand how the hydrography, substrates, and fluid flows together shape seafloor communities. 1992 videos from the Johnson SeaLink revealed dense aggregations of lithodid crabs at bubbling methane seeps on phosphorite hardgrounds at the base of the OMZ off Callao, Peru (660 and 800 m, 12oS). T his was a geological expedition and no biological observation or sampling was done. Because enormous crustacean aggregations (shrimp, galatheids, spider crabs) are a feature associated with the lower OMZ boundary, we suspect that this novel, and as yet unexplored community is the product of seep-OMZ interaction.

Documentation of seep communities in the northern Peruvian Subduction Zone and Sechura Canyon (Olu et al. 1996 a, b) – include dense assemblages of seep bivalves, and unusual serpulid worm aggregations linked to fluid emissions at scarps, but also to temperature anomalies. Similar assemblages on the Costa Rica margin at 1850 m were identified as a novel habitat type – the hydrothermal seep – with characteristics of both vents and seeps, and unusual reliance on aerobic methane oxidation (Levin et al. 2012). Further exploration of Peru margin seeps, both within and below the OMZ may reveal additional anomalous, 'blended' and highly productive habitat types. They are almost certainly support a wealth of new species and unusual species interactions (e.g. crabs filmed in were heavily colonized by tunicates).

Brief Overview of Target Area

The Peru margin is recognized for its high biological productivity and well -developed oxygen minimum zone. As such this region supports significant methane and plays key roles in global nutrient cycling. Key water masses include the Subtropical Surface water (to 100 m), Equatorial Subsurface Water (100- 700 m), the Antarctic Intermediate Water (> 800m). T he margin is crossed by many canyons, some (like the 88 km-long Chiclayo Canyon)_ reach to the Peru Trench.

Ideal Targets include:
(1) Northern Canyons: Chiclayo Canyon and Potential Seeps 06o47 S 81o 25' W (200-> 4000 m depth, 3 tributaries, 33km from the coast
(2) Callao Seeps on phosphorite hardgrounds (660 m) 12$_{o}$ .00 to 12$_{o}$ 01$_{o}$S and 77º51.9' –

77º52.1’ W. Also a 13.5o transect Callao OMZ
(3) Southern Canyons: T he Ocoña canyon (Teves & Evangelista, 1974) is the longest and deepest one, extending from ca. 200 m to 4500 m depth and near 100 km of length; head at 16°26.4’S, 073°10.6’W)

Exploring different sites from North to South will also permit to explore the influence of the OMZ , since it is more intense off the Central and Southern Peruvian coast, than off the North. Other latitudinal gradients are the extent of the continental shelf (wider to narrower) and the pelagic primary productivity (higher off the Northern and Central coast).

Brief Summary of What is Known of Target Area

Across the Peru margin there is a zonation of organic rich muds covered with Thioploca, phophorite nodules and crusts (300-600 m), and glaucony pellets (Arthur and Dean 2013); each substrate is likely to host distinct and unique benthic and demersal biota. The Peru margin is cross cut by at least 12 major canyons. Detailed fishing records for the Patagonian toothfish show activities concentrated in canyons between 6o and 7.5o South (see attached manuscript).

The Peru margin supports key fisheries that include anchoveta, as well as deep-water king crab and toothfish. Fishing for the toothfish, which is associated with Antarctic Intermediate waters – takes place largely in the northern Canyons (5o to 7oS) between 800 and 2500 m of water. Many of these areas are steep, and demersal trawl damage is expected to be minimal, leaving biodiversity more intact. Most of the canyons are unexplored biologically, although bathymetric data have been collected by the Peruvian Navy and IMARPE. The Seychura Canyon is known to support methane seeps (Olu et al. 1996) and there is some evidence for seep-associated biota in Chiclayo Canyon – all below 2000 m. The deep seeps that have been described provide evidence for hydrothermal seepage (sensu Levin et al. 2012), making the region an interesting target for further exploration. An expedition by Harbor Branch in 1992 filmed bubbling seeps at 630 -800 m off Callao, with massive numbers of crabs, but no descriptions exist and no biological samples were collected as this was a geological expedition. T he sites were never reported in the literature.

Feasibility of Studying Target Area

The Peruvian scientists are eager to collaborate in studying the target ecosystems. Callao provides a centralized port and the proposed sites in the north, central and southern margins of Peru are readily accessible. The shelf is narrow and the margin habitats are therefore relatively close to shore. There are Navy bathymetric maps and a thesis (by Eric Chacon) available to assist dive planning.

Educational and Outreach Potential of Target Area

The Peru margin offers educational opportunities related to tectonics and subduction, to hydrography and the formation of the oxygen minimum zone, nutrient cycling and the formation of phosphorites and hardgrounds, canyon and seep biology. Collaboration with IMARPE would enable Spanish presentations and broadcasts that can reach a large audience in North, Central and Latin America.

Gorgona National Natural Park

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Collaborators

Jaime Cantera-Kintz (Universidad del Valle)

Region

East Pacific Rise
E Equatorial Pacific

Rationale for Exploration

Gorgona has been considered as both as a continental and an oceanic island by different authors; this confers the island different conditions whether it comes from granitic or basaltic origin. In the former alternative, this island is possibly part of a mountain range that might be connected to the continent; in the latter alternative, some argue the possibility of the existence of a submerged volcano. Between this island and the continental coast, depth do not exceed 120-150 meters, while in the West coast of the island, depths reach 2000 meters or more very rapidly and it is believed that there are upwellings in this side of the island.

Due to its location, this island presents adequate conditions for the development of coral reefs, which are present in several locations around the island. These coral reefs are relatively well developed, and might be the most developed coral reefs in the southernmost limit for corals in the East Pacific. Gorgona Island is also part of the marine corridor of the Tropical Eastern Pacific. It has been mentioned without confirmation, the existence of deep water corals, something that might be possible to confirm with deep underwater surveys. Gorgona Island is also a place with high marine biodiversity; which is relatively well known in the terrestrial part and in the intertidal and shallow subtidal habitats, but not in the deep water areas.

Brief Overview of Target Area

Gorgona is a Marine Protected Area, officially declared as such in 1984, located on the TEP in the Intertropical Convergence Zone, which makes it very humid with two rainy peaks each year. It comprises an area of 616.8 sqkm, of which 97.5% are underwater. It is the largest island of the two on the Pacific coast of Colombia and the closest to the continent; hence, it has received a rather large amount of research attention, mainly regarding biodiversity of the coral reef ecosystem, but also on the oceanography of surrounding waters and biodiversity of its tropical humid forest and associated fauna and in a lesser extent on other ecosystems (e.g. rocky shores and sandy beaches). Several international research expeditions (e.g. St. George, Allan Hancock and R/V Vega from Stanford University) have visited this island, but the major research impulse began in the late 70's, with a peak during the 90's and a renewed interest during the last decade; especially by researchers of Universidad del Valle (Valle University).

Brief Summary of What is Known of Target Area

On the Pacific coast of Colombia there are only two islands, and it is in this one where the major research effort has been put on. Research has focused mainly on coral reef communities and the inhabitants, especially corals. In a lesser extent, the same focused has been put on rocky shores and sandy beaches till around 20 meters deep. Main known groups of plants and animals include: marine algae, cnidarians, annelids (mainly polychaetes), mollusks, crustaceans, echinoderms, fishes, marine and shore birds and marine mammals, besides the terrestrial flora and fauna. Although it still remains some discussion as to the geological origin of Gorgona Island, perhaps the most plausible hypothesis is that it is a peak of a mountain range originating on the Panamanian border. There is evidence on the presence of komatiites (continental origin) on the southern end and ophiolites (oceanic origin) on the northern end of the island; which reinforces the discussion regarding the geological origin of the island.

Feasibility of Studying Target Area

Gorgona is a marine protected area that depends on the Ministry of Environment and Sustainable Development. We firmly believe that the probability of studying this area is high. However, we, at Universidad del Valle, will negotiate all permits necessary for conducting research projects on Colombian Marine Protected Areas.

Educational and Outreach Potential of Target Area

There are several educational programs directed by different parties, including Universidad del Valle, that show to both academic and the general public, information relating natural issues, to which this initiative could be directly associated. Most of these projects have contributed enormously to the general knowledge of the shallow zones of the island and complementing this with new information and recordings of deeper zones will be a very important step forward in the direction to accomplish the goal of a better understanding and public awareness.

Searching for Hydrothermal Circulation on the Gofar Transform Fault, EPR

Jeff McGuire (WHOI)

Collaborators

John Collins (WHOI)
Chris German (WHOI)
Jessica Warren (Stanford)

Region

Galapagos/Cocos Ridge
East Pacific Rise
E Equatorial Pacific

Rationale for Exploration

Hydrothermal vents represent one of the most intriguing discoveries of the past 40 years of ocean exploration, possibly representing the type of environment that gave rise to the first life on Earth. Countless oceanographic surveys, ROV and submersible dives on spreading centers around the globe have been aimed at finding and studying hydrothermal vents on ridges, yet immediately adjacent to every ridge axis is a long transform fault that has remained almost completely unexplored. Out of more than 10,000 km of active transform fault valleys on the Earth's seafloor, only a handful of locations have been surveyed for evidence of fluid venting. This is surprising given that many similar faults on land – such as the San Andreas Fault – are the sites of numerous hot springs. The zone of damaged rock around faults is highly permeable in the vertical direction, allowing transport of water deep into the fault, where it heats up and reacts with rock-forming minerals before flowing back up to the surface. In the oceans, some of the most interesting vent fields, such as Lost City and Rainbow on the Mid-Atlantic Ridge and Von Damm on the Mid Cayman Rise [Figure 1], result from the reaction of seawater with mantle rocks leading to serpentinzation reactions and release of hydrogen-rich fluids which, in turn, can promote abiotic synthesis of complex organic molecules linked to prebiotic chemistry. These processes should be much more common on transform faults than most mid-ocean ridges, because brittle rock fracture in these faults typically extends to mantle depths, allowing for much deeper penetration of fluids than occurs in the case of typical ridge-crest black smoker systems. While such processes should undoubtedly recur along all deep ocean fracture zones, we have identified the Gofar transform fault at 4.5°S on the Equatorial East Pacific Rise as a particularly strong initial target for future exploration because it is one of the oceanic transform faults with the most detailed previous geophysical studies: our existing data present multiple lines of evidence suggesting there is significant fluid flow within the Gofar fault-zone and, hence, that this specific fracture zone has particularly strong potential for the discovery of seafloor expressions of key phenomena up to and including new forms of seafloor chemosynthetic ecosystems.

Brief Overview of Target Area

The Gofar transform fault at 4.5 S on the East Pacific Rise is one of the best-studied Oceanic Transform faults because it has very regular and short seismic cycles. Magnitude 6 earthquakes repeat on this fault system every ~4-6 years and this regularity has allowed previous seismic experiments to predict and capture large ruptures with instrument arrays. Through a combination of earthquake source, subsurface imaging, and bathymetric mapping studies, it has been demonstrated that there are certain regions of the Gofar fault that repeatedly stop large earthquakes from propagating across the entire fault. These regions hold the key to understanding why ~80% of global plate motion on oceanic faults does not occur as earthquakes but rather the faults slip nearly silenetly. Gofar is a great target for investigating this problem because it has been observed through many seismic cycles and we can target the two different styles of deformation on the fault to obtain a better understanding of earthquake dynamics. This, in turn, allows us to focus on where we are most likely to find novel sites of seafloor fluid flow.

Brief Summary of What is Known of Target Area

Our recent seismological studies of the Gofar transform fault have identified a ~10 km long section of the fault that is a great candidate for pervasive fluid-flow and possible hydrothermal vent sites. First, seismic imaging studies have detected that the porosity of the fault-zone rocks is extremely high throughout the crust (~5-10%). Moreover, the porosity likely changes on time scales ranging from hours to months, like a sponge being squeezed and released by an ever-changing tectonic stress field [Figure 2]. Secondly, the range of depths within the crust and upper mantle that earthquakes rupture is significantly greater here than elsewhere along the fault, extending into the upper mantle. This suggests that there is significant flow of seawater within the fault to cool it down in this location and that the fluids must certainly circulate down into the upper mantle.

We propose a combined geological, fluid-flow, and seismological study of the Gofar fault-zone aimed at discovering what detectable signals of fault-zone fluid flow are there. Our earlier work shows that our instruments should be able to capture and record >250 microearthquakes of a detectable magnitude per day and so, in parallel with our water column and ROV investigations, what would be particularly novel in this study is that we would also deploy a suite of upgraded ocean bottom seismometers in two dense arrays for a ~2 week period covering from the start to the end of our cruise. This component of the study will be important because it will help answer a primary outstanding question: to what depth do rapid (days-months) changes in seismic velocities (and likely fluid-flow transients) extend within the fault-zone? For the majority of the cruise, however, once the seismometers are deployed and recording data, our activities will focus on a combination of CTD-rosette & ROV investigations. Using the CTD-rosette, we will conduct near-bottom surveying for anomalies in temperature, Eh, and particle back-scatter coupled with shipboard measurement of water column CH_4 and H_2 concentrations. This is the same strategy that was first used to search for all known forms of seafloor venting along the Mid-Cayman Rise (German et al., PNAS, 2010) and has, thus far, led to the discovery of a diverse array of novel forms of seafloor fluid flow including the first dives to the Von Damm site in 2011 aboard the Okeanos Explorer and further new discoveries in 2013 aboard the RV Falkor and EV Nautilus. In parallel, we will also conduct high-resolution ROV based geological reconnaissance, mapping and imaging of the fault-zone to help interpret the fluid surveys and both rocks and fluid samples will be collected at interesting locations for more detailed geochemical analyses ashore. In support of our ROV based exploration, we will also conduct a rock dredging campaign to recover samples from the fault-zone. On board the ship, we will characterize these rocks for evidence of fluid interaction with the mantle and crust. Rocks will later be characterized at Stanford to determine rates and styles of deformation and of alteration.

Feasibility of Studying Target Area

The Gofar transform is relatively easily accessed (~3 days transit) from a port call in the Galapagos Islands. A ~21 day cruise round trip from the Galapagos Islands to the Gofar fault would allow us to meet a wide variety of objectives.

Educational and Outreach Potential of Target Area

Graduate students from Stanford University and the MIT/WHOI Joint Program would be involved in the cruise and subsequent data analysis. Given the large ROV component of the cruise, there would be considerable opportunities for real-time video based outreach efforts. These outreach programs could be organized around themes of “Seafloor Fluid Flow” and ‘What Stops Earthquakes?’ since these are the major scientific topics that we seek to address.

Technology

Anna Michel (WHOI)

Collaborators

Scott Wankel (WHOI)
Pete Girguis (Harvard)

Region

Aleutian Trench/Bering Sea/Gulf of Alaska
Galapagos/Cocos Ridge
East Pacific Rise

Rationale for Exploration

We are interested in developing advanced in situ chemical sensors that are compatible with remotely operated vehicles, autonomous underwater vehicles, and human occupied vehicles. From these couplings comes the capability to measure complex chemical data from a wide range of deep ocean environments in order to effectively increase the spatiotemporal resolution of data coverage by orders of magnitude and to provide high-resolution datasets about the biological, chemical, geological, and physical processes underlying these seafloor habitats.

Brief Overview of Target Area

As a collaborative team of scientists and engineers, we are interested in both the quantification of the spatial and temporal dynamics of concentration and isotopic composition of dissolved gases [e.g., methane (CH4), and carbon dioxide (CO2)] in the ocean and developing the tools/sensors to measure them in situ. Such measurements are fundamental to characterizing and constraining the physical and biogeochemical processes that control globally relevant elemental fluxes, though has proven particularly challenging in the deep ocean. Through the use of a deep sea laser spectrometer, which utilizes Off-Axis Integrated Cavity Output Spectroscopy, methane isotopes and carbon dioxide, can be measured in situ. Use of both a currently developed instrument and next generation laser based in situ sensors will bring great value to a range of Pacific Ocean field sites.

Brief Summary of What is Known of Target Area

We are particularly interested in deployment of the sensor in areas in the Pacific Ocean with high concentrations of methane and/or carbon dioxide (e.g. methane hydrates, seeps, vents).

Feasibility of Studying Target Area

The first generation in situ laser based spectrometer has the capability to provide spatially-resolved measurements of carbon dioxide, methane, and methane isotopes. We are currently pushing the technology forward, adding the capability to measure carbon dioxide isotopes in situ, and improving the detection limits of the system. As we work to develop new in situ laser based spectrometers, we will broaden our target analytes and strive to further improve sensitivity. The current and future planned capabilities will provide necessary sensors for in situ biological, chemical, and geological studies in the deep ocean, including in the Pacific Ocean.

Educational and Outreach Potential of Target Area

Through the incorporation of cutting edge technology and novel instrumentation for chemical explorations, we can engage educators, students, underrepresented groups and the general public in ocean engineering and ocean chemistry. Incorporating engineering components into explorations provides a platform for a diverse audience to be exposed to the field through telepresence-based learning.

Formation of an Intra-Transform Spreading Center in the Galapagos Transform Fault

Eric Mittelstaedt (University of Idaho)

Collaborators

Karen Harpp (Colgate University)
Dennis Geist (University of Idaho)

Region

Region 1

Rationale for Exploration

Oceanic transform faults (TFs) are fundamental to accommodating tectonic plate motions along mid-ocean ridges (MORs) [e.g., Wilson, 1965; Sykes, 1967]. TFs are observed along nearly all MOR axes, across a large range of spreading rates [Wilson et al., 1965], where they offset MORs by 10s to 100s of kilometers [e.g., Fox and Gallo, 1984; Macdonald et al., 1988]. The canonical model of TFs defines them as thin zones of shear deformation that strike parallel to plate motion [Menard and Atwater, 1968; Vogt et al., 1969], that are orthogonal to the strike of the adjacent ridge segments [Atwater and MacDonald, 1977], and that have offsets that are inherited from continental break-up [Wilson, 1965]. The majority of TFs do not follow this model, however. Indeed, many TFs are not parallel to plate motion [Taylor et al., 1994] or perpendicular to neighboring ridge axes [e.g., Baines et al., 2007]; oblique compressional (transpressional) TFs develop a distinct central ridge along their length [e.g., Pockalny, 1997], and oblique tensional (trans-tensional) TFs develop wide, deep extensional basins that are sometimes cut by en-echelon faults, oblique to the strike of the TF [Taylor et al., 1994; Mittelstaedt et al., 2012]. Observations also show that many TFs do not inherit continental rift offsets including that they form a significant time after continental break-up [Taylor, 2008], change length and location over time, possibly due to changes in spreading direction [Baines et al., 2007] and ridge jumps [Mittelstaedt et al., 2012], and can divide into multiple strands through the formation of intra-transform spreading centers (ITSCs) [e.g., Fornari et al., 1989; Wendt et al., 1999].

In particular, one aspect of TFs that does not fit the canonical model, the development of segmented transforms through formation of ITSCs, is poorly understood, despite segmented transforms being observed along most MORs [e.g., Searle et al., 1983; Fornari et al., 1989; Lonsdale et al., 1989]. ITSCs are locations of active crustal accretion associated with passive mantle upwelling and melting due to separation of the plates, similar to MORs [e.g., Fornari et al., 1989; Perfit et al., 1996; Carbotte and MacDonald, 1992; Hekinian and Bideau, 1995]. Plate reconstructions using magnetic and bathymetric observations show that ITSCs can form from a single unsegmented TF [Pockalny et al., 1997].

Currently there are two main conceptual models of ITSC formation. One model proposes that ITSCs form as part of multi-transform fracture zones, caused by small changes in plate motion [Searle et al., 1983]. Based upon observations of TFs between 1°N and

20°S along the EPR, Lonsdale [1989] also argued that ITSC formation is a consequence of rotations in plate motion, which place TFs in an “opening” mode of deformation. This is supported by observations that show that ITSCs always offset a TF in the direction that reduces TF obliquity [Searle et al., 1983]. The second model proposes that focused magmatism within the TF creates a volcanic weld across the trace of the TF, initiating a step-over that evolves into a new ITSC [Fornari et al., 1989]. To date, insufficient data are available to differentiate between these two models or to provide insights into other possible processes that may be important to ITSC formation.

The Galápagos Transform Fault (GTF) offers an ideal opportunity to examine the early stages of ITSC formation, when the formation of a step over is imminent. Specifically, observations reveal a linear ridge in the southern portion of the GTF that is likely a proto-ITSC [Mittelstaedt et al., 2012].

Brief Overview of Target Area

The GTF is located at 90°50’W along the Galápagos Spreading Center (GSC), which separates the Cocos and Nazca plates (Supplement Figure 1). The GTF is a right-stepping, oblique (~10° to the relative spreading direction) TF that offsets the GSC by ~100 km. Deformation in response to its oblique orientation has created a ~60 km wide region of high fault density with faults oriented oblique to both the plate motion vector and the TF strike [Harpp and Geist, 2002; Harpp et al., 2003; Mittelstaedt et al., 2012]; these faults and the predicted plate motions suggest that the TF and surrounding crust is actively extending at a rate up to ~8 km Myr-1 [Harpp and Geist, 2002] (Supplement Figure 2). Magnetic reconstructions indicate a relative plate motion parallel to the transform fault of ~52 km Myr-1 [Mittelstaedt et al., 2012].

Morphologically, the GTF can be divided into northern and southern basins based upon differences in the valley width and depth, volcanic characteristics, and faulting patterns [Sinton et al., 2003; Mittelstaedt et al., 2012]. South of 1.15°N, the TF valley is ~25 km wide and reaches a depth of ~2700 meters below sea level (mbsl) at its deepest point. Volcanic cones are numerous throughout the southern valley and are often associated with faults that cross cut the valley in a Riedel-like pattern [Riedel, 1929]. In contrast, north of 1.15°N, the GTF is dominated morphologically by a 1 km deep extensional basin, ~3500 mbsl at its deepest point [Sinton et al., 2003; Mittelstaedt et al., 2012]. The northern basin is ~15 km wide with sparse volcanic cones, and observations find no evidence of faults cross-cutting the northern basin (Supplement Figure 1).

Within the southern basin, a unique, approximately linear, bathymetric high (linear ridge) may be the first stage of formation of an ITSC (Supplement Figure 3). It is unclear based upon the current bathymetry whether linear ridge parallel faulting and/or volcanism occur here, processes that would be expected from spreading along ITSC. If this is indeed the location of a new ITSC, a study of its morphology, eruptive style, and faulting pattern will significantly improve our understanding of ITSC formation and help to distinguish between the two competing models [e.g., Fornari et al., 1989; Wendt et al., 1999].

Brief Summary of What is Known of Target Area

Magnetic reconstructions of the tectonic history of the GTF indicate that the northern basin formed first (~2.5-3.5 Ma) and was followed by formation of the southern basin ~1 Ma, after a ~35 km southward jump of the GSC [Mittelstaedt et al., 2012]. Within the zone of transform deformation, Mittelstaedt et al. [2012] identify ~30 individual volcanic cones, approximately two thirds of which are in the southern valley. Greater volcanic activity in the southern basin may explain gravitationally-derived crustal thicknesses that are ~2 km greater in the southern basin than in the northern basin [Mittelstaedt et al., 2014] (Supplement Figure 4). This is consistent with both a longer period of extension in the older, northern valley and thickening of the crust in the south by recent volcanic activity. The GTF is bounded by a ~60 km wide region of high fault density that may be a response to the oblique angle of the GTF to spreading [Harpp and Geist, 2002; Harpp et al., 2003; Mittelstaedt et al., 2012]. Extension associated with the observed faulting is not sufficient, however, to account for the component of relative plate spreading perpendicular to the TF, suggesting that extensional deformation also occurs in the neighboring plates.

Geochemical analysis of the 5 available samples from the GTF reveals an intriguing glimpse at GTF magmatic and mantle processes. Compared to the adjacent GSC, samples from within the GTF are more primitive (>8 wt% MgO) and have very low incompatible trace element ratios, similar to lavas within the Garrett and Siquieros TFs [Hekinian et al., 1997; Perfit et al., 1996]. The northernmost sample has only 6.4 wt% MgO, which may indicate processing through crustal magma reservoirs beneath the northern valley of the GTF, but possibly the same mantle source, given their similar incompatible trace element (ITE) ratios. In fact, these lavas are more ITE-depleted than the GSC lavas west of 96°W that appear to have no plume component [Schilling et al., 2003; Sinton et al., 2014]. For the GTF lavas, Sm/Yb ratios are also lower, suggesting shallower tops of the melting column beneath the GTF [Gibson et al., 2010; Morrow et al., 2014].

Feasibility of Studying Target Area

Current ship-based multi-beam bathymetry and backscatter are available for the GTF, but the bathymetry resolution is ~50 m and the backscatter data are distorted due to the steep TF walls (Supplement Figure 2). Only 5 dredge samples exist along the ~100 km TF, none of them from the linear ridge (Supplement Figure 1). The features of interest within the GTF are geologically young suggesting that sediment cover should be minimal. This is supported by a single TowCam profile performed during the 2010 MV1007 within the southern GTF valley that reveals variable, but thin sediment cover, with exposed basalts at faults and a volcanic cone. We propose to focus on the linear ridge (Supplement Figure 3) within the southern basin that likely represents an early stage of ITSC development. The linear ridge is well within the depths of operation of the ROV Hercules, between 2500 mbsl and 2300 mbsl. We will use the high-resolution sonars, video cameras, and sampling capabilities of the ROV Hercules to explore the tectonic and volcanic expressions along the linear ridge. Subsets of the rock samples will be analyzed at Colgate University using PI Harpp's Varian 820MS quadrupole inductively coupled plasma-mass spectrometer for trace element analysis and X-ray fluorescence spectrometer, the Philips PW2404, for major element analysis.

Near-bottom, high-resolution maps and imagery, such as those possible using the ROV Hercules, will allow identification of individual lava flows and fault networks, and targeted sampling will reveal differences in basalt chemistry from the previously sampled cones within the TF. These data will allow us to address several, specific questions: 1) Is the linear ridge in the southern basin volcanically active; 2) how does the chemistry of basalts along the southern basin's linear ridge differ from previously sampled cones; 3) is the chemistry consistent with ITSCs at other TFs; 4) what amount of surface extension (fault slip) has occurred along the linear ridge, and in what orientation? The PIs involved in this proposed work have significant experience working in the Galápagos and bring a multi-disciplinary approach to the project using both geochemistry and geophysics.

Educational and Outreach Potential of Target Area

Since 1535, the Galápagos has inspired curiosity and provided a unique laboratory for biological and geological sciences. The region is a textbook example of plume-ridge interaction and the GTF uniquely allows examination of a transform fault in two different stages of evolution. The proposed work is a collaboration between PIs at an undergraduate institution (Colgate University) and a research institution (University of Idaho), and we plan to involve several undergraduates as integral members of the project team. The PIs all have proven track-records involving undergraduates on sea-going expeditions. In 2010, all three of the PIs participated on the MV1007 cruise, which was staffed by nine undergraduates, all of whom participated in a semester-long pre-cruise seminar and completed 1-2 year research projects that were presented at AGU by the students. In addition, PI Mittelstaedt is currently participating in the TREET (Transforming Remotely Conducted Research through Ethnography, Education, and Rapidly Evolving Technologies, PI: Chris German, WHOI), where he is mentoring 2 undergraduates who will perform independent research projects using data to be collected during a telepresence cruise at the Kick'em Jenny Volcano in September 2014. As with the above expeditions, we plan to involve undergraduates in the proposed work by conducting a semester-long seminar series and having the students participate in 1-2 year research projects that can be presented at the Fall Meeting of AGU. In addition, we plan to collaborate with scientists from the Charles Darwin Research Station (CDRS) and INOCAR, the research arm of the Ecuadorian Navy.

Eastern Pacific Seamount Moats

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Collaborators

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Art Spivack (URI GSO)
Steven D'Hondt (URI GSO)
David Smith (URI GSO)

Region

Galapagos/Cocos Ridge
East Pacific Rise
E Equatorial Pacific

Rationale for Exploration

A global analysis of transit multibeam bathymetry data has identified over 600 enigmatic bathymetric depressions surrounding seamounts throughout the world's oceans (Attachments 1 & 2). These bathymetric depressions occur primarily as 1 km-wide, 100 m-deep annular deeps (termed moats) located in sediments surrounding small (< 500 m high) topographic highs [Pockalny et al ., 2007]. The vast majority of these moats are located in the eastern and central Equatorial Pacific Ocean.

A number of mechanisms have been proposed to explain the formation of these seamounts moats, including faulting, lithospheric flexure, current scour, inhibited sediment deposition, mud volcanism, and biogenic sediment dissolution. The small siz e, age and depth of The Equatorial Pacific moats likely preclude flexure, faulting, or mud volcanism mechanisms; however, sediment scour, sediment inhibition and biogenic sediment dissolution are still viable origins for moats (Attachment 3).

Although the source of these anomalous Equatorial Pacific depressions is still very speculative, the large number, their distribution, and their size suggest significant, fundamental, and possibly important implications related to their origin. For example, the current scour or inhibited sediment deposition origins would suggest enhanced abyssal currents in the past or a localized ongoing phenomenon. Both explanations would have important implications for paleo-circulation and deep-water mixing.

Alternatively, a biogenic sediment dissolution model would indicate a novel mechanism and significant convective heat flow is occurring in the region. Though the estimated fluid flow required to create/maintain seamount moats is relatively low (0.01 to 30 m/yr), the broad distribution and estimated moat density for the Equatorial Pacific suggests the total seawater flux through the moats is on the same order of magnitude as vents along the mid-ocean ridge axis on seafloor less than 1 Ma. These low fluid flow rates of low temperature water (<10˚C) emanating from mature basement may also support a unique and unexplored ecosystem.

Brief Overview of Target Area

The moats in the East Pacific target area are located on seafloor located on the Cocos Plate that was accreted along the fast- to ultra-fast spreading East Pacific Rise within the last 20 million years. The region is criss-crossed by numerous shiptracks of multibeam data that image numerous moats and possibly related bathymetric pits. Sediment thickness in the region ranges from 150 – 200 m (Divins, 2006) and is characteriz ed as biogenic ooz e with $CaCO_3$ composition between 30 and 70% (Archer, 2003). The target area is located about 360 km southwest of ODP site 1256 and 180 km north-northeast of DSDP sites 83 and 503. HYCOM ocean circulation models indicate maximum abyssal current speeds of < 5 cm/s in the immediate vicinity of the target area and < 20 cm/s over a broader region of the Cocos Plate (see Attachment 2).

Brief Summary of What is Known of Target Area

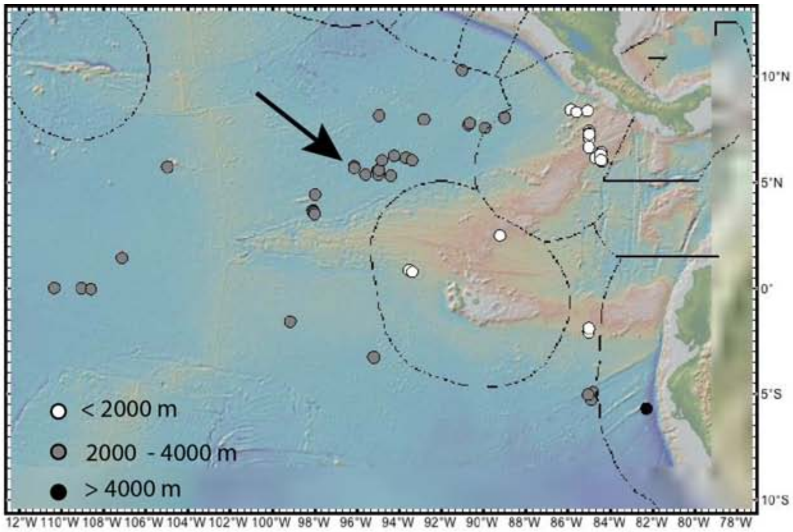
A German cruise in 2007 targeted similar pits in young seafloor on the Cocos Plate in the nearby Guatemala Basin. Heat flow measurements indicate the pits are pathways for cold seawater emanating from the sediments, which leads to a large cooling effect in the vicinity of the pits and seamounts. Preliminary geochemical analyses of pore waters from cores recovered from within and outside of the pits, however, do not immediately confirm the dissolution hypothesis, additional research is required [Schmidt-Schierhorn et al., 2011].

Feasibility of Studying Target Area

The geographic location of the target area is in international waters and provides easy access to deep-water ports (e.g., Puntarenas, Costa Rica). The bathymetry is less than 4000 m so the multibeam, Chirp and ROV systems will be able to reach the proposed targets. This project would benefit significantly from heat flow measurements that can be obtained from an ROV (with some adaptations that have been successfully employed with Alvin an Jason) or from conventional overboard probes deployed from the ship.

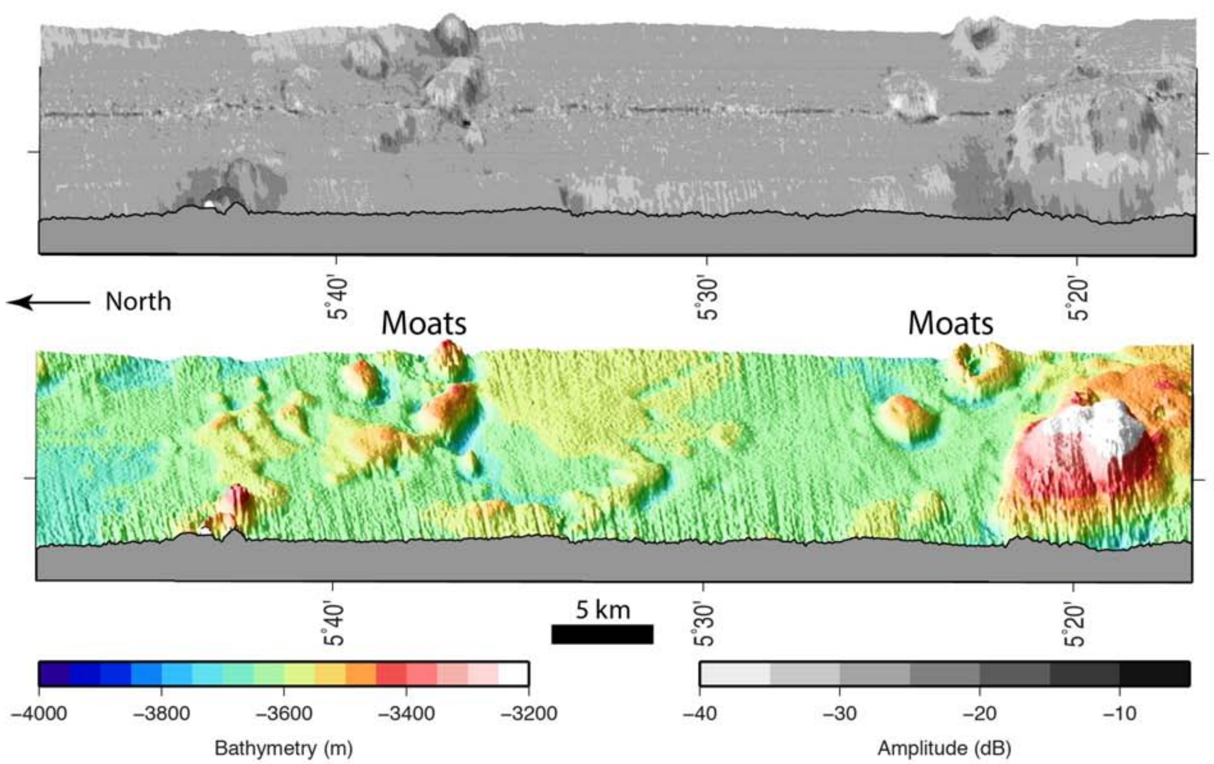
Educational and Outreach Potential of Target Area

Involve a range of activities ranging from seafloor mapping, near-bottom measurements, and sampling that would provide a varied experience for students or the on-line public. This expedition is truly exploratory since the only prior study of these features (in other regions of the Pacific) include two survey programs with Deep-Tow on older seafloor (40 and 100 Ma) and at higher latitudes [Normark and Spiess, 1976; Mayer, 1981]. Two gravity cores of other moats and a pit do exist, but the moat cores have only been visually inspected. The proponents also have extensive experience engaging Middle and High School students and teachers in their programs by taking teachers to sea or visiting classrooms in Rhode Island and rural Upstate New York.



Above: Location of seamount moats (filled circles with depth range) in eastern Equatorial Pacific with maritime territories shown with black outlines. Arrow indicates location of bathymetry and backscatter plots shown below.

Below: Multibeam bathymetry and backscatter draped on bathymetry for representative seamount moats in the eastern Equatorial Pacific. Backscatter data has been corrected for spherical divergence and topographic slopes.



2015 Pristine Seas Expedition to Clipperton

Enric Sala (National Geographic Society)

Region

Clipperton Atoll

Rationale for Exploration

Clipperton is one of the Pristine Seas' target areas for creation of a large marine reserve.

Brief Overview of Target Area

Clipperton: only atoll in Tropical Eastern Pacific surrounded by a 200-nm EEZ that belongs to France.

Brief Summary of What is Known of Target Area

Unihabited atoll, unknown but certainly high fishing pressure. Former shark abundances are gone. Several expeditions created species lists, but there is no quantitative assessment of reef organisms, and few info on the deep seas.

Feasibility of Studying Target Area

Feasible with a platform like the Nautilus.

Educational and Outreach Potential of Target Area

High on coral reefs, deep bottoms and history of the occupation of Clipperton.

Galapagos Rift

Timothy Shank (WHOI)

Collaborators

Scott White (University of South Carolina)
Dave Butterfield (NOAA PMEL)
Jim Holden (University of Massachusetts Amherst)
Robert Embley (NOAA PMEL)

Region

Galapagos/Cocos Ridge

Rationale for Exploration

The 1977 disco very o f deep-sea hydrothermal vents and their associated animal communities at the Galápagos Spreading Center (GSC) transformed the oceanographic and biological sciences and ushered in a new era o f scientific inquiry into life processes in extreme depth and chemical environments (Corlis et al., 1979). Sites near 86°W, like the Garden of Eden, Rose Garden, and Musselbed were historic locations discovered using DeepTow and Alvin, fro m which our early understanding o f hydrothermal fluid chemistry, vent geological settings and chemosynthesis were derived.

Hydrothermal vents were discovered along young volcanic ridges constructed in the middle of the 2-4 km wide rift valley that defines the spreading axis at this intermediate spreading (5-6 cm/yr) MOR. Galápagos vent sites host what we now know to be the iconic “textbook” vent communities - expansive vent fields inhabited by giant tubeworms, dinner-plate size clams, beds o f mussels, bands of gastropod limpets, and alvinocarid shrimp, while the fields’ peripheries were covered by extensive carpets of serpulid polychaetes and anemones.

Although the Galápagos discoveries began in 1977, nearly 30 years later only a dozen vent sites, including inactive or extinct chimneys had been discovered along this ridge, while active black smoker vents remained elusive. Until 2002, the majority of the eastern limb and the entire western limb of GSC remained largely unexplored for hydrothermal activity, largely because o f issues related to diplomatic clearances required to work in the territorial waters of Ecuador, which lie just west of the 86°W vent fields.

Since 2005, several expeditions have been devoted to exploring for the elusive high-temperature vents along the GSC to better understanding the distribution of venting along the spreading center. Another goal was to understand the relationships of faunal communities both along the ridge and to the adjacent EPR.

In December 2005, the GalAPAGoS Expedition (Galapágos Acoustical, Plumes, and Geobiological Surveys) explored an 800 km section of the GSC between 94.5º and 89.5º W. This area is where the spreading center axis topography is bro ad and inflated, reflecting abundant magma supply, similar to the typical topography for the fast-spreading EPR axis.

Perhaps the primary reason for this dramatic change in axial topography along the GSC is that this segment of the ridge is closest to the mantle plume that created the Galápagos Islands, hence the increased magmatism, heat, and resulting shallow topography. During that cruise, several high-temperature vents were discovered using the towed imaging system Argo II, but no samples of fluids or biota were recovered. In June and July 2011, the GALREX 2011 expedition mapped about 40,000 km2 o f seafloor and acquired a 400-km-long hydro thermal plume survey of the unexplored eastern portion of the GSC fro m 101.3°W to 98.0°W (Shank et al., 2012). Additional continuous hydrothermal plume surveys and multi-beam transects were also completed between 89.33°W and 85.75°W. The plume surveys revealed at least 20 distinct water column anomalies along the eastern segment of the GSC, with venting concentrated in two distinct areas. The anomalies included a 50 km-long (88.56°-88.09°W) region of continuous, optically intense plumes rising as high as 250 m above the seafloor, and a suite of discontinuous weaker plumes near the site where Rose Garden had been located and the new Rosebud site (Shank et al., 2003). In short, the bio geographical difference between hydro thermal vent species and communities along the Galapagos Rift and the East Pacific Rise are staggering – more than ~40% of the endemic biological species comprising East Pacific Rise vent communities are reportedly absent from the Galapagos Rift. This may primarily due to the lack of exploratory investigations and sampling of the known high-temperature chimney habitats discovered in 2005/6 and those that likely exist but have yet to be discovered. As a result of exploration in 2005/6 and 2011, there are numerous plume signals from which seafloor source location, fluid chemistry, underlying geology and associated biological communities have yet to be discovered. In addition, further exploration o f several areas discovered as having recent eruptive activity (very recent- fresh lava flows colonized by microbial mats with no attached vent fauna, and only mobile shrimp, copepods and crabs in vigorously venting snow blower areas) provides rare opportunities to discover the evolution of faunal communities and vent systems from their inception.

The venting and animals communities in several o f these areas were documented with high-definition cameras in 2011. Several key ecological species (e.g ., Tevnia jericho nana tubeworm) thought to facilitate and direct the sequential colonization of other fauna (e.g ., Riftia) (Mullineaux et al. 2000) at EPR vents are notably absent at Rosebud. Thus, the ecological mechanisms (e.g ., larval input, species interaction, vent fluid chemistry, etc.) controlling the colonization and development of vent communities at the Galápagos Rift are expected to be markedly different fro m any previously documented at mid-ocean ridges (e.g ., Shank et al 1998; Van Dover 2000).

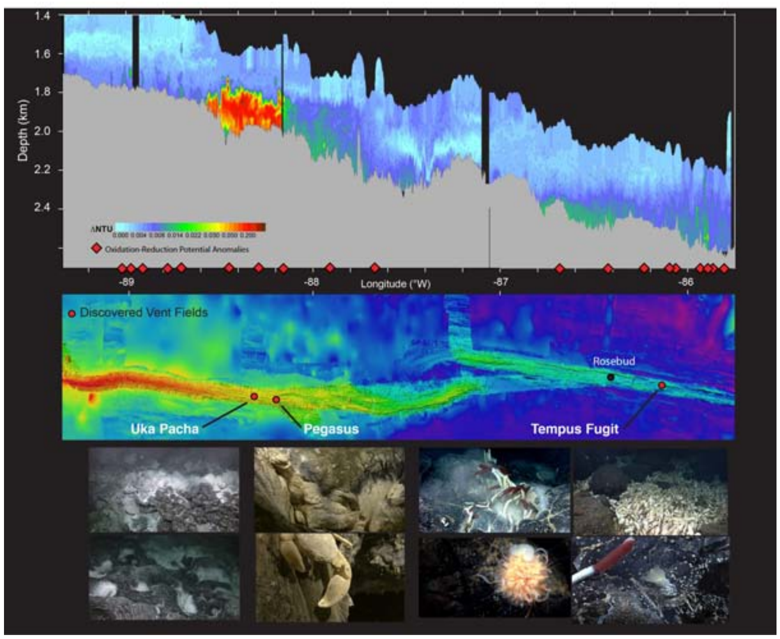
Brief Overview of Target Area

Multibeam bathymetric maps of the Galápagos Rift axis between 101.3°W to 98.0°W were obtained in 2011 along with a coincident continuous CT D transect between 89.33°W and 85.75°W was conducted. T he survey revealed at least 20 distinct water-column anomalies along the eastern arm of the rift, corresponding to an overall spatial density of hydrothermal plumes about twice that of the central rift (Baker et al., 2008).

Venting was concentrated in two distinct areas. Hydrothermal plume survey (top) showing venting sites at 88.56°–88.09°W and 86.25°–85.87°W, bathymetric coverage (middle of attached figure), and images of Uka Pacha (at left) and Tempus Fugit (at right) vent fields discovered during the expedition. In the top panel, Δ NT U corresponds to light backscattering by hydrothermal precipitates, and oxidationreduction potential anomalies mark locations where reduced hydrothermal chemicals (e.g., H2S, Fe+2) were detected. One consisted of contiguous, intense plumes rising as high as 250 m above the seafloor. T he other, hosting weaker plumes, was near the historical vent fields Rose Garden, discovered in 1979, and Rosebud, discovered in 2002 (Shank et al., 2003).

Brief Summary of What is Known of Target Area

All too brief exploration near 88.3°W, the location of the largest hydrothermal plume signal (see attached Figure), found recently erupted lava flows spread over at least 14 km, as well as several regions of vigorous diffuse venting. At two sites, white flocculent material—potentially microbial in origin—issued from the vents in a “snowblower” fashion. Two newly named vent fields, Uka Pacha and Pegasus, featured these white microbial mats blanketing extensive areas along the base and sides of the axial graben. The White et al., white paper outlines the geological summary of the target area.



Feasibility of Studying Target Area

Multibeam maps exist throughout the region. Plume signals indicative of strong hydrothermal venting are also known (as of 2012). Vent species from low-temperature diffuse flow vent sites are well documented for comparison to those they may exist at high-temperature vent sites. The target locations are poised close to Panama and therefore provide a feasible working area with transit between the Atlantic and Pacific target areas, via transit through the canal.

Educational and Outreach Potential of Target Area

Deep-sea hydrothermal vents and their biological communities continue to capture the attention and imagination of the broad public. T he probability of discovering unknown vent sites and species, black smokers, etc., is extremely likely (venting discovered almost every day during limited exploration in 2011). The communities they support have fascinated the public's imagination for more than 35 years. As such, they have served prominently as frameworks for both web-based learning and classroom programmatic science curricula around the world in teaching the fundamental principles of life, on earth and limitations and potential for other planetary bodies. These include the basic tenets of chemosynthesis, symbioses, adaptations, genetic isolation, evolution.

Isle Guadalupe, Mexico

Alexander Simms (University of California Santa Barbara)

Rationale for Exploration

Many estimate for tectonic uplift rates along active coastlines are determined by calculating the difference in elevation between paleoshorelines and estimates of past sea levels. Paleoshorelines provide an important datum for understanding tectonic uplift rates at the millennial to centennial scales. However, before using paleoshorelines as datums for paleotectonic activity, the effects of glacial-isostatic adjustment must be made. Glacial-isostatic adjustments are created by the deformation of the Earth as a result of the buildup of the last great ice sheets and can result in local sea level varying by 10's of meters from the global average (Lambeck and Chappel, 2001). One important paleoshoreline is that formed during the Last Glacial Maximum (LGM) approximately 20,000 years ago. However, to this date, the elevation of the LGM shoreline is not know in an area largely free from tectonic uplift anywhere along the Pacific Coast of North America. The Isle Gaudalupe, Mexico provides a possible location in the hunt for a shoreline from a site largely free of tectonic uplift. The island is thought to represent an extinct volcanic complex and thus largely free from active tectonic uplift. We propose to examine and map the LGM shorelines around the Isle Gaudalupe in order to determine its elevation and hence a datum for LGM sea levels for the Pacific Coast of North America. Our current hypothesis is that the LGM shoreline should lie somewhere between 130-110 m below current sea level.

Brief Overview of Target Area

I assume that a marine terrace surrounds the island at around 130-110 m of water depth. Very little marine work has been done around the island.

Brief Summary of What is Known of Target Area

Very little. Some work has been conducted on the volcanic rocks of the island on land.

Feasibility of Studying Target Area

Unknown

Educational and Outreach Potential of Target Area

None to my knowledge

East Pacific Rise, Off-Axis

Adam Soule (WHOI)

Collaborators

Dorsey Wanless (Boise State University)
Ken Rubin (UH SOEST)
Mike Perfit (University of Florida)
Peter Girguis (Harvard)
Pablo Canales (WHOI)

Region

East Pacific Rise

Rationale for Exploration

By most accounts, magmatism at fast-to-intermediate spreading ridges is narrowly focused at the ridge axis [e.g., Macdonald, 1982; Sinton & Detrick, 1992]. Guided by ridge morphology and past experience, exploration of the ridge axis has, with justification, been considered the most propitious location to examine active MOR processes. However, the few studies that have examined the off-axis regions at a variety of MORs have routinely found evidence suggesting that magmatic accretion in the shallow crust, volcanic extrusion, and hydrothermal circulation occur well beyond the seafloor expression of the plate boundary [e.g., EPR: Garmany, 1989; Crawford & Webb, 2002; Z ou et al., 2002; Haymon et al., 2005; Durant & Toomey, 2009; Guaymas SC: Lizarralde et al., 2010; SW Indian Ridge: Standish et al., 2010; Juan de Fuca Ridge: Canales et al., 2009]. T he importance of off-axis magmatism in crustal accretion, alteration, and biological processes remains to be quantified, and the vast off-axis region has not yet been systematically explored. We propose an Ocean Exploration Trust effort to conduct the first comprehensive examination of the nature and consequences of off-axis magmatism. Critically important to this effort is the recent identification of crustal melt sills at distances of 4-8 km from the EPR axis by 3D MCS surveys [e.g., Canales et al., 2012; Han et al., 2014] that provide viable targets for exploration in the vast off-axis domain.

At the East Pacific Rise 9˚-10˚N, broadly recognized as the type example of axis-centered MOR magmatism, the 1-2 km wide ridge axis is underlain by a nearly continuous shallow-crustal axial melt lens that feeds seafloor eruptions, drives vigorous hydrothermal circulation, and supports vibrant chemosynthetic animal communities. This view has been challenged by the recent 3D multi-channel seismic (MCS) study conducted along the EPR that identified crustal (2-6 km depth) off-axis melt bodies at 4-8 km east the ridge axis at 9˚54'N, 4 km east of the axis and 9-10 km west of the axis at 9˚39'N, from high amplitude seismic reflections with similar character to the well-defined axial melt lens reflector at the EPR [Canales et al., 2012; Han et al., 2014]. In addition, a number of other observations at the EPR suggest off-axis magmatism may be more common than previously believed. These include seismic wave diffraction and P- to S-wave conversions indicating a magma body in the mid crust (~2 km bsf) overlaying an anomalously hot lower crust 20 km east of the EPR axis at 9˚20'N [Durant

& Toomey, 2009]; P-S conversions indicating melt sills at the base of the crust 22 km west of the ridge axis between 12˚0 to 12˚50'N [Garmany, 1989]; mineralogical and biological evidence of high-temperature fluid discharge along abyssal hill faults at 5 km east (10˚20'N) and 26 km west (9˚27'N) of the EPR axis [Haymon et al., 2005]; radiogenic isotope evidence of 'zero-age' volcanic eruptions at distances up to 4 km from the EPR axis at 9˚50'N [Goldstein et al., 1994; Sims et al., 2003]; and anomalously young eruptions as much as 22 km from the EPR axis at 9˚30'N [Zou et al., 2002].

The existing observations supporting off-axis magmatism are not co-located and each relies on a distinct methodology to constrain one manifestation of magmatism. Further, they often reflect a serendipitous discovery of off-axis magmatism and none have provided a systematic exploration of the ridge flanks. As a result, we have an incomplete picture of off-axis melt accumulation and its manifestation at the seafloor. Important questions remain such as the timescale over which these melt bodies persist in the crust, the mechanisms by which they are generated, their prevalence along the ridge axis, their ability to support hydrothermal flow, and their contribution to the integrated crustal column, especially extrusive volcanics and hydrothermal mineralization. In addition, off-axis hydrothermal systems likely support chemosynthetic biological communities that are effectively isolated from ridge-centered communities and would represent an important genetic reservoir for vent species. The results of this investigation will provide the first direct link between known off-axis melt sills and their seafloor expression, producing a critical context for interpreting the disparate observations presumed to reflect off-axis magmatism at this and other ridges that have been compiled to date. Given the importance of MORs in the global mass balance of heat and chemical cycles and the mounting evidence for off-axis magmatism at a variety of MORs, identifying the seafloor manifestation of off-axis melt bodies has the potential to fundamentally alter our perspective on mid-ocean ridges.

Brief Overview of Target Area

The East Pacific Rise between 9˚ and 10˚ north is one of the best-studied fast spreading segments of the global MOR system. The ridge crest, between the Clipperton fracture zone in the north and 9˚03'N overlapping spreading center in the south, is characterized by an axial high indicative of high rates of magma supply, decreased rates of tectonism, and frequent eruptions [e.g., Buck, 2001; Escartin et al., 2007; White et al., 2002]. Volcanism along the ridge axis occurs primarily within a narrow zone defined by the axial summit trough (AST), a narrow graben (50-300 m wide, 5-20 m deep) generated by dike-induced tectonic deformation [Fornari et al., 1998; Chadwick & Embley, 1998; Soule et al., 2009]. The AST also hosts high-temperature hydrothermal venting, driven by axis-centered crustal magma bodies and focused by fault- and dike-induced highpermeabilities beneath the AST [e.g., Haymon et al., 1991; Fornari et al., 2004; Tolstoy et al., 2009]. Eruptions sourced within the AST flow across the ridge crest producing a nearly symmetric, AST-centered swath of young lava flows 3-6 km in width. Beyond that zone, sedimented and tectonically disrupted seafloor is present with the rare occurrence of young lava flows that had sufficient volume to overtop inward facing normal faults and spread beyond the young volcanic zone [e.g., Escartin et al., 2007]. Beyond the axial high, the ridge flanks are dissected by abyssal hill faults with offsets of order 100 m. Abyssal hill faults, spaced 1-2 km grow rapidly out to 15-30 km from the ridge axis [Alexander & Macdonald, 1996; Macdonald, 1998; Bohnenstiehl & Carbotte, 2001]. Fault formation and growth is attributed to stresses generated by plate unbending [Buck et al., 2005]. These stresses and resulting high strain rates may also contribute to melt extraction from the permeability barrier located at the base of the lithosphere to distances up to ~20 km from the ridge axis [Sohn & Sims, 2005].

The proposed study areas are located east of the ridge axis at 9˚53'-9˚56'N (area A) and west and east of the ridge axis at 9˚38'N (area B) over the OAMLs. T he ridge axis at area A does is marked by a narrow (~50 m) AST. The young volcanic zone here is narrow (~3 km), and there are a significant number of off-axis pillow mounds, mostly between the ridge axis and the OAMLs. T he area near the OAMLs display conjugate sets of 50-120 m high abyssal hill faults. The easternmost fault in area A is an ~100 m high outward-dipping fault that displays a hummocky morphology characteristic of a volcanic growth fault [Macdonald et al., 1996]. Thus, this feature may reflect a split volcanic ridge rafted to its current location or possibly recent volcanic accretion sourced well away from the ridge axis.

The ridge axis at area B is marked by a wider AST (~150 m) and a small overlapping spreading center. T he axial melt lens shows a small lateral and vertical offset corresponding to the OSC [Han et al., 2014]. T he young volcanic zone here is 4-5 km in width and extends farther west than east. Above the eastern OAMLs there is an ~1 km wide graben that runs parallel to the ridge axis. T he graben is well defined north and south of the OAMLs, but not over the OAMLs, possibly due to infilling by recent lava flows. Above the western OAMLs, the seafloor is cut by normal faults, some of which appear to be overprinted by small volcanic cones and hummocky seafloor possibly related to off-axis volcanism.

Brief Summary of What is Known of Target Area

In Summer 2008 a team of scientists from LDEO, WHOI, and Dalhousie University conducted a three-dimensional, multistreamer seismic reflection experiment over the RIDGE- 2000 East Pacific Rise Integrated Study Site [Mutter et al., 2009]. T he primary objective of this project was to create an accurate 3D seismic reflection image of the magmatichydrothermal system within the East Pacific Rise 9°50’N site by imaging the structure of the axial magma lens (AML) lid and shallow oceanic crust at a resolution, geometric accuracy, and scale comparable to seafloor observations of hydrothermal, biological, and volcanic activity. One of the major findings to date is the presence of at least three regions with prominent off-axis crustal reflectors with polarity and amplitude similar to the well-characterized axial melt lenses at the EPR. T hese presumed off-axis melt lenses (OAML) are emplaced at mid- and lower-crustal levels to both the east and west of the ridge crest [Canales et al., 2012; Han et al., 2014]. The seismic volume for study area A covers an area 16 km x 13 km over the ridge crest between 9°50’-57’N. A seismic reflection from the top of the AML is present along the full length of the study area at a depth of 1.4 km bsf. Within this 3D reflection volume there are three major intracrustal reflections 4-8 km to the east of the ridge axis interpreted as OAMLs. A 0.53 km x 0.17 km OAML is located 7.5 km east of the axis within the lower crust at a depth of 4.2 km bsf and 1.8 km above the Moho. Two mid-crustal OAMLs (1.5 km x 1 km and 2 km x 1 km) are located 5.5 km and 7 km east of the rise axis at depths of 2.1 and 2.3 km bsf, respectively. T he larger OAMLs are separated by 2.5 km, but a narrow channel of melt pockets may connect them. A second channel of high reflectivity branches out of one of the large sills towards the ridge axis, but it does not intersect the AML. The seismic volume for study area B covers an area 18 km x 4 m over the ridge crest between 9˚37’-39’N. An AML reflection is present through the volume at a depth of ~1.6 km. T he AML shows offsets and rotations comparable to variations in the axial summit trough. To the east of the ridge axis at 4 km, and 4.4 km x 2.2 OAML is located at a depth of 2.4 km bsf. A second, smaller OAML is located at a depth of 4 km directly beneath the shallow OAML. To the west of the axis at 9-10 km, two smaller OAMLs (1.7 km2 and 0.5 km2) are present at depths of 4 and 4.5 km bsf respectively. Nothing is known about the seafloor in the target areas beyond what can be gleaned from ship-based multibeam bathymetry collected in the early 1990s at a spatial resolution of ~80 m/pixel..

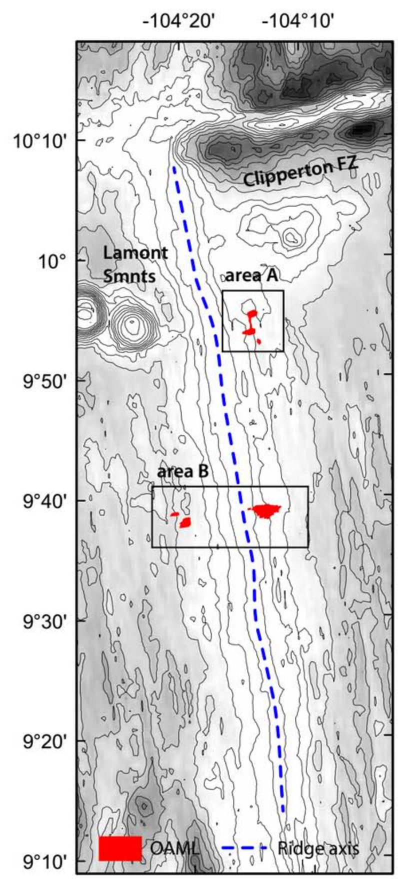


Figure 1: Bathymetric map of the East Pacific Rise. Study areas A & B are indicated by black boxes and contain the location of crustal seismic reflections indicative of off-axis melt accumulations (red). The approximate location of the EPR axis is indicated by the blue dashed line.

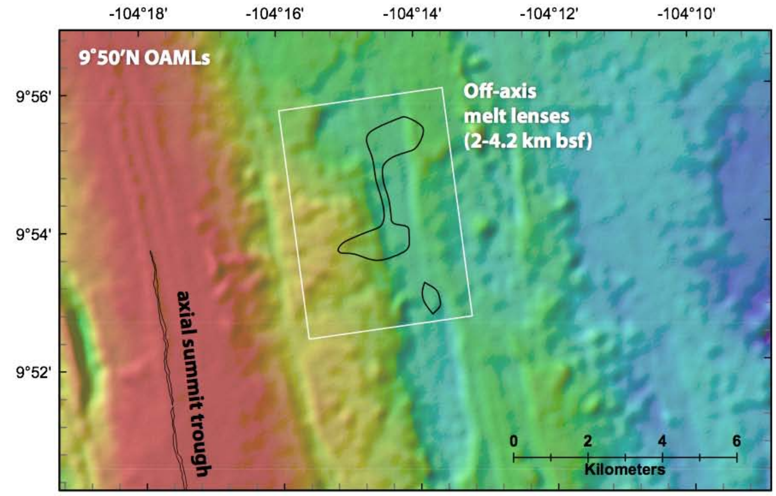


Figure 2: Detailed bathymetric maps of the Study Area A. The axial summit trough, which marks the location of on-axis volcanism and hydrothermalism is indicated. Off-axis melt lenses are present at 4-8 km from the ridge axis and area outlined in black. Depth ranges in the area of interest ~2600-2700 m.

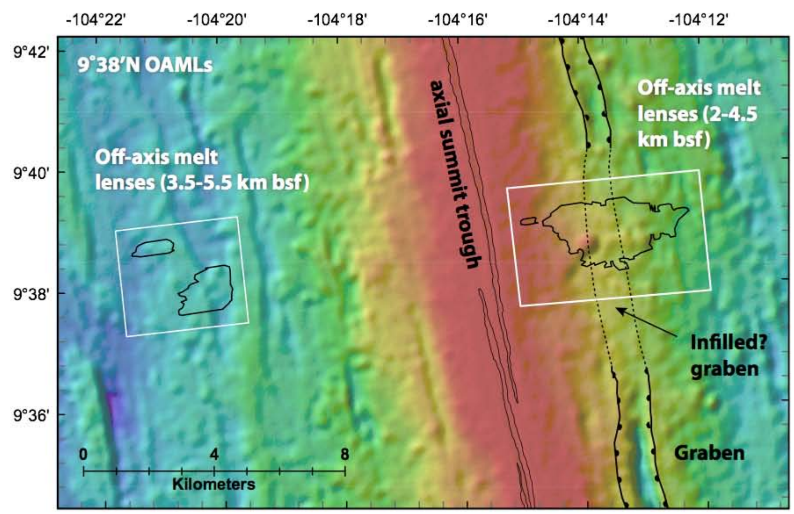


Figure 3: Detailed bathymetric maps of the Study Area B. The axial summit trough, which marks the location of on-axis volcanism and hydrothermalism is indicated. Off-axis melt lenses are present at 2-10 km from the ridge axis and area outlined in black. Depth ranges in the area of interest ~2550-2750 m.

Feasibility of Studying Target Area

The East Pacific Rise between 9˚30'N and 9˚58'N has been the subject of numerous oceanographic studies over the past decade, and I don't anticipate any difficulties in conducting an Ocean Exploration Trust study in the area. As it is outside the EEZ of any country, no clearances are required to work or sample in the area. T he transit times from Mexico are on the order of 2 days.

Educational and Outreach Potential of Target Area

The exploration and outreach potential of the off-axis EPR region benefits from the extensive research conducted onaxis at the EPR over the past few decades. As one of the best-studied segments of the global MOR, it would be possible to produce materials that would provide excellent context for students and members of the scientific community to gain a thorough understanding of this MOR from mantle melting to seafloor chemosynthetic communities. As an example, there is extensive photographic evidence of what seafloor lava flows look like in this region that are less than 1 year old to >10,000 years old. As a result, telepresence participants in the cruise, could better engage in the exploration for and detection of recent lava flows generated by off-axis melt lenses. Similar context could be provided for evidence of hydrothermal venting and chemosynthetic animal communities. From this foundation, telepresence participants could use social media (e.g. Twitter) to note evidence of off-axis magmatism and their responses tracked, providing a crowd-sourced record of observations. Although this is unlikely to aid the scientists, it could provide the telepresence portal with a mechanism to better engage the participants.

Galapagos Deep Pelagic Biodiversity

Michael Vecchione (NMFS National Systematics Lab)

Collaborators

Bruce Robison (MBARI)
Karen Osborn (Smithsonian Institution)
Stephanie Bush (MBARI)

Region

Galapagos/Cocos Ridge

Rationale for Exploration

Preliminary observations from the Johnson Sea Link indicated that the structure of the deep pelagic ecosystem in this area may be substantially different from what has been observed in other areas, including Monterrey Canyon, Gulf of California, Gulf of Mexico/Caribbean.

Brief Overview of Target Area

Deep mesopelagic (>500 m), upper bathypelagic, and benthopelagic in the vicinity of the Galapagos Islands. Some of these observations may be possible during the descent phase of dives on benthic targets.

Brief Summary of What is Known of Target Area

The J-S-L dives revealed some intriguing prospects for study, not the least of which were abundant cirroteuthid cirrate octopods. T here was also an abundance of pelagic holothurians, Pelagothuria natatrix, and a cydippid ctenophore that gripped the bottom with one tentacle while it fished with the other.

Feasibility of Studying Target Area

If a leg of the cruise targets the vicinity of the Galapagos Islands, conducting water-column operations should be accomplishable.

Educational and Outreach Potential of Target Area

Although more dispersed than epibenthic animals, the strangeness of pelagic animals has great potential for education/outreach. Dumbo octopods (cirrates) are among the most popular organisms to many people. It may be possible to set up live telepresence feed into the new education center at the National Museum of Natural History.

Galapagos Platform

Dorsey Wanless (Boise State University)

Collaborators

Adam Soule (WHOI)

Region

Galapagos/Cocos Ridge
East Pacific Rise

Rationale for Exploration

The Galápagos Islands have been instrumental to the development of plate tectonic theory, our knowledge of the chemistry of Earth's interior, and studies in the region have been critical for the development of the biological theory of evolution. Despite the historical and scientific importance, our knowledge of these volcanic islands is primarily restricted to the less than 10% of their volume that exists above sea the submarine portion of the Galápagos Islands to investigate processes responsible for building the remaining >90% of the submerged volcanic edifice. Specifically, we hope to investigate the magmatic pathways that feed volcanic eruptions on the submarine flanks of Galápagos volcanoes through combined geologic mapping and sampling of lavas from a series of submarine cones and rift zones, which will result in extensive exploration of the submarine portion of the Galápagos Platform.

The relationship between submarine and subaerial volcanism would also be of interest to scientists studying fisheries and the unique Galápagos biota. Images of the fauna on the inter-island submarine cones may also provide clues to how species are transported between old and young islands, and would provide an additional dimension to biological studies at the Charles Darwin Research Station (CDRS).

Brief Overview of Target Area

The Galápagos consists of several large volcanic islands and small submarine cones that sit on top of a ~3 kilometer thick pile of lava flows that forms the Galápagos platform. These islands are born through episodic submarine volcanic eruptions over hundreds of thousands of years from vents located on the deep ocean floor (>3000 m) and build the platform on which the islands sit. The source of volcanism at the Galápagos is a mantle plume, a hot localized upwelling of mantle material that melts to produce the lavas that erupt on the seafloor. Based on limited low-resolution bathymetric maps, the submarine platform may consist of small cones, rift zones, and individual lava flows. However, the composition of these lavas and their relationship to adjacent subaerial systems is not known. Systematic mapping and sampling of the submarine portion of the Galápagos platform will allow us to investigate two unresolved aspects of the evolution of the island chain.

Submarine Growth and Development of the Magmatic System – In the Galápagos, there are two distinct morphologies of the subaerial volcanoes that reflect the evolution of the magmatic plumbing system (Fig . 1a). The western islands (Fernandina and Isabela) that sit directly over the center of the plume have active volcanoes with central calderas indicating a shallow magma chamber that feeds subaerial eruptions2, the most recent of which occurred on Fernandina Island in 20093 and on Isabela Island at Sierra Negra volcano in 20054. In these systems, magmas pass through the shallow, centralized magmatic system, prior to erupting from either the summit or rift systems. By contrast, the eastern island volcanoes (Santiago, Santa Cruz, and Floreana), that lie away from the plume center, lack calderas and, presumably, shallow magma chambers and have had relatively few historic eruptions. This suggests that as the subaerial volcanoes mature and move away from the plume center, the magmatic source for subaerial volcanism deepens and becomes less focused. Petrologic studies of subaerially erupted lavas support this dichotomy, with deeper signatures of fractional crystallization observed in subaerial samples from the eastern islands compared to the western volcanoes (Fig . 1b). While the evolution of the subaerial systems is well documented, the concurrent growth of the submarine systems and their response to the changing magma supply through time is not well known. Based on observations from other ocean island systems, there are two possible models for construction of the submarine portion of ocean islands. In one model, submarine eruptions are fed from a shallow magma chamber located beneath the summit in the subaerial volcano to the seafloor. The other model involves direct delivery of magma from deep reservoirs to the submarine flanks of the volcano, without magmas entering the shallow system. The primary difference between these models is the depth of magma storage prior to eruption, which can have profound implications for how the volcano develops, the eruption dynamics, and the volumes of individual submarine eruptions (e.g., deep vents from shallow chambers may lead to large eruptions). The distinct volcano-types in the Galápagos represent an ideal laboratory to test the proposed models for the growth of the submarine portion of ocean islands. By mapping and sampling the submarine edifices and determining the physical pathways of the melts in each volcano-type, we can determine whether the submarine eruptions are fed from shallow or deep magma reservoirs.

Compositional Variations in Galápagos Plume – Prior studies of Galápagos lavas have shown that there are distinct geochemical variations associated with each subaerial volcano or group of volcanoes, but the geographical boundaries are not discernable due to the absence of samples from the submarine portion of the platform. Typically, mantle plumes show enriched signatures as compared to mid-ocean ridges. This enrichment is observed in volatile compositions (e.g., H2O, CO2, Cl and F), incompatible trace element concentrations, and in isotope ratios such as 3He/4 He, 87Sr/86Sr and 206Pb/204 Pb. Based on existing data for the Galápagos Islands, these isotopes show significant variability, but plume signatures do not converge on a single geographic location. For example, commonly used geochemical tracers such as lead, strontium, and helium isotopes predict different geographical plume centers. The highest helium isotope ratios are found in the west, on Fernandina Island, the most volcanically active island (Fig. 1a). However, the highest strontium and lead isotope ratios are found on Pinta Island and Floreana Island; which are separated by ~150 km. Whether this is due to a sampling bias, temporal changes in the plume center or to melting dynamics cannot be discerned with the available subaerial data sets. Systematic sampling of the previously unexplored submarine portion of the Galápagos platform is the key to determining the geographical distribution of magma compositions produced by the Galápagos plume.

Brief Summary of What is Known of Target Area

Although numerous studies have focused on the chemical and biological diversity of the islands, the submarine cones and platform top have not been extensively mapped or sampled. In fact, <1% of the submarine portion of the Galápagos platform has been explored in any detail. Thus, a detailed mapping and sampling campaign focused on the previously unexplored and severely under sampled submarine Galapagos platform will provide insight into numerous outstanding questions on the evolution and growth of the volcanic island chain.

We have identified three primary target regions that are adjacent to both caldera and non-caldera forming volcanoes and will fill in the gaps in the geochemical and petrologic data (Fig. 1a). These targets will allow us to explore the submarine portion of both volcano types and determine if the submarine volcanic systems vary with subaerial volcano type. Currently, bathymetric maps of the submarine platform primarily consist of very low-resolution multibeam data.

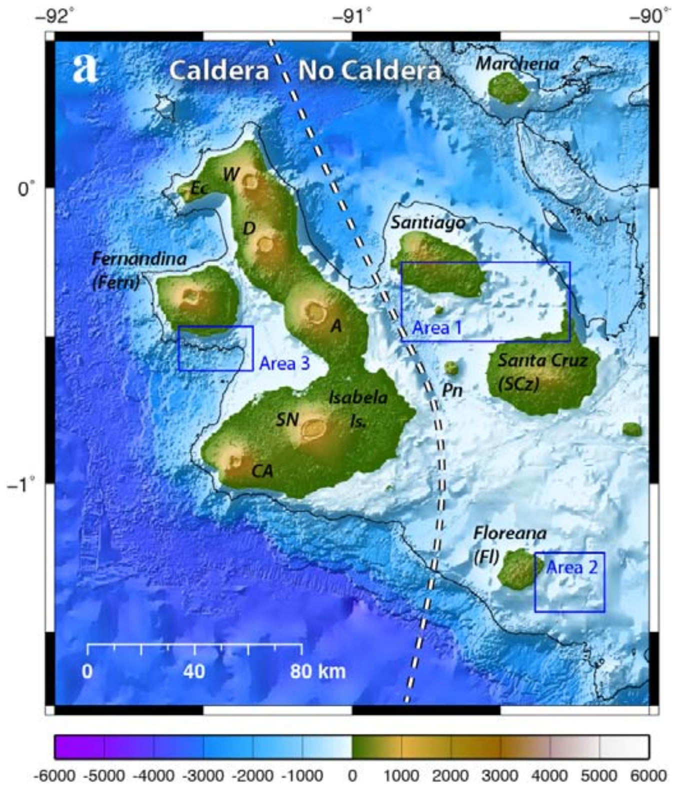
Feasibility of Studying Target Area

Much of the Galápagos platform sits in the Galápagos Marine Reserve, a UNESCO World Heritage site. During past studies, we have routinely worked with and have contacts in the Ecuadorian Navy's oceanographic institute INOCAR and at Charles Darwin Research Station. Our seagoing team will include, a staff scientist from the Charles Darwin Research Station (CDRS), including a specialist in the submarine biodiversity of the Galápagos. We will also include a marine geologist from the Ecuadorian Navy, with which WHOI has a MOU to foster collaborative oceanographic research.

Educational and Outreach Potential of Target Area

Exploration of the submarine platform would be of interest to the Charles Darwin Research Station (CDRS) and the Ecuadorian Galápagos National Park. Researchers from these institutions will be invited to collaborate and participate in the cruise, which would add to the scientific synergy and provide broader outreach to scientists in the region. Outreach in the Galápagos will be facilitated by established programs at CDRS and could include a public talk describing this research to local residents who are keenly interested in documenting and preserving the natural resources of the archipelago. We are excited to work with OET outreach group to develop additional educational outreach strategies.

In addition to the remarkable biodiversity on the Galápagos Islands, the submarine region is considered to be equally as important as a biodiversity 'hot-spot'. Much of the Galápagos Marine Reserve, a UNESCO World Heritage site, is unexplored and under significant threat from overfishing. Our team will include, Dr. S. Banks, a marine biologist and staff scientist at the Charles Darwin Research Station (CDRS), who is a specialist in the submarine biodiversity of the Galápagos.



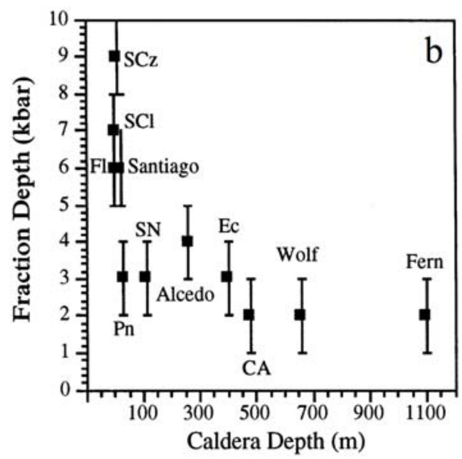


Figure 1. a) Map of the Galápagos Archipelago indicating the dichotomy of volcano-types (with and without calderas). Focus areas for mapping and sampling are indicated by blue boxes. 1000 m depth contour shown in black. **b**) Petrologically determined fractionation depths from subaerial lava samples indicate that volcanoes with calderas are fed from shallower magma reservoirs than those without calderas

Hydrothermal Circulation Search on the Garrett Transform Fault, East Pacific Rise

Jessica Warren (Stanford University)

Collaborators

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Chris German (WHOI)
John Collins (WHOI)

Region

East Pacific Rise

Rationale for Exploration

One of the most intriguing discoveries of the past 40 years of ocean exploration are hydrothermal vents, which possibly represent the environment that gave rise to life on Earth. Many vents have been found on the global midocean ridge system, but the transform faults that offset this system remain largely unexplored. Studies of serpentine-hosted vent systems such as Lost City and Von Damm have focused on slow spreading ridges, under the assumption that fluid/mantle interaction does not occur at the fast spreading East Pacific Rise. However, exposures of serpentinized peridotite along the Garrett transform fault at 13.4S indicate that fluid/mantle reactions occur in the Pacific. In fact, transform faults are the best target for serpentine-hosted vents on the East Pacific Rise as (i) these fault can bring mantle peridotite to the surface and (ii) the zone of highly permeable damaged rock around the fault can lead to deep transport of water. The reaction of mantle peridotite with seawater leads to serpentinization reactions that release hydrogen-rich fluids, which can promote abiotic synthesis of complex organic molecules linked to prebiotic chemistry. We have identified the Garrett transform fault as an ideal target area due to the abundance of serpentinized peridotite that has been dredged from this fault, meaning that it has a strong potential for the discovery of seafloor expressions of key phenomena up to and including new forms of seafloor chemosynthetic ecosystems. T he Garrett transform fault is also underexplored compared to faults further to the north, presenting an exciting opportunity to combine ROV diving with bathymetric mapping and subsurface imaging. In a companion white paper, we propose exploration of the Gofar transform fault on the East Pacific Rise, which has evidence for deep fluid flow on the basis of seismicity but is unexplored in terms of rock lithologies.

Brief Overview of Target Area

The Garrett transform fault at 13.4S on the East Pacific Rise has an offset of 120 km and a full spreading rate of 150 mm/yr, making it the fastest of any oceanic transform fault. Despite this rapid rate of slip, the seismicity of the fault has not been looked at in detail. T he transform fault is dissected by three oblique-trending ridges (alpha, beta, gamma), which have evidence for recent volcanic activity based on Nautile dives in 1991. In the troughs separating the ridges, serpentinized peridotites and rodingitized gabbros have been collected at depths of 3000 to 5000 m. Evidence for fault-induced deformation in recovered samples includes the occurrence of cataclasites (brittle deformation) and mylonites (ductile deformation).

Brief Summary of What is Known of Target Area

Mantle peridotites from the Garrett transform fault have been hydrothermally altered to serpentine and amphibole. Amphibolitization implies alteration at temperatures as high as 700 C, while serpentinization implies temperatures in the range 200-300 C (Bideau et al., 1991). Alteration of gabbros to rodingites indicate fluids compositions controlled by serpentinization reactions (Bach and Klein, 2009). Overall, alteration of lower crust and upper mantle lithologies makes Garrett a strong candidate for finding serpentine-hosted hydrothermal vents. We propose a combined geological, fluid-flow, and seismological study of the Garrett fault-zone aimed at discovering signals of fault-zone fluid flow. EPR transforms are highly active in terms of microseismicity, meaning that even a short deployment of seismometers can establish basic properties. In parallel with our water column and ROV investigations we would deploy a suite of ocean bottom seismometers for a ~2 week period covering the duration of our cruise. This component of the study will help answer basic questions, such as whether the serpentine body produces seismicity and if this seismicity extends to mantle depths? The majority of cruise activities will focus on a combination of CT D-rosette & ROV investigations. Using the CT D-rosette, we will conduct nearbottom surveying for anomalies in temperature, Eh, and particle backscatter coupled with shipboard measurement of water column CH4 and H2 concentrations. This is the same strategy that was first used to search for seafloor venting along the Mid-Cayman Rise (German et al., PNAS, 2010) and has, thus far, led to the discovery of a diverse array of novel forms of seafloor fluid flow including the first dives to the Von Damm site in 2011 aboard the Okeanos Explorer and further new discoveries in 2013 aboard the RV Falkor and EV Nautilus. In parallel, we will also conduct high-resolution ROV based geological reconnaissance, mapping and imaging of the fault-zone to help interpret the fluid surveys. Rock and fluid samples will be collected at interesting locations for more detailed geochemical analyses ashore. In support of our ROV based exploration, we will also conduct a rock dredging campaign to recover samples from the fault-zone. On board the ship, we will characterize these rocks for evidence of fluid interaction, while back at Stanford rocks will be characterized to determine rates and styles of deformation and alteration.

Feasibility of Studying Target Area

The Garrett transform is relatively easily accessed (3-4 days transit) from a port call in Easter Islands. A ~21 day cruise round trip to Garrett would allow us to meet a wide variety of objectives.

Educational and Outreach Potential of Target Area

Stanford University undergraduate and graduate students along with MIT /WHOI Joint Program graduate students would be involved in the cruise and subsequent data analysis. Given the large ROV component of the cruise, there would be considerable opportunities for real-time video based outreach efforts. These outreach programs could be organized around themes of “Seafloor Fluid Flow” and ‘What Stops Earthquakes?’ since these are the major scientific topics that we seek to address.

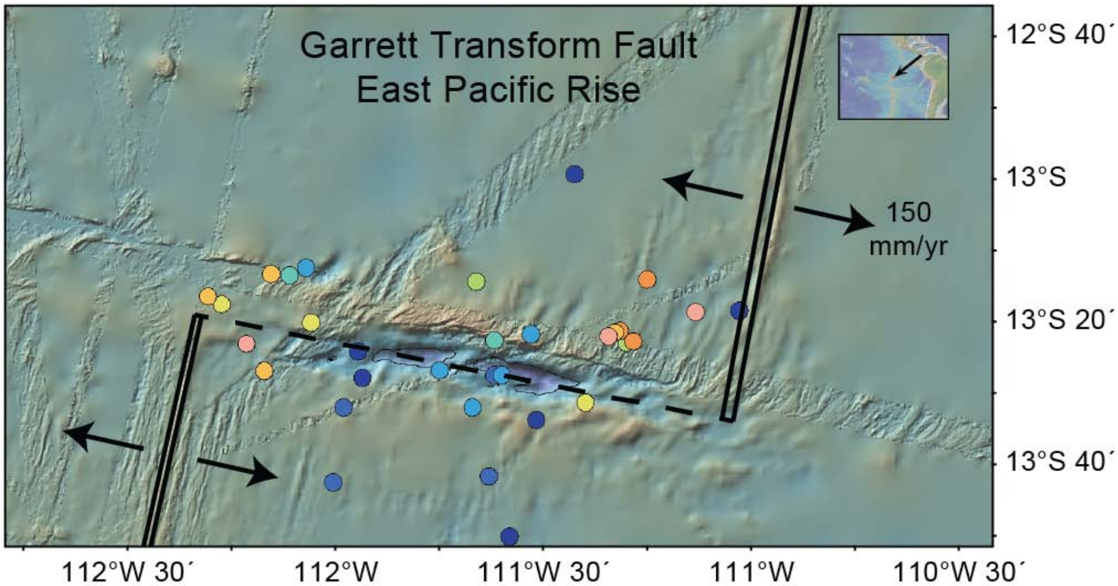

Figure 1. *Bathymetric map of the Garrett transform fault (dashed line), which offsets the East Pacific Rise by 120 km. Remotely sensed earthquakes are color-coded by magnitude, ranging from 5 to 5.8. The scatter of the earthquake locations is due to location error caused by the great distance between Garrett and land-based seismic networks. Experience from other EPR transform faults indicates that these events all likely occurred on a narrow, well-defined fault zone. The bathymetry base map is the Global Multi-Resolution Topography Grid v. 2.6 from GeoMapApp (Ryan et al., 2009), with the 4000 m contour shown as thin black lines.*

East Pacific Rise Off-Axis Eruptions, Lavas and Fluid Flows

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Collaborators

Cliff Hopson (UC Santa Barbara)

Region

East Pacific Rise

Rationale for Exploration

Serendipitous discoveries from a mere handful of studies show that the near-ridge flanks of the East Pacific Rise (EPR) are active volcanically [e.g. Sims et al., 2003; Zou et al., 2002], hydrothermally [e.g. Haymon et al., 2005], and biologically [e.g. Cowen et al., 2003; Benjamin and Haymon, 2006]. The extent and cause of this activity remains unknown. These discoveries force us to critically examine the paradigm that shallow crustal magma bodies are tightly focused at the spreading axis, and raise the possibility that the ridge flanks may be far more volcanically and hydrothermally active than previously thought. Recent geophysical evidence for melt in the crust and upper mantle up to ~20 km off-axis [Key and Constable, 2005; Durant and Toomey, 2004; Garmany, 1989]. To understand the evolution of the volcanic layer and its petrological origin is essential to understanding the architecture of oceanic crust and the extent of the deep-sea biosphere. Seismic studies of the ocean crust at the EPR show that seismic layer 2A (volcanic layer) thickens 2X within 1-4 km of the axis. This indicates that more than half of the volcanic upper crust is emplaced off-axis, and suggests either a much wider volcanic zone along the ridge or an efficient magma delivery system off-axis, or both. The Upper Lavas of in the ophiolite sequences from California Coast Range and Oman are inferred to have formed off-axis on a Mesozoic spreading ridge, and thus corroborate the hypothesis that off-axis crustal emplacment may be far more common than previously thought. The ophiolite studies have prompted a petrogenetic model that is easily tested by explorations here (see Supplementary Attachment). An alternative hypothesis is that large-scale hydrothermal flux through young crust causes cracking and apparent thicking. Supporting evidence includes progressive increase in seismic velocity of Layer 2A in 0-5 Ma crust on the EPR [*Carlson*, 1998] and concomitant decrease in crustal porosity [*Fisher and Becker* , 2000] which are both attributable to void-filling by hydrothermal precipitates. In either case, the implications of this off-axis volcanism for the deep biosphere and seawater chemical budgets call for futher, dedicated exploration. For decades the assumption has been that ridge-flank fluid flow, driven by plate cooling, is so diffuse, cool, and widespread that it has no observable seafloor manifestation. This assumption recently was challenged by the discovery of two locations on abyssal hills flanking the EPR where mineral and biological evidence indicates that vent fluids reached exit temperatures of 50-150°C (Tevnia Site) and >250°C (MM Site) [Haymon et al., 2005; Benjamin and Haymon, 2006]. Such unexpectedly high fluid temperatures may mean that magma, rather than plate cooling alone, contributes heat to ridge flank hydrothermal systems. These are the only non-seamount ridge-flank hydrothermal sites on the EPR that are documented. These hydrothermal observations coincide with the distance off-axis at which small off-axis volcanoes and abyssal hill faults form. Is faulting the sole cause of focused ridge flank volcanic and hydrothermal activity? Or does off-axis magmatism on the EPR play an essential role? While off-axis volcanism and perhaps hydrothermal deposits can be studied in many locations along the spreading centers in the East Pacific since they appear to be relatively common, perhaps the best place to look is the Southern East Pacific Rise. T his area contains both small seamounts and large lava fields, and is an area ripe for sampling since the ridge crest lava and the large off-axis seamount chains are already well studied. Precise rock sampling by ROV is necessary to achieve the objectives and direct visual observations along with CTD measurements by ROV are virtually the only way to reliably find evidence for ridge-flank hydrothermal flow.

Brief Overview of Target Area

The axis of the Southern East Pacific Rise lies atop a 5-20 km broad swell that stands 200 m above the immediate surrounding seafloor at a relatively uniform depth of 2600-2800 m. Pacific and Nazca plates are spreading apart at a full rate of 145 mm/yr, resulting a slow subsidence and a gentle seafloor slope away from the ridge. Thus, the seamounts and lava fields within our target area lie at depths of 2700-3500 m. Regional mapping using multibeam bathymetry and side-scan sonar have found a number of young volcanic features as far as 20 km from the spreading axis. Small, isolated volcanic cones are easily identified in multibeam sonar maps as hummocks or cones >40 m tall and typically <1 km diameter. Our target area contains literally hundreds of these. Large lava flows are more rare, but readily identified from side-scan as high backscatter regions. Large lava flows with a small cone or row of volcanic mounds at the highest point of the flow, which probably represents the source, are the best targets.

8°07’S-8°18’S Gigantic lava flow:
This is the largest and probably the youngest near-ridge lava field along the EPR. A few dredge samples suggest this flow consists of at least 3 lobes. One lobe flowed from the source vent to the northeast (central flow), another extends to the south (south flow), and the last lobe fills a low point between the other two flows. Proposed dive sites are the presumed source vent area,
distal ends of the central, north and south flows. 14°35’-14°56’S Large lava flow: A 30 km long flow filling fault-bounded basins with hummocky mounds aligned in a ridge-parallel row. One dive at the source vent and one at the north end of the flow.

16°02’-16°08’S lava field:
A 12 km long flow filling fault-bounded basins with a hummocky center. One dive track that extends from the flow edge up to the small hummocky mounds of the central high.

16°14’-16°20’S lava field:
This flow is 15 km south of the above flow, filling the same graben, but in contrast has a featureless (flat?) surface with a row of small mounds in the south.

Brief Summary of What is Known of Target Area

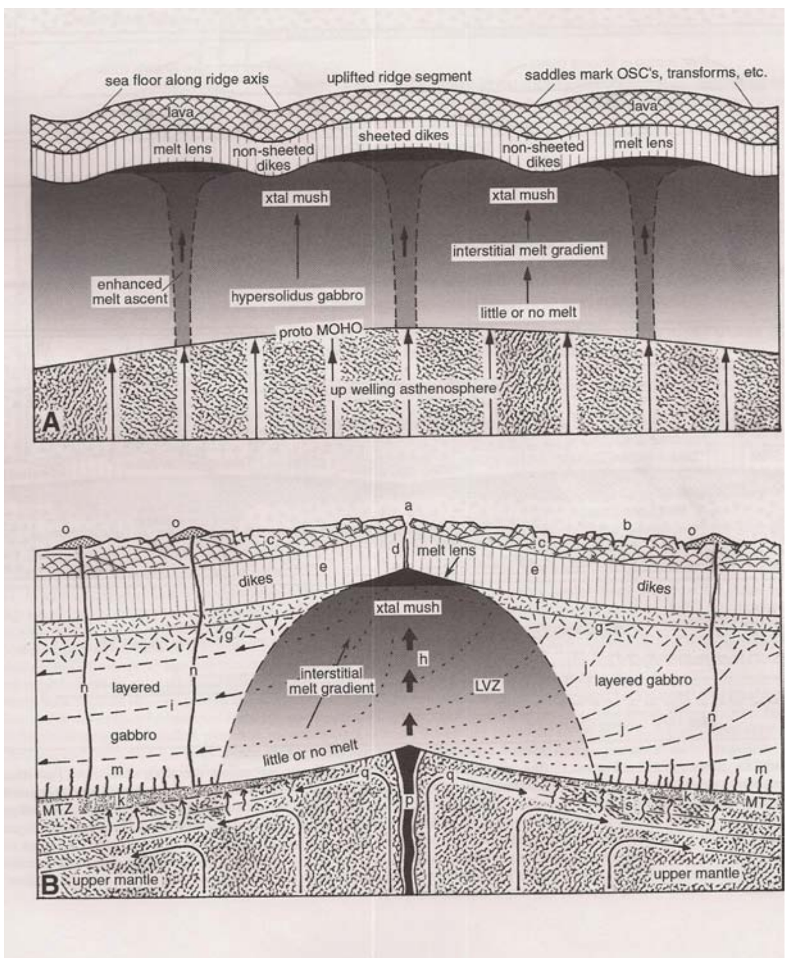
Regional-scale mapping is available that covers the study area. Two SeaMARC II expeditions in 1987 mapped over 210,000 km2 of the EPR and its flanks from 8°-18°N and 3°-23°S. On R/V Melville cruise GLOR02, HMR-1 side-scan sonar was used to map the 15°-19°S. On R/V Melville cruise GLOR08, Sinton and Mahoney dredges seamounts from the Rano Rahi Volcanic Field as well as the gigantic off-axis lava field at 8°S. The [TAMU]2 along the EPR 13°-19°S is available from T. Hilde gives backscatter and side-scan.

Feasibility of Studying Target Area

These areas are 3-4 day transit from Galapagos and 2-3 day transit from Easter Island. All targets are within international waters. The target depths are well within the 4000 m range of ROV Hercules. Sampling would be primarily rocks, mapping via visual observations, and water measurements all within the capability of Hercules.

Educational and Outreach Potential of Target Area

These types of studies are intrinsically interesting, and would couple very nicely with the marine science curriculum at many high schools or colleges. The ophiolite connections will make this interesting to the terrestrial geology community, and assist in bridging that gap which sometime exists between marine and terrestrial geology.



Exploring the Effects of Magma Supply Gradients on the Galapagos Spreading Center and Adjacent Seamounts

Scott White (University of South Carolina)

Collaborators

Ken Rubin (UH SOEST)
Tim Shank (WHOI)
Jim Holden (University of Massachusetts)
Julie Bowles (University of Wisconsin)

Region

Galapagos/Cocos Ridge

Rationale for Exploration

Galapagos Spreading Center (GSC) serves as a typelocality for ridge-hotspot interaction, a natural laboratory for the effect of mantle magma supply variations on active rift processes, and is worldfamous for the discovery of hydrothermal vents in 1977. In spite of the past nearly 4 decades, we are very much still in the exploration and discovery stage of investigation regarding biological communities, hydrothermal vent fields, and geological mapping. Critical gaps remain in our knowledge of the basic volcanic record (size and frequency of eruptions), hydrothermal systems (locations and temperature of venting) and associated chemosynthetic ecosystems (species and abundance) of this natural laboratory. These knowledge gaps are interdisciplinary in nature, and ideally suited to tools and capability of the Nautilus, Hercules, and telepresence. Reconnaissance of the GSC, particularly with modern high-resolution bathymetric and water column data in 2006 and 2011, has revealed a large number of well-constrained targets that have been essentially unexplored and unsampled. One key question that is ripe for discovery at this location is the nature of different types of ridge offsets as geological or biogeographic barriers. Three competing candidates represent different types of seafloor environments Hess Deep, the transform fault offset at 91°W, and the 95°W propagating rift tip. Explorations in this target area will provide new perspectives on magma delivery to midocean ridges, the fundamental nature of mantle plumes, and the biogeography of the mid-ocean ridges. Exploration at the GSC will establish both nature and timing of hydrothermal systems that test the hypothesis that hotspotinfluenced ridges are “hydrothermal deserts” with widespread implications for the global ocean chemical evolution.

Brief Overview of Target Area

GSC is a seafloor spreading center separating the Cocos and Nazca plates in the eastern equatorial Pacific. At 91°W, the GSC lies ~200 km north of the Galápagos Islands, which marks the probable center of the Galápagos mantle plume. The ridge axis of the GSC shoals toward the Galapagos Transform, a 90 km offset transform fault near 91°W, separates the western and eastern GSC. The Wolf-Darwin lineaments are seamount chains that lead from the Galapagos archipelago to the GSC. Key targets for exploration along the GSC include (1) unsampled and poorly mapped hydrothermal fields east and west of the center of hotspot influence on the ridge with the latter associated with (2) a very fresh-looking lava flow that is also unsampled and poorly mapped, (3) Los Huellos double-caldera at 91°W, and (4) seamounts to the north and south of the GSC and within the rift valley.

Systematic explorations comparing the vent biota, microbial communities, geologic setting and hydrothermal venting at the Navidad hydrothermal field (94.5°W) with those at the Tempus Fugit hydrothermal field (86°W) from the two distal ends of hotspot-influence on the GSC would establish for the first time a single transect with constraints in space and time. Exploration of the Los Huellos calderas for the yet-undiscovered source of its hydrothermal plumes and ancillary mapping of the lava flows in this area would reveal the impact of peak magma supply on eruptions, hydrothermal discharge, and the ecosystems that result. It would be very surprising if exploration of the caldera floor did not reveal high-temperature hydrothermal venting and new vent communities, and possibly very recent lava flows.

An early 14 km long lava flow was seen in 2011 at 88°W, along with some sites of diffuse hydrothermal flow, but the ages of the lava and nature of the microbial mats at the diffuse flow sites are unknown due to lack of sampling. This site is ideal to add temporal constraints on volcanism and longevity of the hydrothermal systems on the GSC. Our collaborators, K. Rubin and J. Bowles, are prepared to support geochronology of collected samples from this flow to estimate the age. In connection with the GSC hydrothermal system, limited but tantalizing mapping and isolated ROV video observations of biologically active seamount regions north of the GSC (Paramount Seamount, GALREX 2011) and south (Wolf-Darwin Lineaments, MV1007) discovered extremely abundant and diverse deep-water coral communities and distinct faunal communities, seamount calderas with evidence of hydrothermal flow, seamount summits with evidence of wave erosion, and the presence of drowned reefs.

Brief Summary of What is Known of Target Area

Previous work on the GSC has defined the locus and spread of mantle plume influence from geophysical and geochemical measurements. Multibeam bathymetry now covers from 104°-84°W along the spreading axis and some ridge flank. The GSC shows a hot spot-influenced signature from 95.5° to 85.5°W, with a peak signature near 91°W. Increasing hotspot-influence correlates with progressive transitions from rift valley to axial high morphology along with decreases in mantle density, magma lens depth, and abundance of volcanic cones. Subsequently, detailed geologic mapping by Alvin and Sentry in two 20-km areas representing low- and high- magma-supply at 95°W and 92°W, respectively, found differences in average characteristics between areas generally accord with our present understanding of the effect of variable magma supply, but display an astonishing range of variability that we need to understand.

2005– 2006, TN188 cruise high-resolution mapping of hydrothermal plumes overlying the hot spot–affected Galapagos Spreading Center from 95° to 89.6°W discovered only two active, high-temperature vent fields on the western arm of the GSC, subsequently confirmed by camera tows, although water column anomalies strongly indicated minor venting from at least six other locations. In 2011, EX1103 collected a continuous CTD and multibeam line from 89.33° to 85.75°W that revealed at least 20 distinct water-column anomalies. Two new vent sites were confirmed and ROV videos reveal at least two major, recent volcanic eruptions between 85°W and 89°W suggest the rates of hydrothermal habitat turnover may be considerably higher than previously thought. Finally, in 2010, MV1007 cruise conducted extensive mapping and surveying of the Wolf-Darwin seamounts, including 6 camera tows that hint at the presence of hydrothermal activity and associated biological communities.

Feasibility of Studying Target Area

The area is 1 day transit from Puerto Ayora in Galapagos. Water depths in the areas of investigation are less than 3500 m, within the capability of ROV Hercules, and mostly at depths of 2000 m or shallower. Some permits will be required. The seamount chains and parts of the GSC near the transform are located within the Galapagos National Park of Ecuador. Much of the GSC east of the transform is also within the Ecuadorian EEZ . Both the Park and Charles Darwin Foundation maintain an active interest in managing the GSC and particularly the seamounts, which are considered to be senstitive shark habitat.

Educational and Outreach Potential of Target Area

Aside from the Galapagos being a household word synonymous with nature and evolution, there is a strong interest by the Charles Darwin Foundation in collecting additional marine data (Stu Banks is one such scientist with the CDF). T here is also interest in this area in Ecuador, and specifically by geologists (Silvana Hidalgo is one such collaborator).

Volcano 7 & Other Seamounts Penetrating the OMZ

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Collaborators

Ken Rubin (UH SOEST)
Tim Shank (WHOI)
Jim Holden (University of Massachusetts)
Julie Bowles (University of Wisconsin)

Region

East Pacific Rise
E Equatorial Pacific

Rationale for Exploration

Volcano 7, a seamount (inactive) in the Eastern Tropical Pacific that penetrates up into the extreme oxygen minimum zone (OMZ) of this region, was explored by Alvin dives in 1988 (Wishner et al. 1990). Dramatic benthic and pelagic faunal zonation associated with the sharp oxygen gradients at the base of the OMZ was documented over a narrow depth range from 730 m (upper summit) to 800 m (lower summit) (see refs and slides). OMZ s are predicted to expand in thickness and extent in the future as a result of global warming. By re-visiting Volcano 7, we can directly observe effects of any such changes over the last 27 years. Specifically, has the depth of the lower oxycline changed? If so, has the benthic zonation changed in either depth or species composition? Also, is there a distinct visually evident lower oxycline zooplankton layer, as inferred from net tows, and what types of gelatinous animals occur in that layer?

Brief Overview of Target Area

Oxygen minimum zones (OMZ s) are dominant midwater features of the eastern tropical north and south Pacific. Substantial fishery resources (tuna, billfish) occur in the aerobic habitat above OMZ s, and OMZ s impact coastal margins. Much less is known about the lower oxycline, the base of the OMZ where oxygen starts to increase with depth, especially in open ocean regions. Prior work has shown that there is a specific oxygen concentration (~ 2 μM) at the lower oxycline that is associated with a zooplankton layer (order of magnitude increase in abundance) and strong benthic zonation of meiofauna, macrofauna, and megafauna (papers by Wishner et al. and Levin et al.). The presence of seamounts, such as Volcano 7, that penetrate up into the OMZ , provides a unique focus for studies on OMZ benthicpelagic coupling in an oceanic setting. The possibility of documenting temporal change since the earlier work (Wishner's 1988 Alvin cruise and Batiza's 1984 cruise with Argo photography) would be an exciting contribution to understanding the future impact of expanding OMZ s on oceanic ecosystems. Also, if this exploration concept moves forward, we would seek to identify several other seamounts in the Eastern Tropical Pacific OMZ region with summits at different heights such that the benthic and pelagic zonation could be cross-compared between sites. (These additional potential sites would be identified before the San Francisco meeting.)

Brief Summary of What is Known of Target Area

We know the basic bathymetry of the site from prior work (not multibeam) and locations of prior photographic transects. From the photographic transects, we know the zonation of benthic megafauna between the upper and lower summit (730 - 800 m), as well as the flank at 1200 m and base at 3200 m from a few decades ago (1988). We have information on the benthic infauna and sediment characteristics (Levin et al.1991). For zooplankton, we have benthopelagic distributions from nets on Alvin, water column distributions from MOCNESS tows, in situ feeding studies done with Alvin, and pelagic environmental parameters (papers by Wishner, Saltzman, and Gowing). More recent publications (Wishner et al. 2013) have documented the lower oxycline zooplankton layer and the oxygen concentration associated with that layer elsewhere in the eastern tropical Pacific.

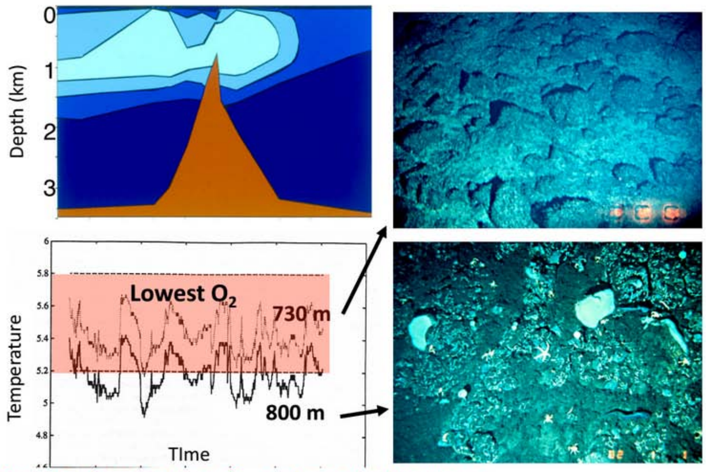
Feasibility of Studying Target Area

It is very feasible to study the seamount. It is in international waters off Manzanillo, Mexico. A high quality oxygen sensor, as well as standard CTD sensors, are required to document the OMZ . In addition to photography, it would be useful to collect cores, water samples, and plankton samples. There is also much present interest in pelagic and benthic microbial gradients through these suboxic zones, and it is likely that microbiologists would be interested in water and sediment samples.

Education and Outreach Potential of Target Area

Oxygen minimum zones are widely publicized as "dead zones" and thus there is much public interest. T he benthic gradients and faunal changes in 1988 were very dramatic and noticeable. T here were large sponges, rattail fish, brittlestar aggregations, and other megafauna. Transects up and down the summit region, conducted over a few hours, would provide dramatic footage for discussion about OMZ expansion and impacts.

Lower Oxycline: Benthic-Pelagic Coupling
Volcano 7 Seamount

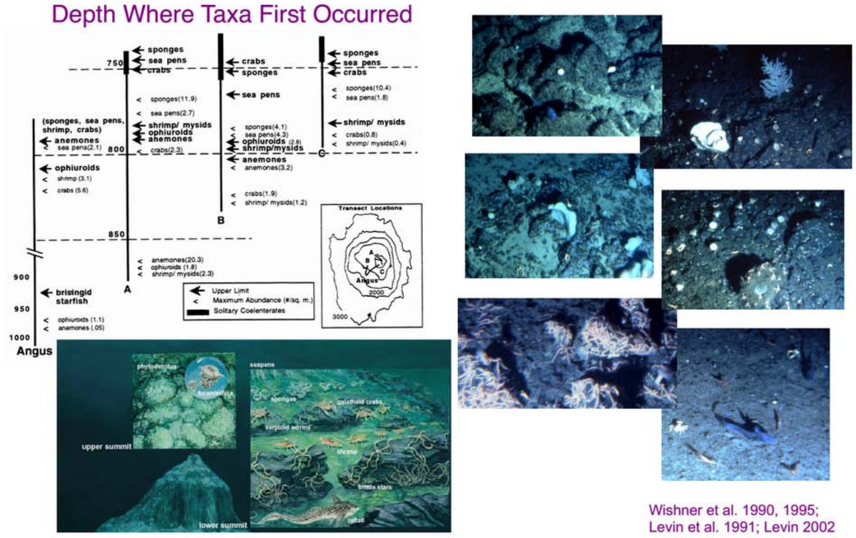


Lower Oxycline temperature, O_2 and zooplankton layer oscillate with tidal cycle
Metabolic, feeding, predator-prey effects (demersal fish?)

Wishner et al. 1990, 1995
Levin et al. 1991, Levin 2002

Vertical Zonation: Volcano 7 Seamount

Depth Where Taxa First Occurred



Wishner et al. 1990, 1995;
Levin et al. 1991; Levin 2002