INTERNATIONAL OCEAN DISCOVERY PROGRAM

International Ocean Discovery Program Expedition 389 Scientific Prospectus

Hawaiian Drowned Reefs

Jody M. Webster
Co-Chief Scientist
Geocoastal Research Group
School of Geosciences
University of Sydney
Australia

Ana Christina Ravelo
Co-Chief Scientist
Ocean Sciences Department
Institute of Marine Sciences
University of California, Santa Cruz
USA

Hannah L. J. Grant
ESO Expedition Project Manager
British Geological Survey
The Lyell Centre, Edinburgh
United Kingdom

Publisher's notes

This publication was prepared by the European Consortium for Ocean Research Drilling (ECORD) Science Operator (ESO) and Texas A&M University (TAMU) as an account of work performed under the International Ocean Discovery Program (IODP). Funding for IODP is provided by the following international partners:

National Science Foundation (NSF), United States
Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan
European Consortium for Ocean Research Drilling (ECORD)
Ministry of Science and Technology (MOST), People's Republic of China
Australia-New Zealand IODP Consortium (ANZIC)
Ministry of Earth Sciences (MoES), India

Portions of this work may have been published in whole or in part in other IODP documents or publications.

This IODP *Scientific Prospectus* is based on precruise *JOIDES Resolution* Facility advisory panel discussions and scientific input from the designated Co-Chief Scientists on behalf of the drilling proponents. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists, the Staff Scientist/Expedition Project Manager, and the Operations Manager that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the science deliverables outlined in the plan presented here are contingent upon the approval of the IODP ESO Director.

Disclaimer

Copyright

Citation

Webster, J.M., Ravelo, A.C., and Grant, H.L.J., 2023. Expedition 389 Scientific Prospectus: Hawaiian Drowned Reefs. International Ocean Discovery Program. https://doi.org/10.14379/iodp.sp.389.2023

ISSN

World Wide Web: 2332-1385

August 2023

Abstract

Our understanding of the links and mechanisms that control eustatic sea level and global climate changes has been significantly hampered by a lack of appropriate fossil coral records over the last 500 ky, particularly into and out of the glacial periods. We propose to directly address this problem by drilling a unique succession of drowned coral reefs around Hawaii (USA) now at 134–1155 meters below sea level. Abundant observational and numerical modeling data indicate that the internal stratigraphy and tops of these reefs are highly sensitive to sea level and climate changes, thereby providing a firm template with which to conduct these operations. As a direct result of Hawaii's rapid (2.5–2.6 m/ky) but nearly constant subsidence, a thick (100–200 m) expanded sequence of shallow coral reef dominated facies is preserved within the reefs. These reefs span important periods in the Earth's climate history, and coral reef records are either not available or highly condensed on stable (Great Barrier Reef, Tahiti) and uplifted margins (Papua New Guinea, Barbados) because of a lack of accommodation space and/or unfavorable shelf morphology. Specifically, these data show that the reefs grew (for ~90–100 ky, albeit episodically) into, during, and out of the majority of the last five to six glacial cycles. Therefore, scientific drilling through these reefs will generate a new record of sea level and associated climate variability during several controversial and poorly understood periods over the last 500 ky.

The project has four major objectives. The first objective will be to constrain the timing, rate, and amplitude of sea level variability over the last 500 ky allowing a definitive test of Milankovitch climate theory and an assessment of controversial abrupt sea level events (meltwater pulses) that occur on suborbital frequencies associated with events occurring in the extratropics (i.e., Dansgaard–Oeschger ice core temperature events and related Heinrich ice-rafted debris events in North Atlantic sediment cores). The second objective will be to investigate processes that determine changes in mean climate and high-frequency (seasonal–interannual) climate variability using high-resolution coral proxy data from times with different climate forcing boundary conditions (e.g., ice sheet size, $p\mathrm{CO_2}$, and solar forcing) over the last 500 ky. The third objective will be to determine the response of coral reef systems to abrupt sea level and climate changes, to test sedimentary models of reef evolution and ecological theories of coral reef resilience, and to establish the role of microbial communities in reef building. The fourth objective will be to refine the variation through space and time of the subsidence of Hawaii and contribute to understanding the volcanic evolution of the island.

Plain language summary

Shallow marine corals are highly sensitive to sea level and global climate change and preserve a reliable record of past sea level and climate conditions. Knowledge of sea level and global climate variations over the past half a million years is severely limited because of a lack of continuous fossil coral records over this time. To address the critical need for coral records, this project focuses on the submerged fossil reefs around the island of Hawaii. Frequent and large volcanic eruptions formed and continue to grow the volcanic island of Hawaii, and the island and surrounding shallow coral reefs are pushed down at a rapid and nearly constant rate because of the weight of the volcanic rock erupted onto the land. As the land and coral reefs subside, coral reef growth can match the subsidence rate, and changes in sea level and global climate are preserved in a unique and near-continuous fossil coral record covering the last half a million years. Scientific drilling of these reefs will provide a new record of climate and sea level change, including several key time periods where sea level and climate conditions are poorly known. The project has four major scientific objectives: (1) to measure the extent of sea level change over the past half a million years, (2) to investigate why sea level and climate change through time, (3) to investigate how coral reefs respond to abrupt sea level and climate changes, and (4) to improve scientific knowledge of the growth and subsidence of Hawaii over time.

1. Schedule for Expedition 389

Expedition 389 is based on International Ocean Discovery Program (IODP) drilling Proposal 716-Full2 and 716-Full2 Addendum 1. Following ranking by the IODP Science Advisory Structure, the expedition was scheduled by the European Consortium for Ocean Research Drilling (ECORD) Facility Board as a mission-specific platform (MSP) expedition to be implemented by the ECORD Science Operator (ESO). At the time of publication of this *Scientific Prospectus*, the offshore phase of the expedition is scheduled to begin the last week of August 2023 and will run for a maximum of 60 days until the last week of October. Science party members will be updated with exact offshore dates as and when they are confirmed. The onshore science party (OSP) at the IODP Bremen Core Repository (BCR) of the Center for Marine Environmental Sciences (MARUM) at the University of Bremen (Germany) is provisionally scheduled to start 1 February 2024 and last for a maximum of 4 weeks (dependent on core recovery).

The following links should be used in conjunction with this *Scientific Prospectus*:

- The Expedition 389 webpage will be periodically updated with expedition-specific information on the platform, facilities, coring strategy, measurements plan, and schedule. The proposal cover pages and addenda can be accessed at **https://www.ecord.org/expedition389**.
- General details about the offshore and onshore facilities provided by ESO are provided on the ESO-specific site on the MARUM website (**https://www.marum.de/en/Offshore_core_curation_and_measurements.html** and **https://www.marum.de/en/Research/Onshore_Science_Party_OSP.html**).
- The supporting site survey data for Expedition 389 are archived in the IODP Site Survey Data Bank (SSDB; **https://ssdb.iodp.org/SSDBquery/SSDBquery.php**; select P716 for the proposal number). Please note that not all site survey data associated with this expedition are publicly available.

2. Introduction

Drowned coral reefs on rapidly subsiding margins (e.g., Hawaii [USA] and Papua New Guinea) contain a unique and largely unexploited archive of sea level and climate changes. Unlike their mainly transgressive, highstand counterparts that developed in stable (e.g., Great Barrier Reef and Florida margin) and uplifted settings (e.g., Huon Peninsula and Barbados), these submerged lowstand reefs developed in response to rapid subsidence (~2–6 m/ky) (Webster et al., 2007, 2009; Hibbert et al., 2016). Depending on the relationship between eustatic sea level changes and reef growth, the rapid subsidence ensures that these settings have the unique potential to continually create accommodation space, thus generating greatly expanded stratigraphic sections compared to reefs from stable and uplifting margins. Moreover, these drowned reefs evolved mainly during different periods of Earth's sea level and climate cycles (i.e., glacial periods) that are not well sampled by reefs at stable and uplifting margins (Woodroffe and Webster, 2014) (Figure **F1**).

Our understanding of the links between eustatic sea level and global climate changes and, therefore, the mechanisms that control abrupt global climate changes is significantly hampered by a lack of appropriate fossil coral records over the last 500 ky, particularly during the transitions into, during, and out of the glacial periods (Lambeck et al., 2002). Crucial new coral data are needed to directly constrain the timing, rate, and amplitude of sea level variability during not only the last glacial cycle, where the data are still controversial (e.g., Woodroffe and Webster, 2014; Yokoyama et al., 2018, 2022), but also over the last 500 ky. Such data will test Milankovitch climate theory and assess controversial abrupt sea level events (i.e., meltwater pulses) that occur on suborbital frequencies (Chappell, 2002; Thompson and Goldstein, 2005; Yokoyama et al., 2001) in concert with climate events occurring in the extratropics (i.e., Dansgaard–Oeschger [D-O]) ice core temperature events and Heinrich ice-rafted debris events in North Atlantic sediment cores).

Identification of the factors and processes that control annual average global climate and seasonal and interannual climate variability in the subtropical Pacific is of equal importance. Theories of

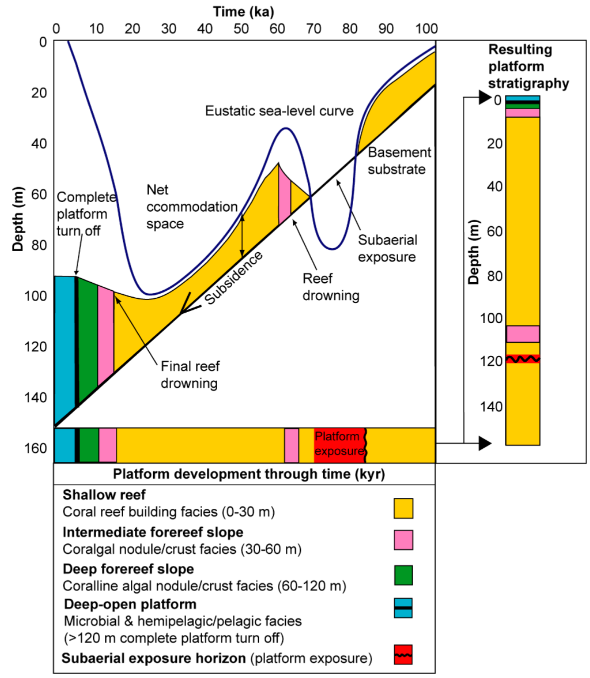

Figure F1. Conceptual model of Pleistocene coral reef initiation, growth, and demise on rapidly subsiding margin (Webster et al., 2007).

how regional climate processes respond to external forcing and/or are a result of internal sources of variability are derived from models or analyses of instrumental records and are generally limited to the last century when only small changes in mean climate occurred (e.g., Dai et al., 2015; Kavanaugh et al., 2018). Earth history over the last 500 ky reveals that the "dynamic range" of climate change is much larger than in the instrumental record and that high frequency global and regional climate sensitivity to external forcing is dependent on mean state (Kohler et al., 2018). Prime tests of these theories require paleoclimate records (particularly seasonal-resolved fossil coral archives) from times when climate forcing, such as pCO_2 and solar heating, were different than today.

3. Background

3.1. Hawaiian Reefs

The drowned coral reefs around Hawaii grew and drowned episodically over the last 500 ky and offer a truly unique opportunity to address these major scientific problems. Hawaii represents the ideal study location for three main reasons (Webster et al. 2009). First, the rapid subsidence (and thus greatly expanded reef sections) is caused by flexure of the oceanic lithosphere due to loading of the growing volcanoes, which in turn is controlled by rheology of the lithosphere and mantle (Watts, 1978), instead of uplift or subsidence due to fault displacement, which occurs at convergent margins where most existing fossil reef records are derived (e.g., Barbados and Papua New Guinea). Short-term fluctuations in volcanic loading are averaged out and the resultant subsidence rate is nearly uniform at 2.5–2.6 m/ky over tens to hundreds of thousands of years (Webster et al., 2009; Puga-Bernabéu et al., 2016). The depths of the reef tops for the sequence of reefs offshore Hawaii fits the timing of the last 6 interglacials only if the subsidence rate has remained nearly constant for the last 500 ky. Second, Hawaii's location in the central Pacific Ocean is well away from the confounding influence of large ice sheets and boundary ocean currents that might obscure the sea level and paleoclimate records. Furthermore, because the abyssal seafloor in the subtropical Pacific Ocean is generally too deep to preserve carbonate-rich sediment for paleoceanographic reconstructions, Hawaii provides a unique opportunity to use coral archives to fill data gaps in our understanding of subtropical climate variability. Third, an extensive database of bathymetry, submersible and remotely operated vehicle (ROV) observations, and sedimentary and radiometric data are available for these reefs. These data confirm that the drowned reefs are highly sensitive to abrupt changes in sea level and climate and that there is a wealth of site survey information to plan scientific drilling operations. We propose to exploit the unique potential of this largely untapped record by drilling the succession of drowned reefs around Hawaii.

3.2. Conceptual and numerical model of reef evolution in response to rapid subsidence

The initiation, growth, and demise of coral reefs on rapidly subsiding margins is represented in Figure **F1**. The relationships between subsidence of the basement, eustatic sea level changes, reef growth, and subsequent changes in accommodation space available for platform sedimentation are shown. Previous workers on Hawaii (Ludwig et al., 1991; Moore and Fornari, 1984) and Papua New Guinea (Galewsky et al., 1996; Webster et al., 2004b) have proposed that reef growth initiates during stable sea level highstands and continues throughout the regression, with final drowning during the early part of the deglaciations, perhaps because of abrupt eustatic sea level rise associated with meltwater pulse events (Webster et al., 2004a). Depending on the rate and magnitude of these parameters and reef response, the reef experiences repeated periods of sustained shallow-water and deepwater accretion, brief subaerial exposure, and drowning events. In this model example, the reef terrace records these different stages forming a complex "layer cake" stratigraphic succession composed of shallow to deep reef and platform packages, separated by repeated subaerial exposure horizons and drowning unconformities. As a direct result of Hawaii's rapid but nearly constant subsidence, a thick (100–150 m) expanded sequence of shallow coral reef–dominated facies should be preserved in the Hawaiian reefs that are either unrepresented or a highly condensed sequence on stable (e.g., Great Barrier Reef [Webster and Davies, 2003; Humblet and Webster, 2017]) and uplifted margins (e.g., Papua New Guinea [Lambeck and Chappell, 2001] and Barbados [Schellmann and Radtke, 2004]) because of a lack of continual creation of accommodation space and unfavorable shelf morphology (Woodroffe and Webster 2014).

To test this conceptual model, Webster et al. (2007) combined observational data and numerical modeling techniques to simulate the stratigraphic evolution of the two shallowest reefs (Figure **F2**). The results suggest that both reefs had long, complex growth histories and internal stratigraphy. Although experiencing subaerial exposure, the interior coral reef deposits (i.e., those deposits retrieved by drilling) are more likely to be diagenetically unaltered when compared with their stable and uplifted fossil reef counterparts given the brevity (<5 ky) of each subaerial exposure event. The data also suggests that the final reef units, marking the final drowning, were unlikely to be

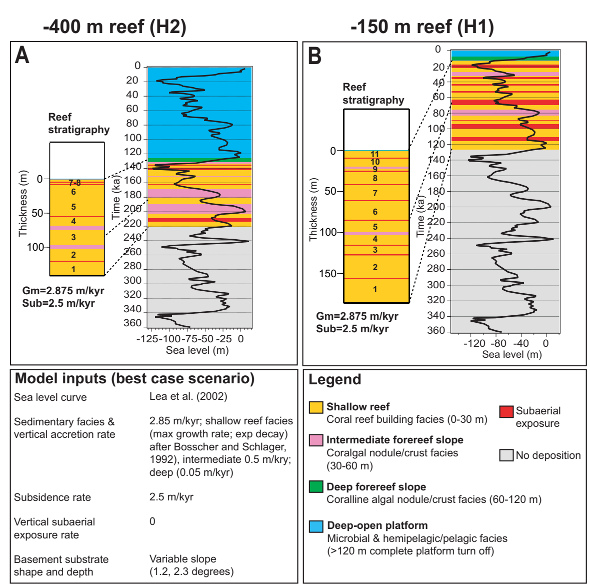

Figure F2. Numerical model outputs showing predicted internal reef evolution and stratigraphy of (A) H2 and (B) H1 around Hawaii (Webster et al., 2007).

subaerially exposed given the rate of subsidence and eustatic sea level rise during the penultimate and last deglaciations (Webster et al., 2004a; Sanborn et al., 2017). Therefore, reef material recovered from the reef interior and certainly the last phase of growth, should yield precise radiometric ages and geochemical climate proxies providing critical information about the timing, rate, and amplitude of eustatic sea level changes and associated climate variability of the last 250 ky (Figure **F3**) (Webster et al., 2009).

Webster et al. (2007) concluded that these reefs grew (albeit episodically) into, during, and out of the majority (~90 ky) of the last two glacial cycles. Therefore, scientific drilling through these two

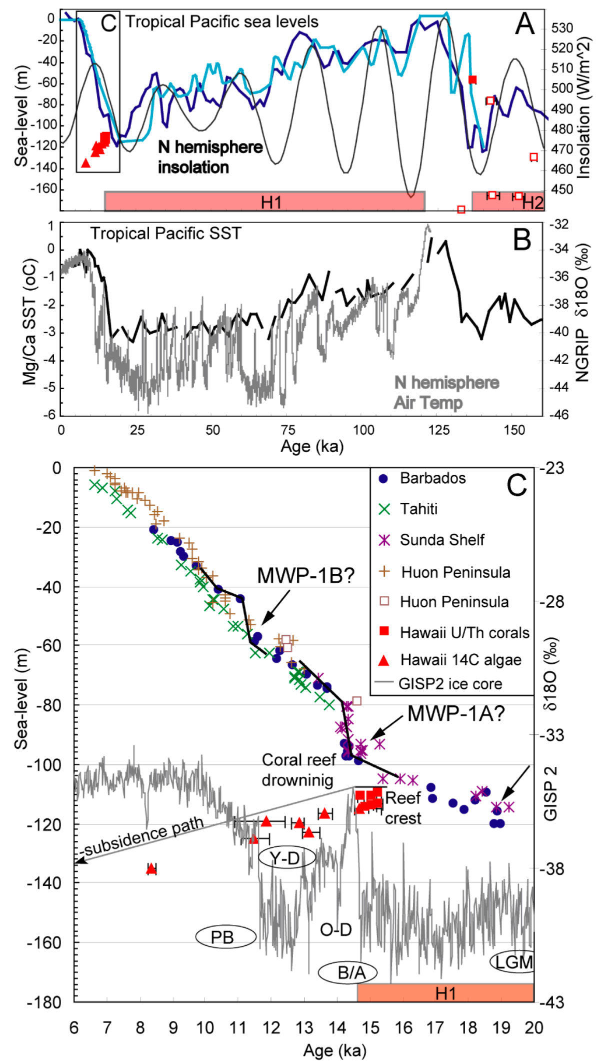

Figure F3. Drowning history of 400 mbsl (H2) and 150 mbsl (H1) reefs around Hawaii. A. Eustatic sea level change (light blue line = Lambeck and Chappell [2001], dark blue line = Lea et al. [2002]) and 60°N hemisphere June solar insolation (black line = Berger and Loutre [1991]) over last 160 ky. Drowning ages and depths of H2 and H1 as defined by radiometric coral (solid squares; U/Th in situ samples from reef crest) and coralline algal ages (triangles; ^{14}C loose samples on reef slope) that have been corrected for island subsidence (after Ludwig et al., 1991; Webster et al., 2004a, 2007; Riker-Coleman et al., 2005). Horizontal bars = age ranges for H2 and H1 reef growth duration based on observational and numerical modeling data (Webster et al., 2007). Box = H1 drowning expanded in C. B. Sea-surface temperature (SST) from western tropical Pacific (black line = Lea et al. [2003]) and Greenland ice record (gray line = NGRIP) for last 160 ky. C. Drowning of 150 mbsl reef (H1) during last deglaciation (after Webster et al., 2004a). Calibrated ^{14}C and U/Th ages from H1 are superimposed on relative sea level records from Barbados, Tahiti, Huon Peninsula, and Sunda Shelf. Original positions (adjusted for subsidence at 2.6 m/ky) of H1 reef crest (and samples) before drowning. Space between crest, subsidence pathway (gray line), and sea level records approximate paleowater depth above reef crest during last deglaciation. Abrupt sea level associated with Site MWP-1A may have drowned H1 and forced subsequent abrupt global scale cooling events (i.e., O-D = Older Dryas and Y-D = Younger Dryas) shown here in ice core data (GISP II). Solid symbols = in situ coral and coralline algal samples collected from reef crest. LGM = Last Glacial Maximum, B/A = Bølling–Allerød transition, PB = Preboreal (after Webster et al., 2009).

reefs alone will generate a new and unique record of sea level and associated climate variability during several controversial and poorly understood periods: Marine Isotope Stage (MIS) 7, the penultimate glaciation (MIS 6) and deglaciation (MIS 6–5), MIS 5, MIS 4, MIS 3, MIS 2 (i.e., Last Glacial Maximum [LGM]), and the last deglaciation (Figure **F3**) (Lambeck et al., 2002; Webster et al., 2009).

3.3. Reef terraces: distribution, morphology, and age data

Based on compiled bathymetric data sets (Figure **F4**) (from MBARI Mapping Team [2000] and Smith et al. [2002]), we have identified 13 major (designated H0–H12 from shallowest to deepest [H is for Hawaii]) and 9 minor reef terraces (designated with suffixes a, b, c, etc.) around Hawaii (Figures **F4**, **F5**, **F6**, **F7**, **F8**). However, to achieve the scientific objectives of Expedition 389, we

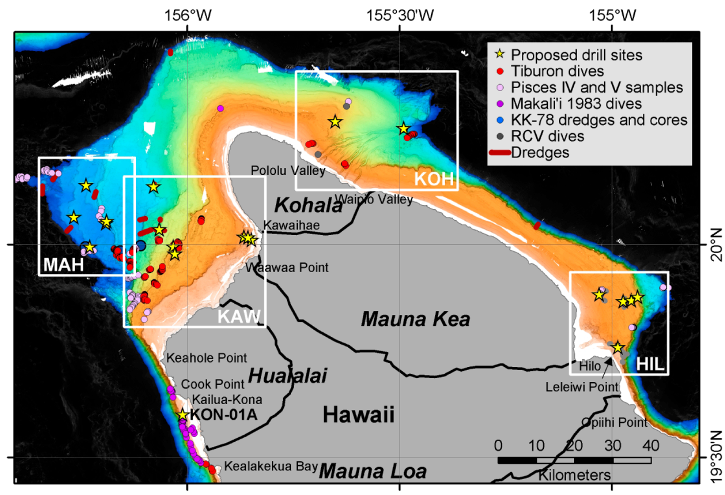

Figure F4. Map showing Expedition 389 proposed drill sites (yellow stars; Table T2) and available site survey data sets (high-resolution bathymetry, backscatter, dredge, submersible and ROV dive observations and samples) for drowned reef terraces. Boxes = locations of close ups (Figures F5–F8) showing details of proposed drill sites (data from MBARI Mapping Team [2000] and Smith et al. [2002]; image created by Jenny Paduan, MBARI).

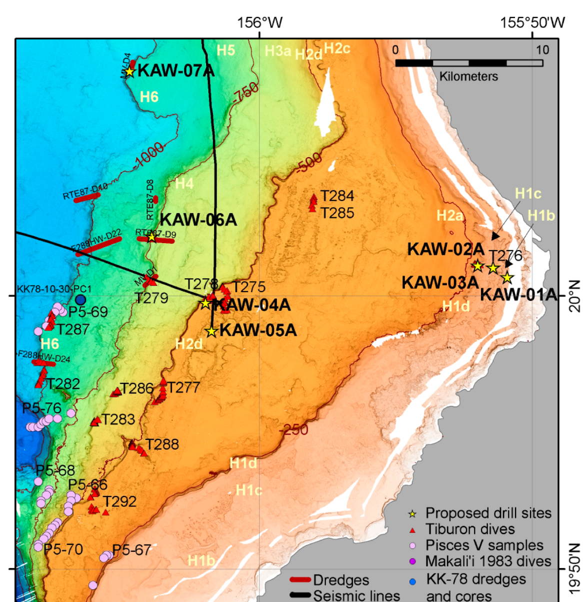

Figure F5. Map of Kawaihae region showing drowned reefs (H1–H6), Expedition 389 proposed drill sites (KAW-01A through KAW-07A), and available site survey data (from MBARI Mapping Team [2000] and Smith et al. [2002]; image created by Jenny Paduan, MBARI).

have identified 11 primary targets and 9 alternate targets. In many cases, the depth of the break-in-slope of a continuous terrace varies as a result of variable subsidence that produces tilting and secondary retreat due to erosional processes. Detailed summaries of the published reef terrace distribution, morphology, and age data are published in the following studies: Webster et al. (2009), Puga-Bernabéu et al. (2016), Sanborn et al. (2017), and Taylor (2019).

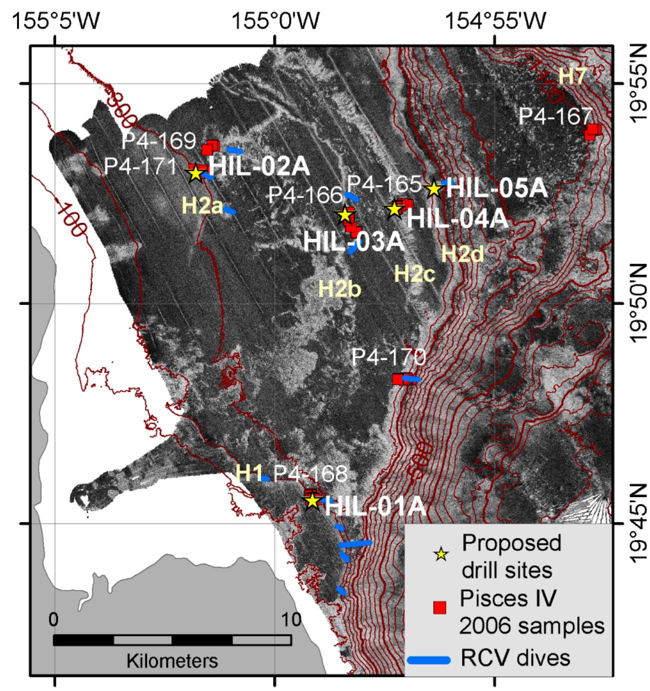

Figure F6. Map of Hilo region showing drowned reefs (H1–H7), Expedition 389 proposed drill sites (HIL-01A through HIL-05A), and available site survey data, including example of high-resolution backscatter data available for proposed drill sites. Drowned reefs are characterized by distinct, high (white) backscatter signatures (data from MBARI Mapping Team, 2000 and Smith et al., 2002, image created by Jenny Paduan, MBARI; also published in Puga-Bernabéu et al. [2016]).

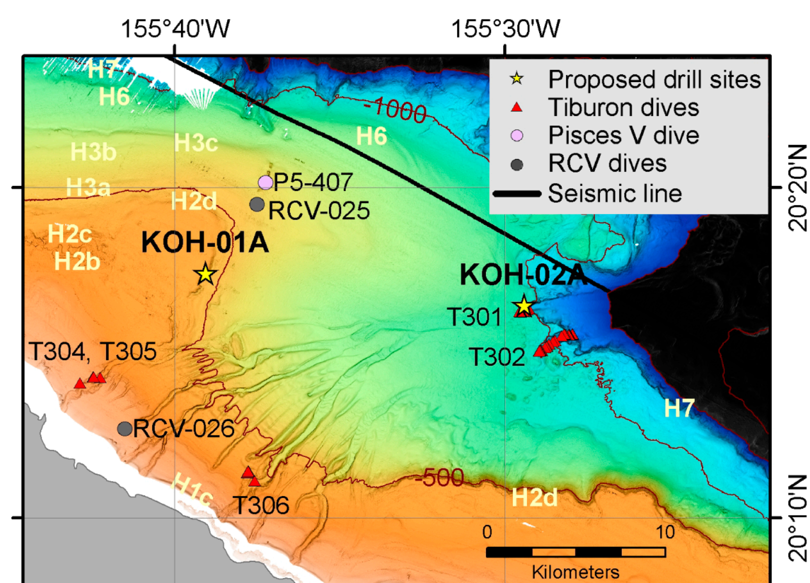

Figure F7. Map of Kohala region showing drowned reefs (H2–H7), Expedition 389 proposed drill sites (KOH-01A and KOH-02A), and available site survey data (from MBARI Mapping Team [2000] and Smith et al. [2002]; image created by Jenny Paduan, MBARI).

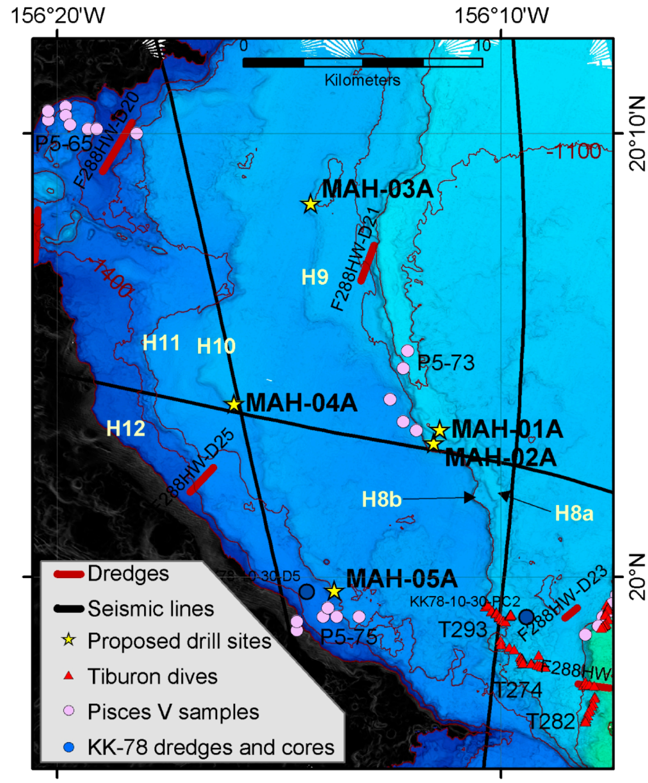

Figure F8. Map of Mahukona region showing drowned reefs (H8–H12), Expedition 389 proposed drill sites (MAH-01 through MAH-5A), and available site survey data (from MBARI Mapping Team [2000] and Smith et al. [2002]; image created by Jenny Paduan, MBARI).

4. Scientific objectives

This project will address the broad themes "Environmental change, processes and effects" and "Deep Biosphere and the Subseafloor Ocean" identified in the IODP Initial Science Plan. Specifically, the scientific objectives for Expedition 389 directly address key IODP initiatives to investigate the mechanisms that control rapid climate change as well as the relationship between changes in mean climate state and high frequency (seasonal–decadal) climate variability. The specific objectives of the project are as follows:

4.1. Objective 1: to define the nature of sea level change in the central Pacific over the last 500 ky

Our objective is to reconstruct the most complete and detailed sea level record from fossil corals, particularly into, during, and out of the glacial periods. These data will allow the following:

- More detailed testing of the Milankovitch climate theory predictions and
- Improved constraints on millennial-scale sea level changes.

This curve will be built using absolute radiometric methods (^{14}C accelerator mass spectrometry [AMS] <50 ka and U/Th) to date in situ corals, paleobathymetric data, and published and directly calculated subsidence rates for Hawaii.

4.2. Objective 2: to reconstruct paleoclimate variability for the last 500 ky and establish the relationship between the mean climate state and seasonal–interannual variability

Drilling will recover massive coral samples and allow us to do the following:

- Reconstruct the mean and seasonal/interannual climate variability of the central subtropical Pacific gyre for the first time and
- Use these Late Pleistocene coral-derived temperature and precipitation records to investigate how high latitude climate (e.g., ice sheet size), atmospheric CO_2 levels, and mean and seasonal solar radiation impact Hawaiian climate including storminess and the position of the Intertropical Convergence Zone.

In combination with theoretical studies of subtropical climate change, these records will allow for the identification and study of critical processes that determine subtropical Pacific climate.

4.3. Objective 3: to establish the geologic and biological response of coral reef systems to abrupt sea level and climate changes

Coring through the succession of drowned coral reefs will allow us to do the following:

- Reconstruct the detailed stratigraphic, geomorphic, and paleoenvironmental evolution of each reef in response to abrupt sea level and climate changes;
- Test ecological theories about coral reef resilience and vulnerability to past and future climate changes by assessing the nature and rate of change in reef communities within and between successive reefs over interglacial–millennial timescales; and
- Establish the nature of living and ancient microbial communities in the reefs and their role in reef building.

4.4. Objective 4: to elucidate the subsidence and volcanic history of Hawaii

We will also be able to do the following:

- Refine the variation through space and time of the subsidence of Hawaii and
- Contribute to understanding the volcanic evolution of the island.

The key to these objectives is to obtain well-dated volcanic samples from the base of each hole and interbedded with or draping over the reefs.

5. Previous drilling

No previous scientific drilling has been undertaken in the vicinity of the proposed drill sites, with the vast majority of previous offshore studies focusing on dredge samples, ROV observations and samples, and geophysical (multibeam bathymetry and seismic) data sets (e.g., Ludwig et al., 1991; Szabo and Moore, 1986; Webster et al., 2004a, 2009; Puga-Bernabéu et al., 2016; Sanborn et al., 2017; Taylor, 2019).

Major onshore scientific drilling has occurred through the Hawaiian Scientific Drilling Project (HSDP), which is a >3000 m deep borehole drilled east of the city of Hilo within 200 m of the shoreline (Moore et al., 1996). Among the numerous scientific findings to come out of the HSDP was a subsidence rate for the eastern side of Hawaii calculated using various dating techniques, including the radiometric dating of corals, which is relevant to the scientific objectives of Expedition 389 (Moore et al., 1996; Sharp and Renne, 2005; Webster et al., 2009; Puga-Bernabéu et al., 2016).

6. Proposed drilling strategy

Given the nature of the target material to be drilled (reefal sediments) and the range of water depths, an MSP has been assigned to implement Expedition 389, with a remotely operated seafloor drill selected to undertake the coring. This approach was chosen because seafloor drills have small environmental footprints and are appropriate for the target water depths (129–1234 meters below sea level [mbsl]) and penetration depths (up to 110 meters below seafloor [mbsf]). A seafloor drill uses narrower coring bits and is not affected by heave, therefore increasing the likelihood of recovering high-quality reef cores compared to heavier coring methods traditionally deployed from a drillship using and a conventional geotechnical wireline drill string. See later sections for details of the drilling system and vessel. In addition, ESO staff have experience in facilitating similar scientific drilling projects (e.g., Integrated Ocean Drilling Program Expeditions 310 and 325), which is valuable for planning the operational strategy for Expedition 389.

The drilling strategy for Expedition 389 will target terraces with sufficient observational and sample data to be confident of their age and reefal origin (Table **T1**). The main strategy of sampling multiple younger reefs (MIS 1–7) from several different regions will allow the science party to better constrain island-wide variations in local climatic zones (e.g., wet windward and dry leeward) and any subsidence behavior. In addition, the secondary strategy of sampling several older (MIS 8–13) but well-defined reefs (Webster et al., 2009), now within the reach of more precise U/Th methods, will extend the sea level and climate records back to 500–600 ka (Figure **F9**).

Alternate target sites have also been selected that will only be drilled if the primary targets are successfully sampled ahead of schedule or in the event of on-site drilling information indicating the alternate sites would yield better preserved coral material.

The two most limiting logistical considerations for the offshore phase of Expedition 389 are the weather and whales. The trade winds can blow strongly during the summer, and great storms in

Table T1. Relevant site survey data set coverage for proposed drill sites around Hawaii, Expedition 389.

Site	Primary/ Alternate	High-resolution bathymetry/ backscatter coverage	ROV/Submersible observations	ROV/Submersible/Dredge sample data
KON-01A	Primary	Yes	Yes	6 fossil reef samples from adjacent part of same reef
KAW-01B	Alternate	Yes	Yes	9 fossil reef samples from adjacent part of same reef
KAW-02B	Alternate	Yes	Yes	9 fossil reef samples from adjacent part of same reef
KAW-03B	Primary	Yes	Yes	9 fossil reef samples from this location
KAW-04B	Primary	Yes	Yes	20 fossil reef samples from this location
KAW-05B	Alternate	Yes	Yes	4 push cores through sediments and 25 fossil reef samples from adjacent part of same reef
KAW-06A	Primary	Yes	Yes	Dredge and 16 fossil reef samples from adjacent part of same reef
KAW-07A	Primary	Yes	Yes	Dredge and 27 fossil reef samples from adjacent part of same reef
MAH-01A	Primary	Yes	Yes	Dredge and 69 fossil reef samples from adjacent part of same reef
MAH-02A	Primary	Yes	Yes	Dredge and 69 fossil reef samples from adjacent part of same reef
MAH-03A	Alternate	Yes	No	
MAH-04A	Alternate	Yes	No	
MAH-05B	Alternate	Yes	Yes	2 fossil reef samples from adjacent part of same reef
KOH-01A	Primary	Yes	No	
KOH-02A	Primary	Yes	Yes	30 fossil reef samples from this location and 20 fossil reef samples from adjacent part of same reef
HIL-01A	Primary	Yes	Yes	25 fossil reef samples from this location
HIL-02A	Alternate	Yes	Yes	12 fossil reef samples from this location
HIL-03A	Alternate	Yes	Yes	18 fossil reef samples from this location
HIL-04A	Alternate	Yes	Yes	17 fossil reef samples from this location
HIL-05A	Primary	Yes	Yes	29 fossil reef samples adjacent part of same reef

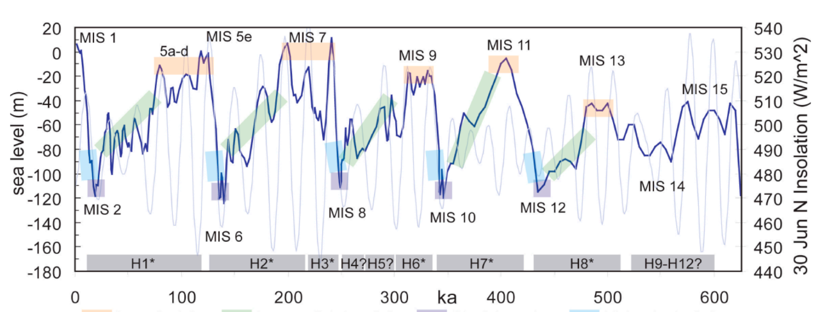

Figure F9. Sea level, climate, and insolation history over last 600 ky (Imbrie et al., 1984; Berger and Loutre, 1991; Lea et al., 2002). Observational and numerical modeling data indicate that succession of drowned Hawaiian reefs (H1–H12) grew episodically over this period during different interglacial, interstadial/stadial, glacial maxima, and deglacial intervals (after Webster, et al., 2009).

the north Pacific generate huge, long-period swells in the winter; both times are to be avoided. The Hilo and Kohala sites are on the windward side of Hawaii, whereas the Kawaihae and Mahukona sites are more protected on the leeward side. The Mahukona sites can also be windy and have rough seas because the trade winds blow through the Alenuihaha channel between Maui and Hawaii. Three of the proposed drill sites (KAW-01A through KAW-03A) are within the Hawaiian Islands Humpback Whale National Marine Sanctuary. Whales arrive in November and depart in February. Therefore, September–October represents the preferred window for drilling.

6.1. Proposed drill site locations

Eleven primary sites and nine alternate sites have been selected, located in water depths ranging from approximately 129 to 1234 mbsl with maximum penetration depths of ≤110 mbsf (Table **T2**). The following provides a brief summary of each primary site.

6.1.1. Site KON-01A

Bathymetry and backscatter data confirm the presence of the major 150 mbsl reef terrace (H1d) offshore Kona, which is the target for site KON-01A. The H1d reef is widespread around Hawaii occurring south of Kealekekua Bay to the northern tip of Kohala Volcano (e.g., Moore and Fornari, 1984), except for two stretches where it is buried by younger lava flows: on the east side of Ka Lae (South Point) (Moore et al., 1990) and east of Hilo to Opiihi Point where it disappears under Kilauea lava flows (Clague et al., 1999). Directly adjacent to Site KON-01A, numerous submersible and ROV dive observations and samples confirm the structure is reefal and likely grew during MIS 1–5. For a summary of all age data see Webster et al. (2009) and Sanborn et al. (2017).

6.1.2. Sites KAW-03B and KAW-04B

The northwest flank of Hawaii represents the area of most intensive investigation over the last 25 y. Complete high-resolution bathymetry and backscatter data coverage, combined with extensive ROV and submersible observations and sampling, has revealed a succession of 12 well-developed reef terraces. For the benefit of operational strategy planning, this area has been divided into the proximal drill sites offshore Kawaihae (prefix "KAW") and the more distal drill sites offshore the western flank of the submerged Mahukona Volcano (prefix "MAH") (Clague and Moore, 1991; Moore and Clague, 1992).

Primary Site KAW-03B intersects the major 150 mbsl reef terrace (H1d) that can be traced around much of the flanks of Hawaii (Moore and Fornari, 1984; Webster et al., 2004a). ROV observations

Table T2. Location and information for proposed primary and alternate sites, Expedition 389. Sites with ≥110 mbsf penetration will penetrate a few meters into underlying basalt basement.

Site	Position (WGS84) (latitude, longitude)	Water depth (m)	Penetration (mbsf)	Primary/ Alternate	Brief site-specific objectives
KON-01A	19.600341, −156.010975	−145	80	Primary	H1d reef that spans MIS 1–5
KAW-01B	19.99093302, −155.8563025	−129	80	Alternate	H1b reef that spans MIS 1–5
KAW-02B	19.99383926, −155.8644029	−132	90	Alternate	H1c reef that spans MIS 1–5
KAW-03B	19.990308, −155.873431	−154	80	Primary	H1d reef that spans MIS 1–5
KAW-04B	19.942109, −156.062876	−414	110	Primary	H2d reef that spans MIS 6–7
KAW-05B	19.957553, −156.039013	−463	100	Alternate	H2d reef that spans MIS 6–7
KAW-06A	20.036417, −156.065696	−737	65	Primary	H4 reef that spans MIS 8–9
KAW-07A	20.137266, −156.079341	−988	70	Primary	H6 reef that spans MIS 10–11
MAH-01A	20.055411, −156.189697	−1102	110	Primary	H8a reef that spans MIS 12–13
MAH-02A	20.050262, −156.192035	−1154	110	Primary	H8b reef that spans MIS 12–13
MAH-03A	20.140405, −156.238194	−1213	50	Alternate	H9 reef that spans MIS 14–15(?)
MAH-04A	20.065165, −156.266945	−1234	50	Alternate	H10 reef that spans MIS 14–15(?)
MAH-05B	20.1797, −156.256232	−1203	70	Alternate	H11 reef that spans MIS 14–15(?)
KOH-01A	20.290268, −155.651218	−410	80	Primary	H2d reef that spans MIS 6–7
KOH-02A	20.273958, −155.490294	−931	45	Primary	H7 reef that spans MIS 10–11
HIL-01A	19.758805, −154.985708	−134	110	Primary	H1d reef that spans MIS 1–5
HIL-02A	19.883005, −155.029932	−271	90	Alternate	H2a reef that spans MIS 4(?)–7
HIL-03A	19.867141, −154.973387	−338	90	Alternate	H2b reef that spans MIS 5a(?)–7
HIL-04A	19.869407, −154.954576	−354	90	Alternate	H2c reef that spans MIS 5a(?)–7
HIL-05A	19.876999, −154.939618	−402	110	Primary	H2d reef that spans MIS 6–7

and samples at this site confirm its reefal nature. This terrace drowned between 15.3 and 8.1 ka (Webster et al., 2004a; Sanborn et al., 2017) and likely grew during MIS 1–5 (Webster et al., 2009). The 400 mbsl terrace forms a well-developed and continuous reef (H2d) off Kawaihae. This reef has been extensively sampled and observed by submersible, and U/Th ages on corals range from 133 ka to approximately 170 ka (Webster et al., 2009). Primary Site KAW-04B is situated specifically to recover MIS 6–7 aged materials from this reef.

6.1.3. Sites KAW-06A and KAW-07A

Two further primary sites aim to recover material from deeper reefs offshore Kawaihae; Site KAW-06A intersects Reef H4 at approximately 740 mbsl, and Site KAW-07A intersects Reef H6 at approximately 990 mbsl. Based on available age data (Ludwig et al., 1991), these reefs likely grew during MIS 8–9 and MIS 10–11, respectively.

6.1.4. Sites MAH-01A and MAH-02A

The two primary sites offshore the submerged Mahukona Volcano intersect perhaps the most prominent reef structure (H8) on the northwest flank of Hawaii. This feature is divided into two subterraces; dive observations, samples, and dredges show that these robust features are both coral reefs (H8a and H8b), and U-series dating of three corals yielded ages of 360, 406, and 475 ka (Ludwig et al., 1991). Site MAH-01A will penetrate the upper reef (H8a) in a water depth of 1102 mbsl, Site MAH-02A will penetrate the lower reef (H8b) in a water depth of 1154 mbsl, and their reef records will likely span MIS 12–13.

6.1.5. Sites KOH-01A and KOH-02A

Two primary sites have been selected offshore Kohala on the northeast side of Hawaii. Site KOH-01A was selected on the basis of the bathymetric/backscatter data and forms an important replicate site, along with Site HIL-05A (see below) located ~85 km further to the south east, that will intersect the 410 mbsl reef (H2d) on the eastern margin of Hawaii. Site KOH-02A will intersect the prominent reef terrace (H7) at 930 mbsl that is well exposed by a submarine plunge pool system (Webster et al., 2009). At this location, ROV sampling at the base and top of this exposed section, combined with detailed observations, reveals at least six distinct reef units. These are characterized by different in situ coral volumes and framework types that are separated in places by planar surfaces, perhaps representing either thick coralline algal crusts and/or subaerial exposure surfaces. U-series dating of two coral samples from near the base of this reef yield ages of 377–392 ka (Webster et al., 2009) indicating this reef likely grew during MIS 10–11 (Figure **F10**).

6.1.6. Sites HIL-01A and HIL-05A

The two primary sites offshore Hilo intersect the two most prominent reef structures on the eastern flank of Hawaii: the 135 mbsl reef (H1d) (Site HIL-01A) and the 400 mbsl reef (H2d) (Site HIL-05A). Submersible dive observations and samples confirm these features are coral reefs that likely span MIS 1–5 and 6–7 (Puga-Bernabéu et al., 2016).

6.2. Site survey data

The assembled site survey data set used to select the primary and alternate sites represents work by many institutions and researchers over the last 25 y. Table **T1** summarizes the main data sets used to select proposed drill sites around Hawaii. As with the approach adopted for Expeditions 310 (Tahiti Sea Level) and 325 (Great Barrier Reef Environmental Changes), the high-resolution swath bathymetry and backscatter, in combination with ROV/submersible and dredge data from location or adjacent locations, were the primary data sets used to define the extent and characteristics of the fossil reefs and select the proposed drill sites.

Swath bathymetric data were collected in 1998 with a 30 kHz Simrad EM300 system by the Monterey Bay Aquarium Research Institute (MBARI) on the Kohala Terrace (named by Campbell, 1986) and the northeast margin of Kohala Volcano (Clague et al., 1998; MBARI Mapping Team, 2000) and by the United States Geological Survey (USGS) offshore Hilo (Dartnell and Gardner, 1999). These data are much higher resolution and have superior navigation to all previous surveys, and they form the primary data used for site selection. In addition to the new 30 kHz data, Sea-

Beam swath bathymetry was collected during a series of cruises by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), starting in 1998 (Smith et al., 2002). Additional swath data has been collected by the University of Hawaii and the National Oceanic and Atmospheric Administration (NOAA) Mapping Group. All data were used to define the extent and characteristics of the reefs and select drill sites. Several air gun lines crossing the terraces were collected during the GLORIA surveys (USGS Cruise F6-86-HW) in 1986. Unfortunately, like most attempts to seismically image reefal carbonates, these profiles are dominated by multiples and reverberation, revealing nothing about the internal structure of the reefs or the depth of the volcanic substrate. Furthermore, several high-resolution Chirp seismic lines collected in 2003 by the R/V *Robert C. Seamans* do not penetrate the reef structure. Chirp data crossing depressions behind Reef H2d resolved at least 30–50 m of unconsolidated sediments filling the lagoons. Similarly, a 2007 site survey cruise to investigate the drowned shelf edge reefs in the Great Barrier Reef (see IODP Proposal 519) was able to seismically image (Topas PS18 and Sparker) subbottom sedimentary packages in the paleolagoons and fore-reef slopes but little information directly within the reef structures. In these reefal carbonate environments, high-resolution bathymetry and backscatter, combined with observational and lithologic data, are the best tools for selecting reef drilling targets.

A great deal of work has already been done to sample and observe the reefs around Hawaii, starting in 1983 with Makali'i submersible dives (M288–M298), mainly on Reef H1d but also one dive on Reef H2c off Kohala (Dive M287). In 1985, Pisces V submersible dives (P5-65 through P5-78) explored and sampled many of the reefs off the Kona coast. Dredging programs were undertaken from the R/V *Melville* in 1987 (RTE87-D7 through RTE87-D9) and again in 2005 (TUIM-MV-D1 through TUIM-MV-D4) and from the R/V *Farnella* in 1988 (F2-88-HW-D18 through F2-88-HW-D25) and 1991 (F2-91-HW-D2) on the northeast Reef H2d on Mauna Kea. One additional Pisces V dive (P5-407) and two ROV dives (RCV25 and RCV26) in 1999 took place on the terraces east of Kohala. A total of 7 Pisces IV dives (P4-165 through P5-171) and video transects during 13 RCV-150 ROV dives (RCV334–RCV346) were conducted on the reefs offshore Hilo. In 2001, MBARI's

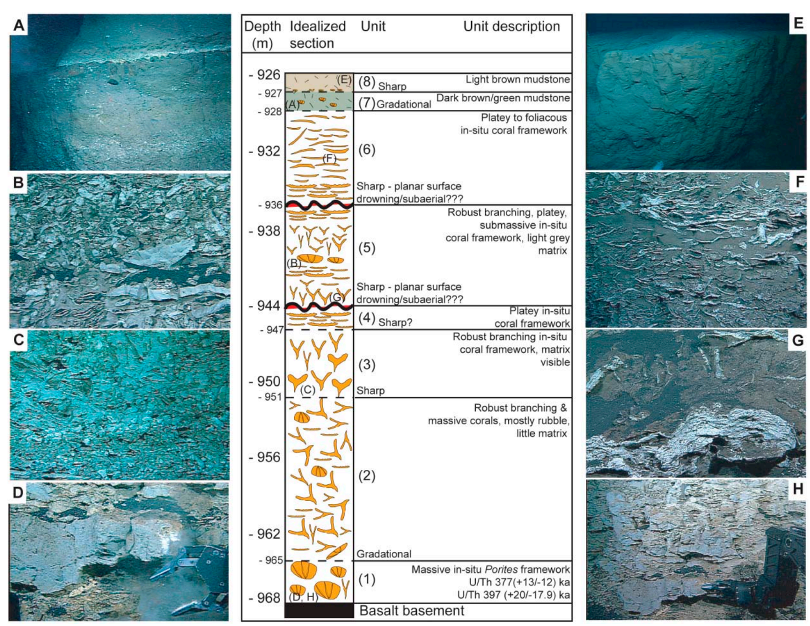

Figure F10. Stratigraphic section through drowned Reef H7 (–950 m) off Kohala, northeast Hawaii, and outcrop photographs. A. Transition from Unit 6 to Unit 8. Note sharp contact defined by carbonate? debris between Units 7 and 8. B. In situ platey and submassive coral framework from Unit 5. C. Transition from Unit 2 to Unit 3 characterized by coral rubble and in situ robust branching coral framework respectively. D, H. Unit 1 dominated by in situ massive *Porites lobata*? forming shallow coral reef facies. U/Th age data indicate unit was deposited during MIS 11 (377–397 ka). E. Light brown hemipelagic mudstone forming Unit 8 at top of section. F. In situ platey to foliaceous coral framework toward top of Unit 6. Unit is characterized by thin overlapping agaricid corals (*Leptoseris* and *Pavona*) with intergrowing coralline algae (i.e., *Lithothamnion prolifer*) representing intermediate, fore-reef slope facies. G. Sharp planar surface separating Units 4 and 5 (after Webster et al., 2009).

ROV *Tiburon* completed 14 dives on the reefs southwest of Kohala (T275–T279, T282–TT288, and T291–T293), and 5 dives on the reefs and canyons east of Kohala (T301, T302, and T304–T306). The Hawaii Undersea Research Laboratory has also conducted at least 100 additional submersible dives and ROV video transects on these reefs for fishery and other biological studies. In total, over 550 samples of reef carbonate collected during these operations have been examined.

7. Operational strategy

7.1. Drilling platform

The expedition platform will be the dynamically positioned multipurpose vessel *MMA Valour*, operated by MMA Offshore. This versatile vessel has previously undertaken various offshore tasks including launching ROVs, and deploying the selected seafloor drill: the Benthic Portable Remotely Operated Drill (PROD). The vessel is characterized by a forward accommodation block, a midship launch area, and a generous rear working deck that provides space for PROD equipment and ESO containerized laboratories.

The *MMA Valour* is 84 m long with a gross tonnage of 4258 tons and an average economical speed of 10 kt. The total capacity is 60 people, and it is anticipated that most, if not all, of the berths will be utilized. A midexpedition port call is required for ship resupply and to rotate some of the drilling crew.

Coring will be performed by Benthic's 5th generation PROD (PROD5). The PROD5 is rated to 4000 m water depth and can take cores up to 150 mbsf. The PROD5 system is lowered to the seabed using an umbilical that carries power, communication, and control. The drill pipe, core barrels, and other tools are manipulated to and from a magazine using robotics, an onboard top drive provides the rotation for coring, and an onboard mast feeds the drill pipe into the seabed. The PROD5 collects 75 mm diameter piston cores in soft sediment and 72 mm diameter rotary cores in harder formations. On the seabed, PROD5 is unaffected by surface conditions, increasing the likelihood of higher quality cores than ship-mounted systems that rely on heave compensation.

7.2. Coring methodology

The PROD5 will utilize piston coring and rotary coring, depending on the material encountered and whether it is consolidated rock or soft sediment. The PROD5 can switch dynamically between these two coring styles in a single deployment or a single hole, allowing penetration into hard rock or soft sediment without the need to recover the drill to the vessel. Individual core runs will be up to 2.75 m, which is the maximum length of core that can be housed in a PROD5 core barrel at 100% recovery.

The PROD5 can carry up to 37 sample tools (either piston or rotary core barrels) on each dive. With full penetration on each core run, this equates to a maximum penetration of 101.75 m per dive. However, core runs may be shortened because of technical challenges (e.g., a blocked core barrel), and it is unlikely that full penetration will be reached in a single dive. When all core barrels are used up, the PROD5 needs to be recovered. To continue deeper coring at the same site, the PROD5 needs to be redeployed to "wash" down (no coring) to the previous depth in a new borehole close by.

The PROD5 onboard drilling mud system uses seawater as the drilling fluid, which can be dosed with biodegradable viscosifier only when required.

7.3. Downhole logging

Like all commercial seafloor drills, the PROD5 does not have the capability to collect standard IODP downhole logs. Consequently, no downhole logging data will be acquired during Expedition 389. Drilling parameters will be collected by the PROD5 system during core runs at 1 s intervals. Drilling data collected will include drill bit depth, bit weight, torque, rotary speed, drill water flow rate, drill water flow pressure, and penetration speed.

7.4. Site priorities and contingency considerations

Expedition 389 has 20 proposed sites divided into 11 primary and 9 alternative sites (Table **T2**). The 11 primary sites were identified on the balance of key scientific criteria for the expedition: (1) terraces with sufficient observational and sample data to be confident of their age and reefal origin, (2) our main strategy of sampling multiple younger reefs (MIS 1–7) from several different regions to better constrain island-wide variations in local climatic zones (e.g., wet windward and dry leeward) and any subsidence behavior, and (3) our secondary strategy of sampling several older (MIS 8–13) but well defined reefs now within the reach of more precise U/Th methods that will extend the sea level and climate records back to 500–600 ka. In terms of specific site prioritization, the first site is likely to be a medium or lower priority primary site subject to weather and other logistical constraints. An overall site priority scheme will be produced for all sites, in addition to a local priority scheme in the event weather forces operations on a specific side of the island for a time. Any agreed strategy may be superseded by events in the field, and ultimately site decisions will be made at sea. Site decisions should be made for the following 48 h minimum to inform the Benthic drilling team.

7.5. Core on deck

Unlike traditional coring from drill ships, all of the core from the dive will arrive on deck at the same time when the PROD5 is recovered. Theoretically this could be up to ~100 m at full penetration; however, in practice, this is anticipated to be less. It takes approximately 1 h for all core barrels to be unloaded from the PROD5, with another 3 h required to reset the system for the next dive.

Once removed from the drill, cores will be divided by ESO curators into a maximum of 1.5 m sections, utilizing natural core breaks as much as possible. The core barrel number is recorded in the drillers log indicating which core interval it contains. A list of the core barrels and intervals will be provided to the curator on shift to allow them to accurately define the core depths.

Polycarbonate and aluminum liners will be provided for the PROD5 system for both piston and rotary coring. The preferred method will be to core with polycarbonate liner as far as possible. However, if the formation is not conducive to coring with polycarbonate liner, aluminum liner will be used to reduce the likelihood of irregular core pieces jamming the liner and causing it to collapse. In the event that aluminum liner is used, cores will be freed by cutting the liner along two sides before being curated and transferred into polycarbonate liner. This will result in aluminum shards from the liner cutting process being spread along the outer surface of the core and will be noted in the curation database to inform subsequent analytical steps. The core transfer process, should it be used, will be fully documented in the Expedition 389 methods chapter of the Expedition reports. When the aluminum liner workflow is used, there may be a limited opportunity for selected science party members to make brief observations of the unlined core before it is sectioned, curated, and transferred to polycarbonate liner. If lithologies allow, pore water sampling of curated unlined sections may happen before they are transferred into polycarbonate liner.

After curation, the polycarbonate-lined sections and any core catcher pieces will enter the core workflow described later in this *Scientific Prospectus*.

8. Science operations

A Sampling and Measurements Plan (SMP) for Expedition 389 has been prepared by ESO and the Co-Chief Scientists to meet the scientific objectives of IODP Proposal 716-Full2 and 716-Full2 Addendum 1 (see **Appendix**).

8.1. Offshore science activities

It is the nature of MSP expeditions that there is limited laboratory space and accommodation on the platforms compared to the larger research drilling vessels R/V *JOIDES Resolution* and D/V *Chikyu*, and as such there is no splitting of the cores at sea; instead, selected scientific analyses are carried out on board by a subset of the science party (in this case, 8 members). Science activities on the platform are confined to those essential for decision making at sea, core curation, measurement of ephemeral properties, and securing of samples for pore water chemistry. Offshore microbiological sampling is not required for Expedition 389. It is anticipated that cores will be cut into 1.5 m sections for curation. Most of the scientific analyses are carried out during the OSP in Bremen when the cores are split.

The following is a summary of the offshore scientific activities that will be undertaken (see **https://www.marum.de/en/Research/Exp..html** and the online tutorial **http://www.marum.de/en/Offshore_core_curation_and_measurements.html**):

- Basic curation and labeling of core.
- Measuring all cores (>10 cm) on the multisensor core logger (MSCL; gamma density, *P*-wave velocity, electrical resistivity, magnetic susceptibility, and natural gamma radiation). Note that the choice of liner will affect which measurements can be conducted successfully. Only natural gamma ray and density data can be acquired for core in aluminum liners. In addition, the likely vuggy nature of the reef sediments may cause drainage of some pore water during core cutting or potential transfer from aluminum to plastic liners, which may negatively affect the quality of electric resistivity and *P*-wave velocity measurements. Scientists should keep in mind that transfer of sediments from one liner type to another may change the core consistency and, thus, its physical properties.
- Core catcher (CC) description and sampling (if available) for initial sedimentologic, micropaleontological, petrophysical, and/or structural characterization, including potentially taking a CC image.
- Sampling and proper storage of samples for gas analyses.
- Acquisition and splitting of pore water samples where possible.
- Pore water geochemistry analysis and any other ephemeral properties agreed in the SMP.
- Core storage.

To deliver the scientific requirements on the platform with a subset of the science party, a staffing plan has been devised. The plan requires flexibility of approach from all participants, with priority given to safety, core recovery, curation, and procedures for the measurement of ephemeral properties.

Report preparation will take place on board as required; the reports to be compiled are as follows:

- Daily and weekly operational reports will be compiled by ESO and provided to the management and panels of ECORD and IODP, science party members, and any other relevant parties. Scientific reports are provided by the Co-Chief Scientists. Summarized daily reports will be publicly available on the ESO website for any interested parties.
- Completion of the offshore sections of the Expedition reports (primarily the Expedition 389 methods chapter, but also recording of initial results from offshore observations, measurements, and analyses) will be undertaken by offshore science party members and ESO staff.
- Press releases in line with ECORD outreach policy and information for posting on the ESO expedition website will be managed by the ESO Outreach Team.

8.2. Onshore science activities

The OSP will be held at the IODP BCR of MARUM at the University of Bremen, Germany. The scientific work will follow the SMP to be developed in conjunction with the Co-Chief Scientists. The majority of the scientific reporting for the expedition will also be undertaken during the OSP by science party members.

Details of the facilities that will be available for the OSP at the IODP BCR and MARUM laboratories can be found in the Expedition 389 SMP at **https://www.marum.de/en/Research/Exp..html**. Additional facilities can be made available through continuing close cooperation with additional laboratories at MARUM and the Department of Geosciences at the University of Bremen, all of which are situated nearby on campus.

The following briefly summarizes the OSP scientific activities (see **Appendix**):

- Prior to the OSP, thermal conductivity measurements will be taken on all cores (as appropriate) using a needle probe. Additional standard IODP physical properties measurements may be undertaken on whole cores at this time in the event offshore data sets are incomplete.
- Core splitting: the archive half will be set aside as per IODP procedure.
- Core description: ESO will provide a data entry system that is IODP standard. For data entry, ESO will employ the Expedition mobile Drilling Information System (mDIS) that is entirely compatible with others being used in IODP. See **Data management**.
- High-resolution digital imaging using a digital linescan camera system.
- Color reflectance spectrophotometry using a spectrophotometer.
- *P*-wave velocity will be measured on discrete samples using an MSCL Discrete *P*-Wave (MSCL-DPW) system.
- Moisture and density (MAD) will be measured on discrete samples using a pycnometer.
- Core sampling for expedition ("shipboard") samples (to produce IODP measurements data for the Expedition reports; e.g., petrophysical properties *P*-wave, and MAD analyses).
- Smear slide preparation (undertaken by sedimentologists and/or micropaleontologists at regular intervals as required).
- Thin section preparation (as requested).
- Biostratigraphy.
- Inorganic geochemistry (whole-rock and pore water chemistry) and organic geochemistry (total organic carbon).
- Bulk mineralogy: X-ray diffraction (XRD) analysis.
- Paleomagnetic measurements.
- Core sampling for personal postexpedition research: a detailed sampling plan will be devised after the scientists have submitted their revised sample requests following completion of the offshore phase (see **Research planning: sampling and data sharing strategy**). This will likely include whole-round samples for experimental postexpedition analysis, taken prior to splitting of the cores. Sample allocation will be determined by the Sample Allocation Committee (SAC; see below for further details);
- The inclusion of hyperspectral scanning measurements during the OSP is also under consideration to potentially facilitate mineralogical mapping of the cores and to assist sampling.

In view of the existing geographical distribution of all Deep Sea Drilling Project/Ocean Drilling Program/Integrated Ocean Drilling Program/IODP cores, it is currently understood that the IODP Gulf Coast Repository will be the long-term location for the Expedition 389 cores.

Report preparation will take place during the OSP as required by ECORD. The reports to be compiled include the following:

- Weekly progress reports to ECORD and relevant parties. Scientific reports are provided by the Co-Chief Scientists.
- Preliminary Report compiled by the science party (submission to *JOIDES Resolution* Science Operator [JRSO] Publication Services at the end of the OSP).
- The Expedition reports compiled by the science party (submission to JRSO Publication Services as soon as practically possible after the OSP).

For more information, please refer to the SMP at **https://www.marum.de/en/Research/Exp..html** and the online tutorial at **http://www.marum.de/en/Research/Onshore_Science_Party_OSP.html**.

8.3. Core scanning

Prior to the OSP, a single-beam X-ray computed tomography (CT) scanning program at the Core Scanning Facility (CSF) at the British Geological Survey (BGS) in the United Kingdom will take place to scan core recovered from the offshore phase of Expedition 389. Cores will be offloaded from the *MMA Valour* and shipped to the BGS at both the proposed midexpedition port call, and the final demobilization following the offshore phase at the beginning of November 2023. Scanning will take place in December 2023 and January 2024, and cores will then be transported to the

IODP BCR of MARUM at the University of Bremen for the OSP in February 2024. Ideally, all core recovered during the expedition will be scanned; however, depending on core recovery and time constraints, specific cores may be prioritized.

8.4. Staffing

Scientific staffing is determined on the basis of task requirements and nominations from the IODP Program Member Offices (**https://www.iodp.org/program-member-offices**). ESO staffing is based on the need to carry out the drilling and scientific operations safely and efficiently (Table **T3**).

8.5. Data management

A data management plan for the expedition will be developed once the data requirements and operational logistics are finalized. The outline plan is as follows:

- The primary data capture and management system will be the Expedition mDIS. This is a relational database, which will capture drilling, curation, and geoscience metadata and data during the offshore and onshore phases of the expedition.
- The Expedition mDIS includes tools for data input, visualization, report generation, and data export.
- The database can be accessed directly by other interpretation or decision-making applications if required.
- A file server will be used for the storage of data not captured in the database (e.g., documents and image files) and the inputs/outputs of any data processing, interpretation, and visualization applications used during the expedition.
- On completion of the offshore phase of the expedition, the Expedition mDIS database and the file system will be transferred to the BCR to continue data capture during the OSP.
- Between the end of the offshore phase and the start of the OSP, the expedition scientists will have access to the data via a password-protected website.
- On completion of the OSP, expedition scientists will continue to have access to all data through a password-protected website throughout the moratorium period.
- During the moratorium, all metadata and data will be transferred to PANGAEA for long-term archiving.
- The Petrophysics Staff Scientists will manage the MSCL data and other physical properties data.
- After the moratorium, cores and samples will be archived at the BCR (final decision pending).
- After the moratorium, all the expedition data will be made accessible to the public.

8.6. Outreach

The ECORD Outreach Task Force (EOTF) will be working to promote the expedition and the science generated by this investigation. As guidance, the EOTF produced a communications plan that will be distributed to the science party prior to sailing. The main objectives are as follows:

Table T3. Summary of science party and operator (ESO) personnel, Expedition 389.

	Science party	
ESO (9)	Offshore science team (10)	Expedition scientists (33)
1 ESO Operations Manager 2 ESO Expedition Project Managers (EPMs) 2 ESO Curators 1 ESO Geochemist 2 ESO Petrophysics Staff Scientists 1 ESO Data Manager	2 Co-Chief Scientists 2 sedimentologists 2 inorganic geochemists 2 physical properties specialists 1 coral specialist 1 microbiologist	Offshore and onshore science party members Co-Chief Scientists EPMs Petrophysics Staff Scientists
Offshore team total: 19		

- To interact positively with the media, nongovernmental organizations, governments, and the general public to demonstrate the benefits of the IODP Hawaiian Drowned Reefs scientific expedition and IODP in general, thus linking the scientific objectives and societal relevance;
- To maximize the expedition's publicity impact among scientists and a wider public;
- To ensure that all outreach is conducted in a consistent way;
- To promote scientific research in respect to the scientific goals;
- To strengthen links between the IODP/ECORD community and the international media; and
- To successfully continue the media relationships established during the previous eight ECORD MSP expeditions and other IODP expeditions.

To facilitate the above, there will be a number of outreach activities will be conducted throughout the expedition.

The following outreach activities will take place before the start of the Hawaiian Drowned Reefs expedition:

- Develop a detailed Communications Plan in close cooperation with Co-Chief Scientists and ECORD/ESO staff, especially the Expedition Project Managers;
- Produce and distribute an expedition flyer (**https://www.ecord.org/expedition389**).
- Produce a media pack on the ESO website, including the expedition's webpage and biographies of the Co-Chief Scientists and other science party members;
- Organize a media event prior or during a possible port call and/or an event for a general, local audience, stressing the societal relevance of the expedition on a local and global scale;
- Distribute an international media release in parallel with media event;
- Organize ship visits for the media during mobilization or during the port call in Hawaii, if possible;
- Prepare outreach documents for the science party, explaining their responsibilities and showing possibilities (i.e., different formats) on how to get involved;
- Produce a "Frequently Asked Questions" document to distribute to the science party;
- Produce a guide to social media to distribute to the science party and suggestions for potential blogs;
- Assess the possibility of having an Onboard Outreach Officer during the offshore phase and define tasks and possibilities;
- Network with participants' university media offices, particularly the Co-Chief Scientists' host organizations and other partners to maximize the audience for media relations; and
- Produce an official expedition logo for use on all promotional materials (finalized).

The following outreach activities will take place during the offshore phase of the Hawaiian Drowned Reefs expedition:

- Maintain daily/weekly expedition logbook on ESO website (coordinated by ESO Outreach Manager or nominated deputy);
- Publish media releases and/or news items (in the case of special events/findings and, if appropriate, at the end of the expedition);
- Organize video coverage of the working processes on board the expedition vessel (B-roll footage) to be collected by ESO staff, science party members, or an Onboard Outreach Officer when time allows;
- Promote the expedition through national and international media and organize interviews with Co-Chief Scientists and other science party members as necessary/requested;
- Promote social media blogs compiled by the science party, ESO members, or an Onboard Outreach Officer; and
- Work with Program Member Offices to promote the expedition through their channels (links have already been established with Australia-New Zealand IODP Consortium and U.S. Science Support Program).

It is possible that a hired Outreach Officer will sail for the first and/or second phase of the expedition to document activities and acquire footage and material for further outreach and educational activities, and they may also attend the OSP in February 2024.

The following outreach activities will take place during the OSP (February 2024):

- Prepare background material to provide to the media,
- Hold a media day toward the end of the OSP and invite key journalists and TV teams,
- Publish an international media release (tentative results),
- Facilitate involvement of science communicators for a portion of the OSP, where project appropriate, and
- Document activities with photos and video footage.

The following outreach activities will take place after the expedition:

- Promotion at international conferences (booths and talks) at, for example, the European Geosciences Union (EGU) and American Fall and Ocean Sciences Meetings;
- Promotion of the science through development of education resources in collaboration with science communicators and national organizations/visitor attractions and museums;
- General outreach to the media as scientific results of the expedition become available; and
- Continued logging of any outreach activities undertaken by any of the science party members including interviews, blogs, and abstracts submitted. ESO outreach team will depend on science party members to alert us to anything they do in addition to ESO setting up an Agility Alert for the expedition, which will scan all printed media globally.

9. Research planning: sampling and data sharing strategy

All researchers requesting samples should refer to the IODP Sample, Data, and Obligations Policy and Implementation Guidelines posted at **https://www.iodp.org/program-documents**. This document outlines the policy for distributing IODP samples and data to research scientists, curators, and educators. The document also defines the obligations that sample and data recipients incur. The SAC (composed of Co-Chief Scientists, Expedition Project Managers, and IODP Curator for Europe [BCR and MSPs] or offshore curatorial representative) will work with the entire science party to formulate an expedition-specific sampling plan for "shipboard" (expedition: offshore and OSP) and postexpedition (personal postexpedition research) sampling.

Members of the science party are expected to carry out scientific research for the expedition and publish it. Before the expedition, all members of the science party are required to submit research plans and associated sample/data requests via the IODP Sample, Data, and Research Request Manager (SDRM) system at **https://web.iodp.tamu.edu/sdrm** before the deadline specified in their invitation letters. Based on sample requests submitted by this deadline, the SAC will prepare a tentative sampling plan that can be revised on the ship and once cores are split as dictated by recovery and cruise objectives. All postexpedition research projects should provide scientific justification for desired sample size, numbers, and frequency. The sampling plan will be subject to modification depending upon the material recovered and collaborations that may evolve between scientists during the expedition. This planning process is necessary to coordinate the research to be conducted and to ensure that the scientific objectives are achieved. Modifications to the sampling plan and access to samples and data during the expedition and the 1 y postexpedition moratorium period require the approval of the SAC.

Offshore sampling will be restricted to that necessary for acquiring ephemeral data types that are critical to the overall objectives of the expedition and to preliminary lithologic and biostratigraphic sampling to aid decision making at sea and planning for the OSP.

All sample frequencies and volumes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the expedition objectives. Some redundancy of measurement is unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests.

If critical intervals are recovered, there may be considerable demand for samples from a limited amount of cored material. A sampling plan coordinated by the SAC will be required before critical intervals are sampled.

The SAC strongly encourages and may require collaboration and/or sharing among the shipboard and shore-based scientists so that the best use is made of the recovered core. Coordination of postexpedition analytical programs is anticipated to ensure that the full range of geochemical, isotopic, and physical properties studies are undertaken on a representative sample suite. The majority of sampling will take place at the OSP, and the SAC encourages scientists to start developing collaborations before and during the offshore phase of the expedition.

10. Acknowledgments

This publication was prepared by the authors using contributions provided by the proponents of IODP Proposal 716, ESO staff members, and the Drilling Contractor.

References

Berger, A., and Loutre, M.F., 1991. Insolation values for the climate of the last 10 million years. Quaternary Science Reviews, 10(4):297–317. **https://doi.org/10.1016/0277-3791(91)90033-Q**

Bosscher, H., and Schlager, W., 1992. Computer simulation of reef growth. Sedimentology, 39(3):503–512. **https://doi.org/10.1111/j.1365-3091.1992.tb02130.x**

Campbell, J.F., 1986. Subsidence rates for the Southeastern Hawaiian Islands determined from submerged terraces. Geo-Marine Letters, 6(3):139–146. **https://doi.org/10.1007/BF02238084**

Chappell, J., 2002. Sea level changes forced ice breakouts in the Last Glacial cycle: new results from coral terraces. Quaternary Science Reviews, 21(10):1229–1240. **https://doi.org/10.1016/S0277-3791(01)00141-X**

Clague, D.A., Hagstrum, J.T., Beeson, M.H., and Champion, D.E., 1999. Kilauea summit overflows: their ages and distribution in the Puna District, Hawai'i. Bulletin of Volcanology, 61(6):363–381. **https://doi.org/10.1007/s004450050279**

Clague, D.A., and Moore, J.G., 1991. Geology and petrology of Mahukona Volcano, Hawaii. Bulletin of Volcanology, 53(3):159–172. **https://doi.org/10.1007/BF00301227**

Clague, D.A., Reynolds, J. R., Maher, N., Hatcher, G., Danforth, W., and Gardner, J. V., 1998. High-resolution Simrad EM300 Multibeam surveys near the Hawaiian Islands: canyons, reefs, and landslides. Eos, Transactions of the American Geophysical Union, 79:F826.

Dai, A., Fyfe, J.C., Xie, S.-P., and Dai, X., 2015. Decadal modulation of global surface temperature by internal climate variability. Nature Climate Change, 5(6):555–559. **https://doi.org/10.1038/nclimate2605**

Dartnell, P., and Gardiner, J.V., 1999. Sea-floor images and data from multibeam surveys in San Francisco Bay, Southern California, Hawaii, the Gulf of Mexico, and Lake Tahoe, California-Nevada. U.S. Geological Survey Data Series. **https://doi.org/10.3133/ds55**

Galewsky, J., Silver, E.A., Gallup, C.D., Edwards, R.L., and Potts, D.C., 1996. Foredeep tectonics and carbonate platform dynamics in the Huon Gulf, Papua New Guinea. Geology, 24(9):819–822. **https://doi.org/10.1130/0091-7613(1996)024<0819:FTACPD>2.3.CO;2**

Hibbert, F.D., Rohling, E.J., Dutton, A., Williams, F.H., Chutcharavan, P.M., Zhao, C., and Tamisiea, M.E., 2016. Coral indicators of past sea-level change: a global repository of U-series dated benchmarks. Quaternary Science Reviews, 145:1–56. **https://doi.org/10.1016/j.quascirev.2016.04.019**

Humblet, M., and Webster, J.M., 2017. Coral community changes in the Great Barrier Reef in response to major environmental changes over glacial-interglacial timescales. Palaeogeography, Palaeoclimatology, Palaeoecology, 472:216–235. **https://doi.org/10.1016/j.palaeo.2017.02.003**

Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L., and Shackleton, N.J., 1984. The orbital theory of Pleistocene climate: support from a revised chronology of the marine $\delta^{18}O$ record. Proceedings of the NATO Advanced Research Workshop, 1984:269. **https://ui.adsabs.harvard.edu/abs/1984mcur.conf..269I**

Kavanaugh, M.T., Church, M.J., Davis, C.O., Karl, D.M., Letelier, R.M., and Doney, S.C., 2018. ALOHA from the edge: reconciling three decades of in situ Eulerian observations and geographic variability in the North Pacific subtropical gyre. Frontiers in Marine Science, 5. **https://doi.org/10.3389/fmars.2018.00130**

Köhler, P., Knorr, G., Stap, L.B., Ganopolski, A., de Boer, B., van de Wal, R.S.W., Barker, S., and Rüpke, L.H., 2018. The effect of obliquity-driven changes on paleoclimate sensitivity during the Late Pleistocene. Geophysical Research Letters, 45(13):6661–6671. **https://doi.org/10.1029/2018GL077717**

Lambeck, K., and Chappell, J., 2001. Sea level change through the last glacial cycle. Science, 292(5517):679–686. **https://doi.org/10.1126/science.1059549**

Lambeck, K., Esat, T.M., and Potter, E.-K., 2002. Links between climate and sea levels for the past three million years. Nature, 419(6903):199–206. **https://doi.org/10.1038/nature01089**

Lea, D.W., Martin, P.A., Pak, D.K., and Spero, H.J., 2002. Reconstructing a 350 ky history of sea level using planktonic Mg/Ca and oxygen isotope records from a Cocos Ridge core. Quaternary Science Reviews, 21(1):283–293. **https://doi.org/10.1016/S0277-3791(01)00081-6**

Lea, D.W., Pak, D.K., and Spero, H.J., 2003. Sea surface temperatures in the western equatorial Pacific during Marine Isotope Stage 11. In Droxler, A.W., Poore, R.Z., and Burckle, L.H. (Eds.), Earth's Climate and Orbital Eccentricity: The Marine Isotope Stage 11 Question. Geophysical Monograph, 137: 147–156. **https://doi.org/10.1029/137GM11**

Ludwig, K.R., Szabo, B.J., Moore, J.G., and Simmons, K.R., 1991. Crustal subsidence rate off Hawaii determined from $^{234}U/^{238}U$ ages of drowned coral reefs. Geology, 19(2):171–174. **https://doi.org/10.1130/0091-7613(1991)019<0171:CSROHD>2.3.CO;2**

MBARI Mapping Team, 2000. MBARI Hawaii Multibeam Survey, Digital Series No. 2. Monterey Bay Aquarium Research Institute. **https://www3.mbari.org/data/mapping/hawaii/index.htm**

Moore, J.G., and Clague, D.A., 1992. Volcano growth and evolution of the island of Hawaii. Geological Society of America Bulletin, 104(11):1471–1484. **https://doi.org/10.1130/0016-7606(1992)104%3C1471:VGAEOT%3E2.3.CO;2**

Moore, J.G., and Fornari, D.J., 1984. Drowned reefs as indicators of the rate of subsidence of the Island of Hawaii. The Journal of Geology, 92(6):752–759. **https://doi.org/10.1086/628910**

Moore, J.G., Ingram, B.L., Ludwig, K.R., and Clague, D.A., 1996. Coral ages and island subsidence, Hilo drill hole. Journal of Geophysical Research: Solid Earth, 101(B5):11599–11605. **https://doi.org/10.1029/95JB03215**

Moore, J.G., Normark, W.R., and Szabo, B.J., 1990. Reef growth and volcanism on the submarine southwest rift zone of Mauna Loa, Hawaii. Bulletin of Volcanology, 52(5):375–380. **https://doi.org/10.1007/BF00302049**

Puga-Bernabéu, Á., Webster, J.M., Braga, J.C., Clague, D.A., Dutton, A., Eggins, S., Fallon, S., Jacobsen, G., Paduan, J.B., and Potts, D.C., 2016. Morphology and evolution of drowned carbonate terraces during the last two interglacial cycles, off Hilo, NE Hawaii. Marine Geology, 371:57–81. **https://doi.org/10.1016/j.margeo.2015.10.016**

Riker-Coleman, K., Gallup C., Clague, D., Webster, J. M., Edwards, L., and Cheng, H., 2005. New ^{230}Th ages from the –400 m reef of northwestern Hawaii. Eos, Transactions of the American Geophysical Union, 86(52):PP21C-1574. **https://abstractsearch.agu.org/meetings/2005/FM/PP21C-1574.html**

Sanborn, K.L., Webster, J.M., Yokoyama, Y., Dutton, A., Braga, J.C., Clague, D.A., Paduan, J.B., Wagner, D., Rooney, J.J., and Hansen, J.R., 2017. New evidence of Hawaiian coral reef drowning in response to meltwater pulse-1A. Quaternary Science Reviews, 175:60–72. **https://doi.org/10.1016/j.quascirev.2017.08.022**

Schellmann, G., and Radtke, U., 2004. A revised morpho- and chronostratigraphy of the Late and Middle Pleistocene coral reef terraces on Southern Barbados (West Indies). Earth-Science Reviews, 64(3):157–187. **https://doi.org/10.1016/S0012-8252(03)00043-6**

Sharp, W.D., and Renne, P.R., 2005. The $^{40}Ar/^{39}Ar$ dating of core recovered by the Hawaii Scientific Drilling Project (phase 2), Hilo, Hawaii. Geochemistry, Geophysics, Geosystems, 6(4):Q04G17. **https://doi.org/10.1029/2004GC000846**

Smith, J.R., Satake, K., and Suyehiro, K., 2002. Deepwater multibeam sonar surveys along the southeastern Hawaiian ridge: guide to the CD-ROM. In Takahashi, E., Lipman, P.W., Garcia, M.O, Naka, J., and Aramaki, S. (Eds.), Hawaiian Volcanoes: Deep Underwater Perspectives. Geophysical Monography, 128: 3–9. **https://doi.org/10.1029/GM128p0003**

Szabo, B.J., and Moore, J.G., 1986. Age of -360-m reef terrace, Hawaii, and the rate of Late Pleistocene subsidence of the island. Geology, 14(11):967–968. **https://doi.org/10.1130/0091-7613(1986)14<967:AOMRTH>2.0.CO;2**

Taylor, B., 2019. Shoreline slope breaks revise understanding of Hawaiian shield volcanoes evolution. Geochemistry, Geophysics, Geosystems, 20(8):4025–4045. **https://doi.org/10.1029/2019GC008436**

Thompson, W.G., and Goldstein, S.L., 2005. Open-system coral ages reveal persistent suborbital sea-level cycles. Science, 308(5720):401–404. **https://doi.org/10.1126/science.1104035**

Watts, A.B., 1978. An analysis of isostasy in the world's oceans, 1. Hawaiian-Emperor Seamount Chain. Journal of Geophysical Research: Solid Earth, 83(B12):5989–6004. **https://doi.org/10.1029/JB083iB12p05989**

Webster, J.M., Braga, J.C., Clague, D.A., Gallup, C., Hein, J.R., Potts, D.C., Renema, W., Riding, R., Riker-Coleman, K., Silver, E., and Wallace, L.M., 2009. Coral reef evolution on rapidly subsiding margins. Global and Planetary Change, 66(1–2):129–148. **https://doi.org/10.1016/j.gloplacha.2008.07.010**

Webster, J.M., Clague, D.A., Riker-Coleman, K., Gallup, C., Braga, J.C., Potts, D., Moore, J.G., Winterer, E.L., and Paull, C.K., 2004a. Drowning of the -150m reef off Hawaii: a casualty of global meltwater pulse 1A? Geology, 32(3):249–252. **https://doi.org/10.1130/G20170.1**

Webster, J.M., and Davies, P.J., 2003. Coral variation in two deep drill cores: significance for the Pleistocene development of the Great Barrier Reef. Sedimentary Geology, 159(1–2):61–80. **https://doi.org/10.1016/S0037-0738(03)00095-2**

Webster, J.M., Wallace, L., Silver, E., Potts, D., Braga, J.C., Renema, W., Riker-Coleman, K., and Gallup, C., 2004b. Coralgal composition of drowned carbonate platforms in the Huon Gulf, Papua New Guinea; implications for lowstand reef development and drowning. Marine Geology, 204(1):59–89. **https://doi.org/10.1016/S0025-3227(03)00356-6**

Webster, J.M., Wallace, L.M., Clague, D.A., and Braga, J.C., 2007. Numerical modeling of the growth and drowning of Hawaiian coral reefs during the last two glacial cycles (0–250 kyr). Geochemistry, Geophysics, Geosystems, 8(3):Q03011. **https://doi.org/10.1029/2006GC001415**

Woodroffe, C.D., and Webster, J.M., 2014. Coral reefs and sea-level change. Marine Geology, 352:248–267. **https://doi.org/10.1016/j.margeo.2013.12.006**

Yokoyama, Y., Esat, T.M., and Lambeck, K., 2001. Coupled climate and sea-level changes deduced from Huon Peninsula coral terraces of the last ice age. Earth and Planetary Science Letters, 193(3):579–587. **https://doi.org/10.1016/S0012-821X(01)00515-5**

Yokoyama, Y., Esat, T.M., Thompson, W.G., Thomas, A.L., Webster, J.M., Miyairi, Y., Sawada, C., Aze, T., Matsuzaki, H., Okuno, J., Fallon, S., Braga, J.-C., Humblet, M., Iryu, Y., Potts, D.C., Fujita, K., Suzuki, A., and Kan, H., 2018. Rapid glaciation and a two-step sea level plunge into the Last Glacial Maximum. Nature, 559(7715):603–607. **https://doi.org/10.1038/s41586-018-0335-4**

Yokoyama, Y., Lambeck, K., De Deckker, P., Esat, T.M., Webster, J.M., and Nakada, M., 2022. Towards solving the missing ice problem and the importance of rigorous model data comparisons. Nature Communications, 13(1):6261. **https://doi.org/10.1038/s41467-022-33952-z**

Appendix

Sampling and measurement plan

This plan was discussed and agreed on with the Co-Chief Scientists. Nevertheless, this plan is subject to amendment according to the scientific needs and interests of the science party or operational constraints. The most pressing operational constraint during the offshore period is likely to be space, even with containers being located on the deck level. To minimize core transit between containers, the core flow scheme below has been devised.

Offshore sampling and analysis

Please see **https://www.marum.de/en/Research/Offshore_core_curation_and_measurements.html** in addition to the text and diagrams below.

Core curation

There will be a core curation laboratory container on board the drilling vessel, supervised by the Chief Curator. A second curator will cover the opposite shift. The curators will have delegated responsibility in the absence of the ESO Curation Manager and IODP Curator Dr Ursula Röhl. Two core storage containers (reefers) will be on the drilling vessel; one will be discharged at the midway port call to allow the collected core to be shipped to the UK for CT scanning. There will be no splitting of the cores at sea because it will be more efficient to carry out most of the following scientific analysis during the OSP in Bremen.

Because the cores will be collected in a polycarbonate liner or an aluminum liner (before being transferred to a polycarbonate liner on the drill floor), the usual IODP curation procedures will be followed (please also refer to **https://www.marum.de/en/Core_curation.html**). Aluminum liners will only be used if collection in a polycarbonate liner detrimentally affects core recovery. The core will be cut on board into 1.5 m lengths and curated.

It has been noted that it is important to store coral in dry conditions to avoid growth of fungi and bacteria that can develop in coral skeletons, resulting in the strong possibility of alteration to the original geochemical signals.

Lithologic and macropaleontological description

Core catcher samples will be collected, split, and labeled, and the working half will be handed over for lithologic and macropaleontological description. If no core catcher is collected, a sample from the lower end of the section can be taken for shipboard lithologic and macropaleontological analysis. If the lower end of the core is a massive coral, no sample will be cut off of the core.

Offshore core flow

The offshore core flow is shown in Figure **AF1**.

Inorganic geochemistry

No major mud sequences are expected to be encountered at the proposed drill sites. Site survey cruises indicate that potentially some minor sequences of carbonate-rich and possibly hemipelagic sediment are expected. However, if suitable material is recovered, pore water sampling will be conducted for fluid chemistry/circulation studies. In this case, pore water should be extracted immediately from a core sample, and ephemeral properties such as salinity, alkalinity, and ammonia will be analyzed immediately (**https://www.marum.de/en/Research/Interstitial_pore_waters_IW.html**).

Depending on the parameter, the interstitial water sample might be specially treated to conserve it for later analyses.

Microbiology

There is no microbiological sampling planned during the offshore phase.

Offshore petrophysics measurements (core logging)

Cores will be logged on the drilling vessel in a modified 20 ft container, housing a single MSCL track comprising one magnetic susceptibility loop, gamma density, natural gamma radiation, *P*-

wave velocity, and electrical resistivity sensors (**https://www.marum.de/en/Research/Physical_Properties.html**). The single core logger system will include a full spares kit.

All temperature-equilibrated core log data acquired at sea will provide QC/QA checks when compared to repeat measurements planned for the OSP.

Onshore sampling and analysis

Onshore core flow

The onshore core flow is shown in Figure **AF2**.

Location

After due consideration, it has been decided that there will be no splitting of the cores at sea. The OSP will be undertaken at the IODP BCR of MARUM at the University of Bremen, Germany, in combination with access to the laboratories at MARUM and the Department of Geosciences.

Planned analysis and available facilities

The following facilities will be available for the expedition scientists at the BCR (please refer to the online tutorial at **https://www.marum.de/en/Research/Onshore_Science_Party_OSP.html**); note that it is not considered prudent to transport all of these facilities onto a drilling vessel:

- X-ray CT scanning prior to the OSP at the BGS Core Scanning Facility. Depending on offshore core recovery, either all core recovered will be scanned or selected priority cores/intervals.
- Thermal conductivity measurements will be taken on all cores (as appropriate) using a needle probe.

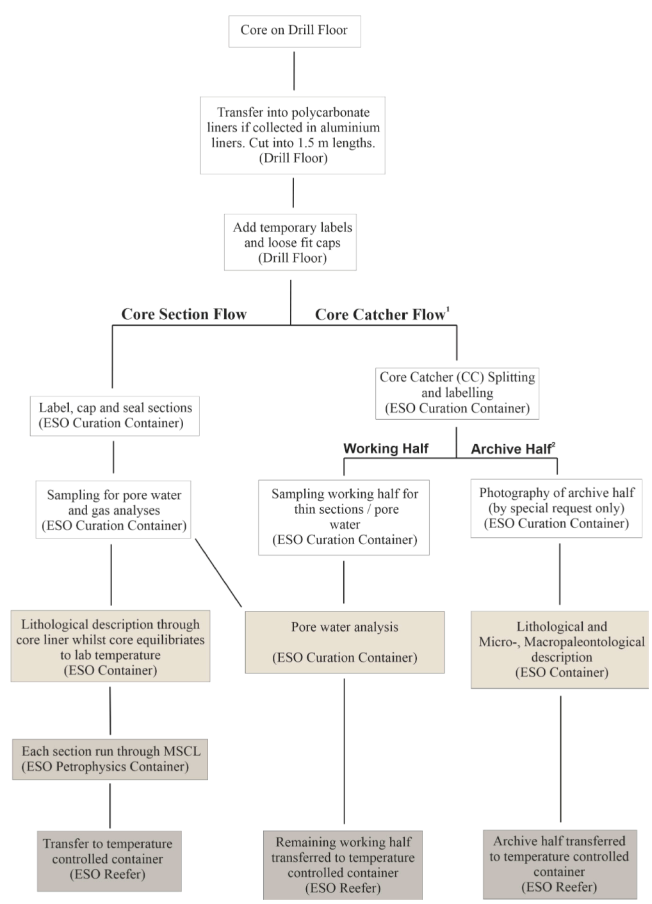

Figure AF1. Offshore core flow, Expedition 389. 1 = if no core catcher is collected, a sample from lower end of section can be taken for shipboard lithologic and macropaleontological analysis; if lower end of core is a massive coral, no sample will be cut off of the core. 2 = depending on core catcher length, additional material from archive half of core catcher can be used for shipboard lithologic description and preliminary shore-based studies.

- Core splitting: an archive half will be set aside as per IODP policy.
- Core description: ESO will provide a system that is IODP standard. For data entry, ESO will employ the mDIS that is entirely compatible with others being used in IODP (see **Data management**).
- Core linescanning on a routine basis.
- Core sampling: a detailed sampling plan will be devised at the completion of the offshore (and CT scanning) phase and after the scientists have submitted their revised sample requests.
- Thin section and smear slide preparation (as requested): preparation, description, and interpretation.
- Microscopy: microscope laboratory (with hood for sample preparation if acids need to be applied).
- Inorganic geochemistry: whole-rock and pore water chemistry; inductively coupled plasma–mass spectrometry and ion chromatography (pore water); X-ray fluorescence, carbonate, and total organic carbon content (Leco) (whole rock).
- XRD analysis: bulk mineralogy (e.g., carbonate mineralogy on a set of selected samples).
- Petrophysical measurements:
  - Physical properties of discrete samples (moisture/sample density): determination of index properties (*P*-wave velocity, wet bulk density, grain density, porosity, and void ratio). Following IODP procedure, core samples will be oven-dried, the dried sample volume will be quantified using a Quantachrome pentapycnometer, and masses will be measured using a high-precision balance.
  - Color reflectance measurements (Minolta spectrophotometer).
  - The inclusion of hyperspectral measurements is under consideration to facilitate mineralogical mapping of the cores and to assist sampling.
  - Digital linescan camera on split core MSCL track.

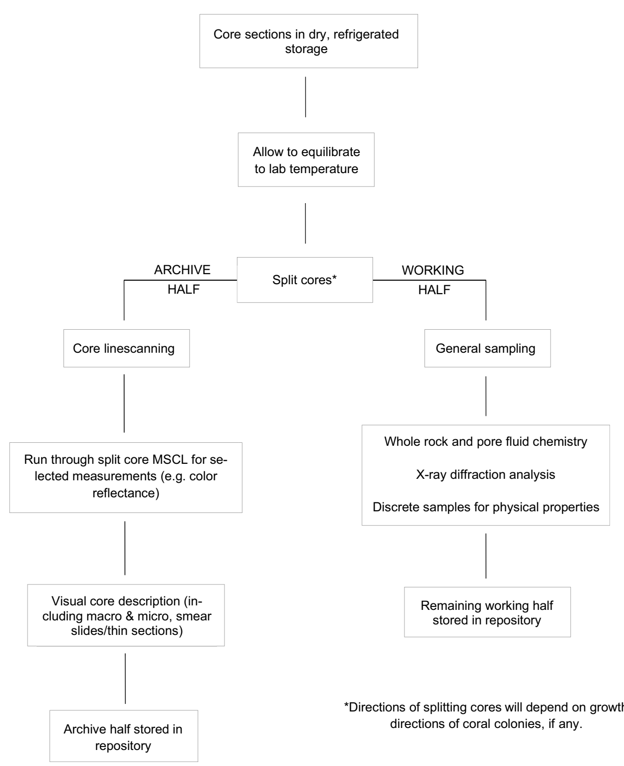

Figure AF2. Onshore core flow, Expedition 389.