U.S. SCIENCE SUPPORT PROGRAM

WORKSHOP REPORT:

Targeting Pacific Highs for Past Records of Warm Climates

October 1 – 4, 2024

Franz Theodore Stone Laboratory, Put-in-bay, Ohio, U.S.A.

Steering Committee:
Elizabeth M. Griffith, Bärbel Hönisch, Donald Penman, William Sager, Thomas Westerhold, and James Zachos

Photo Credit: Will Sager

IODP INTERNATIONAL OCEAN DISCOVERY PROGRAM

ECORD European Consortium for Ocean Research Drilling

JAMSTEC

Australian and New Zealand International Scientific Drilling Consortium

Workshop participants: 1 Will Sager, 2 Julio Sepúlveda, 3 Chris Lowery, 4 Kelsey Doiron, 5 Lucien Nana Yobo, 6 Brian Huber, 7 Kevin Konrad, 8 Victoria Taylor, 9 Ken MacLeod, 10 Pratigya Polissar, 11 Batoul Saad, 12 Thomas Westerhold, 13 Dustin Harper, 14 Elizabeth Sibert, 15 Bärbel Hönisch, 16 Brittany Hupp, 17 Alexandra Villa, 18 Yi Wang, 19 Don Penman, 20 Shamar Chin, 21 Adriane Lam, 22 Sietske Batenburg, 23 Serena Dameron, 24 Junichiro Kuroda, 25 Chijun Sun, 26 Maureen Walczak, 27 Liz Griffith. Not in the photo: Shannon Haynes (in person), Tali Babila (in person), Jim Zachos (remote), Christina Ravelo (remote), Catherine Davis (remote), Yuhao Dai (remote), Flavia Boscolo-Glazzo (remote), Chiara Borrelli (remote), Jesse Farmer (remote), Mitch Lyle (remote), Sandy Kirtland-Turner (remote), Simon Brassell (remote), Peter Davidson (remote), Halima Ibrahim (remote), Neil C. Mitchell (remote), Rebecca Robinson (remote), Torben Struve (remote), Yunlang Zhang (remote).

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Executive Summary

The USSSP workshop "Targeting Pacific Highs for Past Records of Warm Climates" was held at Stone Lab on Gibraltar Island in Lake Erie, Ohio from October 1-4, 2024, with a hybrid modality for remote participants through Zoom. It brought together multidisciplinary scientists from the United States, Europe, Japan, and Australia to identify existing material and consider how to obtain new material critical for deploying novel proxies and methods that have the potential to advance our understanding of ocean dynamics and changes in marine ecosystems during periods characterized by elevated atmospheric CO_2, ocean deoxygenation and ocean acidification. A more detailed understanding of ocean conditions throughout the Pacific Ocean, the largest and deepest ocean basin with some of the oldest seafloor dating back to 200 million years ago, is key to probing the stability of past warm climates, resilience of biota during climate disruptions, and evolution of climate sensitivity to various forcings, including changes in ocean productivity and carbon storage.

Marine sediment archives from Pacific Highs provide a unique opportunity to recover potentially high-resolution and well-preserved sediments even during peak warming and ocean acidification events. However, many Pacific Highs have not been revisited since they were first spot-cored using rotary drilling with limited recovery during the first phase of scientific ocean drilling (Deep Sea Drilling Program from 1968 to 1983). During the workshop, it became clear that due to the sparse coverage of drilled sites and the state of the core material recovered in the region, key spatial gaps remain to test current ocean models of past warm climate dynamics. New records are needed to advance our understanding of the Pacific's role in regulation of the global carbon cycle, if and how the storage of carbon has fluctuated during short term disruptions, and how fast the system recovered.

Workshop participants outlined three "core repository expeditions" that will reexamine existing core materials from Pacific Highs: Neogene pelagic sediment drapes on and near Pacific Guyots, Eocene Pacific latitudinal transect, and Cretaceous Pacific Records. These proposals will attempt to address key scientific questions in the Pacific using existing core material and identify where critical gaps exist. This work directly contributes to Flagship Initiative 1 "*Ground truthing future climate change*" and Flagship Initiative 4 "*Diagnosing ocean health*" from the 2050 Science Framework. Additional scientific questions that might be addressed with seismic surveys in the region focused on Pacific large igneous province (LIP) volcanism in space and time were also proposed by workshop participants related to Flagship Initiative 2 "*Probing deep Earth*".

As we enter a new era of scientific ocean drilling with the end of the International Ocean Discovery Program, it is critical for the scientific ocean drilling community to continue engaging with a diverse group of researchers invested in the future of scientific ocean drilling research. This workshop is one such example of the investment necessary to build international communities around shared research questions and find solutions to investigate existing core material and acquire new core material. We must not forget the *Enduring Principles* critical to the past success of scientific ocean drilling as articulated in the 2050 Science Framework. Workshop participants discussed the importance of embracing these principles moving into the new era of scientific ocean drilling – including "collaborative and inclusive international

programs", "transparent regional planning", "open access to samples and data", "enhancing diversity", and "bottom-up proposal submissions and peer review".

1. Workshop Rationale

The workshop sought to lay out strategies to study, retrieve, and expand paleoclimatic archives of past, warmer-than-today climate intervals, contributing to Flagship Initiative 1, "*Ground truthing future climate change*," and Flagship Initiative 4, "*Diagnosing ocean health*" from the 2050 Science Framework. A more detailed understanding and better geographic coverage of past conditions throughout the Pacific, which is the oldest and largest of the major ocean basins on our planet (**Figure 1**), is key to improving our understanding of past warm climates dynamics, the resilience and structure of marine ecosystems during warm climate states and climate perturbations, as well as the evolution of mean climate sensitivity through time and in response to various forcings, including changes in ocean productivity and carbon storage. "The Pacific Ocean ... is a fundamental component of global heat transport and circulation, the dominant locus of primary productivity, and consequently, the largest reservoir for carbon exchange between the oceans and the atmosphere" (Lyle et al., 2008) and thus essential to our understanding of the Earth's climate system.

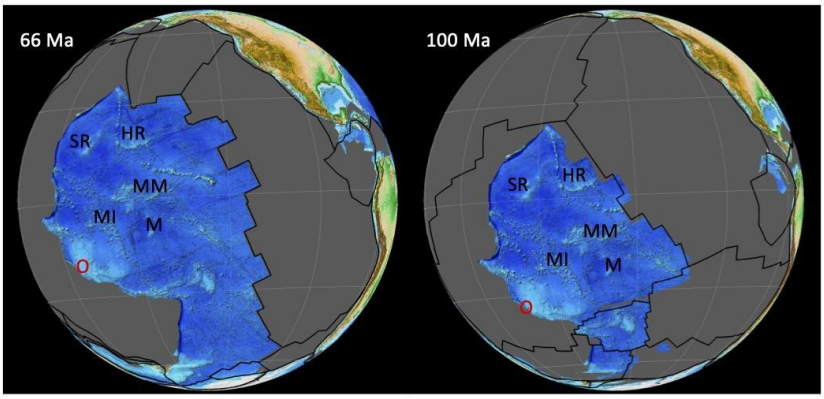


Figure 1. *Reconstruction of the Pacific Ocean seafloor (and locations of ocean plateaus and highs) at 100 Ma and 66 Ma, created using GPlates (Müller et al., 2018). Pacific Highs indicated: Shatsky Rise (SR), Hess Rise (HR), Mid-Pacific Mountains (MM), Magellan Rise (M), and Marshall Islands (MI). Red "O": Ontong Java Plateau. Figure credit: Westerhold*

The focus of the workshop was to build communities around shared research questions that could be addressed by reexamining available sediments and by developing new expedition proposals targeting Pacific Highs such as the Mid-Pacific Mountains. Unconsolidated 100 to 200 meters of pelagic sediment drape deposits carpeting shallow tropical to temperate plateaus (<2km water depth) provide high-resolution windows of time across past warm climates. At these shallow depths, carbonate sediments can be well preserved even during peak warming and ocean acidification events, when the carbonate compensation depth (CCD) shoaled, leaving deeper sediment deposits devoid of calcareous microfossils, which are critical to reconstructing past environmental changes.

Due to the end of the International Ocean Discovery Program (IODP) this year and the non-renewal of the cooperative agreement with Texas A&M University for operations and maintenance of the drilling vessel *JOIDES Resolution*, this workshop considered expanding the use of existing core material as well as a wide range of alternate or mission-specific scientific ocean drilling platforms, including sea-floor drill rigs that can safely operate in 2 km of water depth. During this time of transition as IODP has ended, it is critical to foster discussions within the community of scientists working on deep ocean sediments, including researchers at different

career stages. The workshop provided an opportunity to welcome new scientists into the ocean drilling community to discuss future strategies for scientific ocean drilling. The impact of such efforts covers a range of topics of broad interest to society, including improving climate models, assessing future ocean health, and inspiring future generations through ocean exploration and discovery in alignment with the 2050 Science Framework.

2. Workshop Objectives

1. Identify key scientific questions for past warm climates and targets of analysis that can be addressed by both re-examining existing core material recovered from locations on Pacific Highs and acquiring new material.
2. Develop a list of locations that are essential targets to re-examine existing core material in the three IODP core repositories and to recover new sediment cores that can provide answers to these key scientific questions.
3. Outline proposal(s) and strategies to investigate existing core material and successfully recover new material – including identifying the required drilling platforms (e.g., sea-bed drill rig type expeditions) – and support these and future efforts given the changing landscape of scientific ocean drilling.
4. Draft a white paper that summarizes the workshop findings to coordinate efforts with the global scientific ocean drilling community and lay a road map for making progress towards answering the key scientific questions and approaches.

3. Workshop Outcomes

3.1 Defining key scientific questions for the Pacific

Ground truthing climate change and evaluating marine ecosystems response to climate and ocean change now is of highest societal relevance. The Cretaceous and Cenozoic warm climates do provide the Greenhouse test cases for climate models, which mostly have been focused over more recent times from the Last Glacial Maximum to Holocene. Establishing long and short-term variations in ocean circulation over the Cretaceous and Cenozoic can help to understand related tipping points in the Earth's climate system, if the overturning circulation is sensitive to planetary changes in temperature gradients, and if bottom water ever formed in the Pacific region in warmer periods.

Due to the size of the Pacific, it is pivotal to establish the role of this major ocean basin in regulation of the global carbon cycle, if and how the storage of carbon has fluctuated during short term disruptions, and how fast the system recovered. Key here will be geological archives to reconstruct if changes in overturning circulation affected nutrients and oxygen distribution enhancing warming or cooling effects, and thus the biological communities. Deep sea records recovered by scientific drilling can play a major role in understanding how the ocean changes will impact future society.

Specifically, the following questions were identified by the workshop participants as being key scientific questions that should be addressed by future initiatives targeting Pacific Highs:

A. Cretaceous-Cenozoic warm climate dynamics

- How warm was the tropical and subtropical Pacific? How did the latitudinal temperature gradient differ in the Pacific across past warm periods relative to today?
- What was the impact of warm and extremely warm conditions on the intensity and patterns of surface to deep ocean circulation? How did this affect carbon storage in the Pacific?
- What was the impact of opening major ocean gateways on climate, ocean circulation, and deposition of organic and carbonate-rich sediments in the Pacific? To what extent did this control regional and global warming?

B. Evolution of climate sensitivity and carbon cycle feedbacks

- How sensitive was the climate to past CO_2 levels of 500 to 1000 ppm and more? Did climate sensitivity change in intervals when CO_2 levels were stationary?
- How productive was the Pacific surface ocean across major climate perturbations and transitions? How did transient warming events affect productivity?
- How effective was remineralization of carbon in warmer oceans and did it change during transient warming events? Which are the key carbon cycle feedbacks in a warmer ocean and how are they affected by ecosystem disruption?

C. Resilience of marine biota during Cretaceous-Cenozoic warm climates

- How do marine ecosystems respond to ≥1.5–3°C warming events? What are the rates of such biotic reactions and ecosystem recovery?
- How do ocean anoxia and acidification affect the origination, extinction, composition, and diversity of planktic and benthic assemblages in the Pacific?
- What processes led to recovery of organisms and biotic communities after climatic perturbations in the Pacific?

D. Evolution of Pacific Ocean large igneous province (LIP) volcanism in space and time

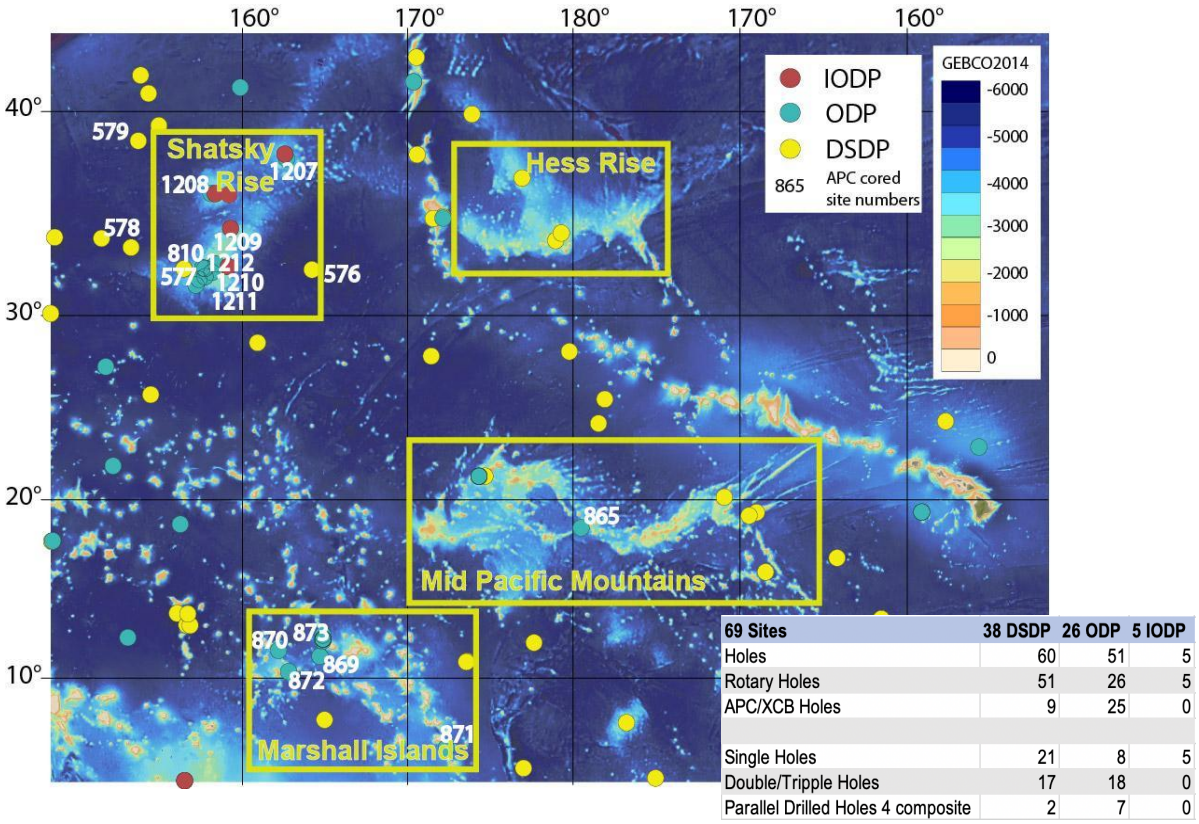
- Which oceanic plateaus in the Mid-Pacific represent true LIPs with environmental impacts versus oceanic mid-plate superstructures built over long time periods?
- What was the duration of LIP volcanism?
- What is the origin of widespread volcanic deposits found within Pacific sediments and do they have a warming or cooling effect on climate?
- What drives secondary volcanic eruptions (e.g., post-erosional cones and ridges associated with LIPs)? Are they related to distinct mantle source reservoirs and degrees of mantle melting?

3.2 Identifying future pathways for scientific ocean drilling research in the Pacific

Workshop participants discussed the need to consider:

- Why do we need to investigate existing or drill new sediments from Pacific Highs? Why are these locations necessary?
- What will be the benefit and added value for a better understanding of the climate system using these records?
- What types of material and which drilling platforms are needed (and where) to address the scientific questions? What is known about specific locations and is new seismic survey data needed to develop a full drilling proposal?
- How can we create synergy with other 2050 Science Framework initiatives? And ties to the National Academies Report on "Progress and Priorities in Ocean Drilling" (NASEM, 2024)?

A key thread through the discussions was considering whether sampling/investigation of legacy assets was sufficient or if there was a need to drill new cores (in specific locations) for critical intervals such as the Cenomanian/Turonian boundary, the Aptian/Albian boundary, the Eocene global warming events, the Early Eocene including the PETM and the aftermath, the Eocene/Oligocene Transition, and the Miocene Climate Optimum. It became clear during the discussion that the existing cores (**Figure 2**) can only provide rudimentary records to help establish changes in the Pacific circulation and carbon cycle regulation, for example Pacific to Atlantic geochemical gradients (e.g., carbon isotopes, nutrients, neodymium isotopes). Most of the cores from the regions investigated in the workshop were recovered by rotary drilling in the 1970's and 1980's. As a result, many of these cores do not provide the continuous sequences required for high resolution studies, but they do provide key information on sediment type and age, and the means to rigorously test the suitability of the sediment for state-of-the art geochemical investigations and to help determine future drilling targets. Due to the sparse coverage of drilled sites in the region key spatial gaps do remain, where ocean models could be used to identify key (missing) locations needed to retrieve new material to test their results and predictions. Near future platform options for ocean drilling expeditions in the new International Ocean Drilling Programme-3 (IODP[3] set to begin in January 2025 with ECORD and Japan) are MSP and the Japanese D/V *Chikyu*. China is also currently testing its first ocean drilling vessel *Mengxiang*, which means "dream" in Chinese.



69 Sites	38 DSDP	26 ODP	5 IODP
Holes	60	51	5
Rotary Holes	51	26	5
APC/XCB Holes	9	25	0
Single Holes	21	8	5
Double/Tripple Holes	17	18	0
Parallel Drilled Holes 4 composite	2	7	0

Figure 2. *Bathymetric map with Pacific Highs that were discussed at the workshop. Ocean drilling sites indicated with symbols (see legend) with site numbers labeled only for those recovered using advanced piston coring (APC). Table summarizing sites in the region drilled. Note that the last two phases of IODP recovered no cores for paleoceanographic research, i.e., double or triple holes for composite records. Figure credit: Westerhold.*

To address the key scientific questions above and find solutions to investigate existing core and acquire new core requires different approaches that are possible and realistic in the immediate/short-term (through 2026), mid-term (through 2030), and longer- term (through 2035 and beyond). These include the following:

A. ***Immediate/Short-term (next 2 years)*** - investigate the potential of legacy cores by targeted "core repository expeditions", investigate the potential of mission specific platform (MSP) expeditions targeting Pacific Highs with seabed drills using existing seismic data sufficient for interpretation, and investigate the potential to propose a D/V *Chikyu* expedition in the Shatsky Rise region.

B. ***Mid-term (next 5 years)*** - define exploratory missions that use spot cored DSDP and ODP information to collect new bathymetric and seismic data, as well as targeted surface sediment samples to determine the age of reflectors. Those survey missions should target locations that will be used to later develop proposals for a variety of drilling options including MSP with seabed lander drilling (shallower targets), giant piston coring for deeper targets, and use of liftboats for shallower-water targets.

C. ***Longer-term (next 10 years)*** - develop a critical number of drilling proposals in the Pacific that require a riserless drilling research vessel (e.g., multiple holes drilled at multiple sites with non-magnetic core barrel advanced piston coring; basement drilling). These expeditions will require that we first (current action) define where additional seismic surveys are necessary and write survey proposals to be conducted within the next ~5 years. Of particular importance is seismic characterization of chert, which causes poor recovery with present coring techniques. Site characterization surveys may include dredging to obtain age of basalt, piston coring for recovery and characterization of sedimentary packages, and near-surface sampling by lander or seafloor drill.

3.3 Outlining and planning for writing proposals

The following pre-proposals were outlined at the workshop by participants (**Appendix A**), and plans were made to develop these into full proposals. These pre-proposals include different approaches outlined previously that are possible in the immediate/short-term (through 2026), mid-term (through 2030), and longer-term (through 2035 and beyond).

The workshop identified the following three "core repository expeditions" (CRE) that should include scanning cores using updated instrumentation, revising the biostratigraphic zonations, obtaining geochemical data and physical properties data, redoing sedimentological descriptions, imaging the archive half, etc., as well as sampling cores for pilot studies to investigate potential of legacy material. Funding for the three CRE is envisaged to be covered by complementary 3 U.S. NSF and 3 IODP[3] Scientific Projects using Ocean Drilling ARChives (SPARCs) proposals to assure international participation and collaboration.

CRE Neogene pelagic sediment drapes on and near Pacific Guyots
Leads**:** Farmer, Griffith, Lam, Taylor, Westerhold
Target: Neogene pelagic drapes
Locations: **Marshall Islands**: Limalok Guyot (ODP Holes 871A,B,C), Lo-En Guyot (ODP Holes 872A,C), Wodejebato Guyot (ODP Hole 873B); **Western Mid-Pacific Mountains**: Resolution Guyot (DSDP Site 463, ODP Site 866); **Eastern Mid-Pacific Mountains:** Horizon Guyot (DSDP Sites 171, 313)

Science objectives: Update age models and take test samples to investigate if biological pump, ocean oxygenation, ocean alkalinity can be reconstructed by well-preserved microfossils. Investigate the potential to redrill areas using lander/seabed drilling to get more continuous sediment recovery in these top sediment drapes drilling multiple holes similar to what was done at ODP Site 865 on Allison Guyot.

CRE Eocene Pacific latitudinal transect

Leads**:** Borrelli, Boscolo-Galazzo, Griffith, Hupp, Taylor, Westerhold
Target: Eocene sediments on Pacific Highs
Locations: **Manihiki Plateau** (DSDP Site 317), **Magellan Rise** (DSDP Site 167), **Marshall Islands** (ODP Sites 871, 872, 873), **Mid Pacific Mountains** (ODP Site 865), **Shatsky Rise** (ODP Leg 198)
Science objectives: Update/confirm age models and take pilot samples to investigate the potential to reconstruct paleoceanographic and biotic changes, carbon cycle feedbacks and pCO_2. Investigate the potential to redrill areas using MSP and/or riserless drilling vessel to get better (continuous) recovery of transient climate perturbations during the Eocene.

CRE Cretaceous Pacific records

Leads**:** Griffith, Lam, Nana Yobo, Taylor, Wang, Westerhold
Target: Cretaceous sediments on Pacific Highs
Locations: **Resolution Guyot** (DSDP Site 463), **Magellan Rise** (DSDP Site 167), **Shatsky Rise** (IODP Site U1348 Tamu Massif, ODP Sites 1207 Shirshov Massif and 1208 Ori Massif)
Science objectives: Exploration of what is available in the Pacific, what more can be done with the existing material. Update/confirm age models and take test samples to evaluate potential for proxy-based paleoclimate reconstructions. Evaluating the potential to develop riserless drilling proposals and D/V *Chikyu* redrill of Shatsky Rise Paleogene and Cretaceous.

Related to the CREs outlined above, the following exploratory **site seismic survey missions** are currently planned:

- Funded seismic survey of eastern **Mid Pacific Mountains** Horizon Guyot (DSDP Site 171), western **Mid Pacific Mountains** Resolution Guyot (DSDP Site 463), and the **Emperor seamount chain** Colahan Guyot, Abbott Guyot, Yuriyaku Guyot, Koko Guyot; CARAPACE: Calcite-Aragonite transition Across Pacific Atolls from the Cretaceous to the Eocene, PI Cedric M. John (UK) – 40 days seismic survey; reconstruct the evolution, internal geometry and response to eustasy of shallow-water carbonates from the Cretaceous to the Eocene or early Cenozoic
- Seismic survey proposal **Magellan Rise** (DSDP Site 167), PI Junichiro Kuroda (Japan) submitted November 2024
- Seismic survey proposal Eastern to mid **Mid-Pacific Mountains** (DSDP Site 313, ODP Site 865), PI Thomas Westerhold (Germany) to be submitted fall 2025
  Objectives: survey area for middle Miocene to Early Eocene, and down to Maastrichtian aged sediments; monitor flanks of mountains for flow structures
- Seismic survey proposal Southern **Hess Rise** Mellish Bank (DSDP Sites 465 and 466), PI Thomas Westerhold (Germany) to be submitted fall 2025
  Objectives: survey area for Paleocene, K/Pg boundary, Maastrichtian and older (Santonian); monitor flow along southern rim of the bank

During the workshop the following **drilling expedition proposal opportunity with the D/V *Chikyu* drilling Shatsky Rise** was developed and will be pursued:

An expedition proposal is currently being prepared by PIs Yasukawa and Tanaka (Japan) for IODP^3 to target Cretaceous sediments on southern Shatsky Rise. During the workshop, a plan was developed to propose a back-to-back expedition to drill the Cenozoic to late Cretaceous on Shatsky Rise for more complete recovery using existing extensive seismic data as in Clark et al. (2018). Shamar Chin (University of Iowa) will act as lead PI for the U.S. led proposal targeting the Cenozoic to late Cretaceous. Coordinated between PIs Yasukawa and Tanaka and the workshop team both IODP^3 (Kuroda, Westerhold) and SODCO (U.S.) should be approached for advice. Although there are still operational barriers and difficulties to overcome to make feasible drilling on the Shatsky Rise (and other Pacific Highs) using D/V *Chikyu*, potential proponents will continue to work with the platform provider to explore the feasibility of drilling on the Pacific Highs.

Proposed Targets and Objectives:

- Redrill IODP Site U1348, which has well-preserved calcareous microfossils (Ando et al., 2013) in the Santonian, Coniacian and Aptian, at a site about 40 km to the south of Site U1348 where a more complete Cretaceous record can be recovered and weak reflectors indicate possibly fewer cherts. The new site is expected to yield about 200 m of Cenozoic without cherts and about 300 m of Cretaceous sediments.
- Redrill Shirshov Massif, ODP Site 1207 in 3103 m water depth to recover an expanded ~160 m Neogene section. Only a single hole from this site was drilled for this interval. Recovery of deeper sediments should be attempted to retrieve Campanian to Albian records, including Ocean Anoxic Event (OAE) 1a and OAE2 as well as the Aptian/Albian boundary at ~500 m.
- Redrill of Ori Massif, ODP Site 1208 in 3346 m water depth to recover a triple APC cored 320 m thick expanded Neogene section. Only a single hole from this site was drilled during Leg 198. Triple-coring the site will obtain sediments that will provide insights into Neogene climate analogues during times when Earth's background warming was ≥1.5–3°C higher than background temperatures.

Finally, the following target areas and time intervals for developing new riserless drilling proposals were identified to address the key scientific questions for the Pacific:

- western **Mid Pacific Mountains** Resolution Guyot – Cretaceous OAEs
- eastern to mid **Mid-Pacific Mountains** – middle Miocene to Early Eocene
- Southern **Hess Rise** Mellish Bank – Paleocene, K/Pg boundary, Maastrichtian to Santonian
- **Magellan Rise** and **Manihiki Plateau** – Miocene Climate Optimum (MCO)

3.4 Enhancing Collaboration Between and Among International Scientists

As scientific ocean drilling is entering a new era with the upcoming IODP^3 initiative and, at the time of the workshop, unclear development of scientific ocean drilling in the U.S., the need for future cooperation and co-funding schemes were discussed during the workshop. There was consensus among the participants that there needs to be a call from the scientific community to open new avenues by funding agencies for international co-sponsored endeavors. A truly international approach is needed to cover all expertise and continue the IODP spirit / mode of scientific partnership and exploration, and to ensure training of the next generation of scientists.

U.S. participation and leadership in the scientific discoveries made over the past 50+ years by international and interdisciplinary scientific ocean drilling community represents "one of our

nation's most successful and impactful investments in advancing basic research about Earth, as well as in advancing STEM education, the economy, and workforce development" (Bontempi, 2022). "Without new infrastructure or sampling investments, participation of U.S. scientists on expeditions will become limited, and access to new ocean drilling samples and data will be curtailed. These conditions will impact progress on globally vital and urgent research." (NASEM, 2024).

The 2050 Science Framework outlined eight *Enduring Principles* critical to the past success of scientific ocean drilling and highlighted strengths of the past program. These include "transparent regional planning", "open access to samples and data", "collaborative and inclusive international programs", "enhancing diversity", and "bottom-up proposal submissions and peer review". Workshop participants discussed the importance of embracing these principles moving into the new era of scientific ocean drilling – and incorporating additional communities and individuals who were not at the workshop into discussions at all stages of planning future work and developing new proposals targeting Pacific Highs.

Specifically, following this workshop (1) we have created a listserv to facilitate communication, (2) we started writing (and will publish) a white paper together as a Paleoceanography & Paleoclimatology Commentary, (3) we are coordinating proposals (submitting each to all potential funding opportunities), and (4) we are planning future meetups (including remote participation) at AGU 2024 (Harper), EGU 2025 (Westerhold), International Conference on Paleoceanography #15 (August 2025), and Climate and Biota of the Early Paleogene (planned in 2026).

4. Workshop Planning

The Steering Committee proposed an agenda that was modified once the 3-day workshop was approved for funding in May 2024. The final agenda (**Appendix B**) allowed for sufficient time to have (limited) presentations, large and small group discussions. Altogether, the length of the workshop was sufficient to accomplish our workshop objectives. It did require participants to invest a significant amount of time to participate fully either in person or remotely. This can be challenging during the regular academic semester; however, it was an ideal time of year for the venue (Stone Lab) to host the workshop.

The workshop was located at The Ohio State University's island campus on Lake Erie which allowed the incorporation of hands-on, outdoor activities each day after lunch led by staff on the island (**Figure 3**). This included a walking tour of Gibraltar Island – including seeing glacial grooves in bedrock of the island, and an aquatic tour on a boat – with a trawl and fish identification including invasives. These activities provided unique learning experiences for the in-person participants. This allowed everyone to learn about the history and environment of this special location in the Great Lakes. Participants could better connect and appreciate the place that they traveled to be together. These activities away from the conference room and classroom building also gave participants time to digest and reflect on the science/discussions from earlier in the day, and to network informally. This time was enjoyed by everyone who participated.

Figure 3. *Activities on (and off) the island included a walking historic and geologic tour of Gibraltar Island and aquatic tour by boat and trawl. Photo credit: Griffith and Lam.*

Figure 4. *Gathering in the evening around the bonfire was a favorite activity at the workshop. Photo credit: Sager.*

The isolated location – on an island campus that was only accessible by boat or water taxi – kept participants interacting together outside of the more structured workshop. Informal networking, mentoring and making connections outside of the "classroom" in a relaxed environment thus was made possible. Activities like gathering around a bonfire and making s'mores (**Figure 4**) helped facilitate this time together in the evenings (after sunset at ~7pm). Workshop participants commented on how nice it was that these activities in the isolated location provided additional time to network and connect with everyone at the workshop – people didn't scatter in many different directions in the evenings but hung out altogether. However, because of the remote location, there was significant travel time to (and from) the island campus. Accommodating this significant "extra" travel time to the island campus (~ 1 to 2 hour drive from the nearest major airports + 30 minute ferry ride + shuttle to the boat or water taxi to the final destination) was critical and required flexibility in arranging for early arrivals (or late departures) depending on each participant's origination. Altogether the isolated location was seen as a major benefit to building a community of international and interdisciplinary scientists at different career stages from many different institutions that were able to work together to accomplish the objectives of the workshop.

An open call was made to recruit individuals to apply to participate in the workshop facilitated through USSSP and the Steering Committee (using Google forms). The application asked for a statement of interest, including prior expertise specific to the workshop topic if applicable (suggested word count ~250 words) and CV. The criteria for participation (and evaluation) was also included in the application survey. All of the information in the application was found to be useful for evaluating applicants by the Steering Committee and allowed the Steering Committee to select a diverse group of scientists with different research expertise at different career stages to

participate (**Figure 5**). This was noted by participants at the workshop who appreciated interacting with such a diverse group of scientists at the workshop.

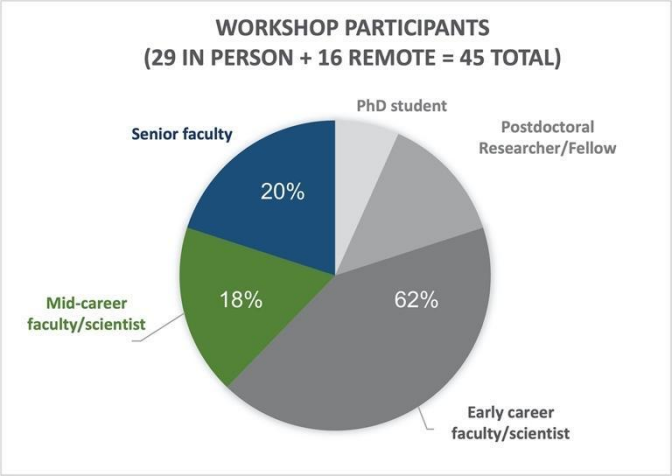


Figure 5. *Workshop participant career stage (including both remote and in person). Early Career (defined as a PhD student or researcher within 10 years of earning their PhD) made up 62% of the participants. Mid-Career faculty/scientists made up 18% and Senior faculty/scientists made up 20% of the participants. 20% were international scientists and 80% were U.S.-based scientists. In person participants supported by USSSP included 1 PhD student, 4 Postdoctoral scholar/scientists; 13 Early career; 4 Mid-career; and 3 Senior faculty/ scientists. This is 72% Early Career, 16% Mid-Career, and 12% Senior Scientists.*

To encourage researchers to apply, the announcement was sent out to individuals directly that might be interested based on their prior research in the field. Having a diversity of individuals at different career stages on the Steering Committee, including an early career researcher, helped facilitate a large pool of potential applicants. Several researchers emailed the Steering Committee asking if there might be a remote option for individuals who had a conflict with some or part of the meeting or who could not travel at the time of the workshop. It was decided soon after the deadline for applications that in order to increase participation, a remote option would be made available. This also allowed USSSP to join remotely and two presenters (one Steering Committee member and one invited presentation from NSF) to participate. No additional funds were budgeted to facilitate this additional mode of participation, but because of recent advances in hybrid meetings and course delivery, it was deemed possible using existing Ohio State University Stone Lab technology without any additional costs. The hybrid mode was sufficient to allow remote participation, but it was not seamless. A dedicated person (and associated costs) to facilitate full remote participation would be necessary to ensure a seamless operation.

One of the Steering Committee members, Westerhold, was from outside the U.S. which allowed the group early on to consider how to engage with the international community and secure funds for international participants who are not supported by USSSP. Based on the experience gained, it is clear that international funding organizations (e.g., ANZIC, ECORD, JAMSTEC) and specific individuals who may be interested in participating but do not work in the U.S. need to be approached early in the planning process. Early expressions of interest are needed to secure funding and facilitate their participation (e.g., arrange for payment of participation fees for non-U.S. participants).

We reiterate that it is critical that funding include full support (i.e., no out-of-pocket expenses) for participants. This is necessary to allow all researchers to participate, especially early career researchers (ECRs). Including a remote option ultimately did allow for participation by a larger group of individuals which was viewed as an overall positive. Of the 21 individuals who asked to participate in the workshop remotely, 76% logged in and participated at some point during the 3-day workshop. The remote option increased the size of the workshop from 29 to 45 participants or an increase of 55% (**Appendix A**). Participants joined from thirty-eight different institutions.

Appendix A. List of Participants (29 in person, 16* online = 45 total participants)

Online participants indicated with a (*)

Name	Institution	Career Stage
A Christina Ravelo*	University of California, Santa Cruz	Senior faculty
Adriane R. Lam	Binghamton University	Early career faculty
Alexandra Villa	University of Wisconsin	Postgraduate student
Bärbel Hönisch	Lamont-Doherty Earth Observatory	Mid-career faculty
Batoul Saad	Ohio State University	PhD student
Brian Huber	Smithsonian Institution	Senior Research Geologist
Brittany Hupp	George Mason University	Early career faculty
Catherine Davis*	North Carolina State University	Early career faculty
Chiara Borrelli*	University of Rochester	Early career faculty
Chijun Sun	University of California, Davis	Early career faculty
Chris Lowery	University of Texas at Austin	Early career faculty
Don Penman	Utah State University	Early career faculty
Dustin Harper	University of Utah	Postdoctoral researcher
Elizabeth Sibert	Woods Hole Oceanographic Institution	Early career faculty
Flavia Boscolo-Galazzo*	MARUM, Germany	Postdoctoral researcher/ Fellow
Halima Ibrahim*	Binghamton University	PhD student
Jesse Farmer*	University of Massachusetts, Boston	Early career faculty
Jim Zachos*	University of California, Santa Cruz	Senior faculty
Julio Sepúlveda	University of Colorado, Boulder	Mid-career faculty
Junichiro Kuroda	AORI & University of Tokyo, Japan	Mid-career faculty
Kelsey Doiron	Harvard University	Postdoctoral researcher/ Fellow
Ken MacLeod	University of Missouri	Senior faculty
Kevin Konrad	Oregon State University	Early career faculty
Liz Griffith	Ohio State University	Mid-career faculty
Lucien Nana Yobo	Texas A&M University	Early career faculty
Maureen Walczak	University of Washington	Early career faculty
Mitch Lyle*	Oregon State University	Senior faculty
Neil C. Mitchell*	University of Manchester, UK	Senior faculty

Peter Davidson*	GEOMAR, Germany	Early career scientist, postdoc
Pratigya Polissar	University of California, Santa Cruz	Mid-career faculty
Rebecca Robinson*	University of Rhode Island	Senior faculty
Sandy Kirtland-Turner*	University of California, Riverside	Mid-career faculty
Serena Dameron	University of Missouri	Postdoctoral researcher/ Fellow
Shamar Chin	University of Iowa	Early career faculty
Shannon Haynes	Princeton University	Early career scientist (Associate Professional Specialist)
Sietske Batenburg	Utrecht University, Netherlands	Early career faculty
Simon Brassell*	Indiana University, Bloomington	Senior faculty
Tali Babila	Case Western University	Early career faculty
Thomas Westerhold	MARUM, Germany	Mid-career faculty
Torben Struve*	University of Oldenburg, Germany	Mid-career scientist
Victoria Taylor	University of Bergen, Norway	Postdoctoral researcher/ Fellow
Will Sager	University of Houston	Senior faculty
Yi Wang	Tulane University	Early career faculty
Yuhao Dai*	Australian National University, Australia	Postdoctoral researcher/ Fellow
Yunlang Zhang*	University of Southern California	PhD student

Appendix B. Workshop Agenda, Local time (in Ohio) is U.S. Eastern Time Zone (New York)

ZOOM links provided for each room: Conference Room Red Room Blue Room Green Room

Tuesday, October 1st		**LOCATIONS/ZOOM:**
3:30 PM New York	Arrival Stone Lab, Gibraltar Is.; Move-in dorms	
4:30 PM New York	Orientation Dining Hall Patio	
5:00 PM New York	Dinner, Dining Hall	
6:15 PM New York	Introductions; Icebreaker (Bingo)	
Wednesday, October 2nd		
07:30 AM New York	Breakfast, Dining Hall	
08:15 AM New York/ 13:15 London/ 05:15 AM Los Angeles	Welcome, Workshop goals, Code of Conduct - Liz Griffith; Introduction & Welcome from USSSP Angela Slagle (remote)	Conference Room
08:30 AM New York/ 13:30 London/ 05:30 AM Los Angeles	The geology and (paleo-)oceanography of Pacific Highs: Scientific exploration and drilling history on Pacific Highs - Thomas Westerhold	Conference Room
09:00 AM New York/ 14:00 London/ 06:00 AM Los Angeles	Shatsky Rise Climate Chronical–reconstructions & shortcomings - Jim Zachos (remote)	Conference Room
09:30 AM New York/ 14:30 London/ 06:30 AM Los Angeles	Exploring the (im)possible: Potential to expand modern paleoceanographic studies deep into the Cretaceous - Brian Huber	Conference Room
10:00 AM New York/ 15:00 London/ 07:00 AM Los Angeles	Promise and pitfalls: Past experience of designing and conducting Scientific Drilling expeditions in the region - Will Sager	Conference Room
10:30 AM New York	Coffee Break	
11:00 AM New York/ 16:00 London/ 08:00 AM Los Angeles	Update from Chair of JR Advisory Board Larry Krissek	Conference Room
11:30 AM New York/ 16:30 London/ 08:30 AM Los Angeles	Group discussion led by Jim Zachos (remote) with introduction: 2050 Science Framework and National Academies Progress and Priorities in Ocean Drilling	Conference Room
12:00 PM New York	Lunch, Dining Hall	
1:00 PM New York	Walking Tour of Gibraltar Island	
2:00 PM New York/ 17:00 London/ 11:00 AM Los Angeles	Group discussion: What are the outstanding scientific questions? Where are the gaps? Organize into smaller groups for breakouts to dive into details.	Conference Room
2:30 PM New York	Coffee Break	
3:00 PM New York/ 18:00 London/ 12:00 PM Los Angeles	U.S. NSF update - Kevin Johnson (remote)	Conference Room
3:30 PM New York/ 18:30 London/	Breakout Session 1: Identify specific key science questions; Why target Pacific Highs?	Red Room Blue Room

12:30 PM Los Angeles		Green Room
5:00 PM New York	Dinner, Dining Hall	
6:15 PM New York/ 21:15 London/ 3:15 PM Los Angeles	Open mic/ open floor: A free space to share (e.g., past, current, future research). Volunteered presentations from Kevin Konrad, Elizabeth Sibert, and Don Penman.	Conference Room
	Sunset @ 7:05pm New York (see cover photograph) Bonfire social time with s'mores	
Thursday, October 3rd		
07:30 AM New York	Breakfast, Dining Hall	
08:15 AM New York/ 13:15 London/ 05:15 AM Los Angeles	Junichiro Kuroda presentation on *Chikyu* operations and proposal. Group discussion: Report out from breakout groups. Consensus on key scientific questions? Re-introduce available core material, seismic for potential new targets	Conference Room
10:00 AM New York	Coffee Break	
10:30 AM New York/ 15:30 London/ 07:30 AM Los Angeles	Breakout Session 2: Continued detailed discussions; re-organize groups as needed.	Red Room Blue Room Green Room
12:00 PM New York	Lunch, Dining Hall	
1:00 PM New York	Group photo by dock; Aquatic tour by boat	
2:30 PM New York	Coffee Break	
3:00 PM New York/ 18:00 London/ 12:00 PM Los Angeles	Group discussion: Report out from breakout groups. Priorities for legacy core research, new ocean drilling (type and timelines)	Conference Room
5:30 PM New York	Conference Dinner, Put-in-Bay, South Bass Island	
	Sunset @ 7:03pm New York Bonfire social time with s'mores	
Friday, October 4th		
07:30 AM New York	Breakfast, Dining Hall	
08:15 AM New York/ 13:15 London/ 05:15 AM Los Angeles	Will Sager present new seismic in the region. Outline white paper as a group providing road map to coordinate efforts	Conference Room
09:15 AM New York/ 14:15 London/ 06:15 AM Los Angeles	Breakout Session 3: Organize into writing groups, create framework for coordinating efforts for future with timeline	Conference Room Red Room Blue Room Green Room
10:30 AM New York/ 15:30 London/ 07:30 AM Los Angeles	Group photo in Conference Room with online participants Report out from breakout groups; Final remarks – Thomas Westerhold	Conference Room
12:00 PM New York	Lunch, Dining Hall	
1:00 PM New York	Depart Stone lab, Gibraltar Is.	

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