**Abyssal Science Workshop Survey Summary**
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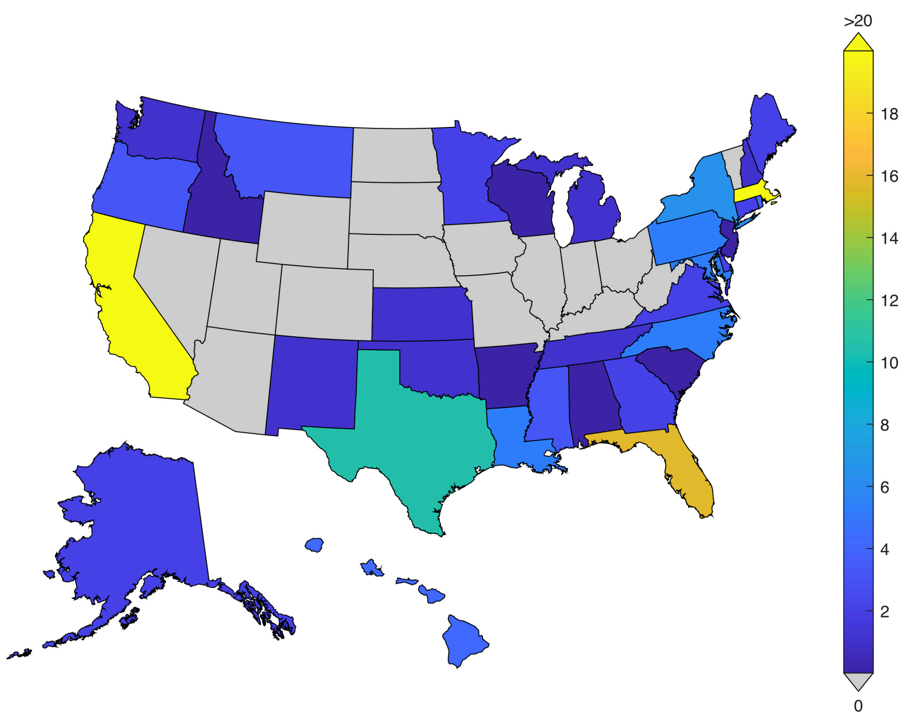
An online survey was conducted to gain insight into the perspectives of the community on the opportunities and challenges associated with deep submergence science at abyssal depths. The survey was initiated at the Fall AGU DeSSC meeting and advertised through the UNOLS list serve and social media. There were over 180 responses to the survey. Below we summarize the constituency that was polled and trends in responses.

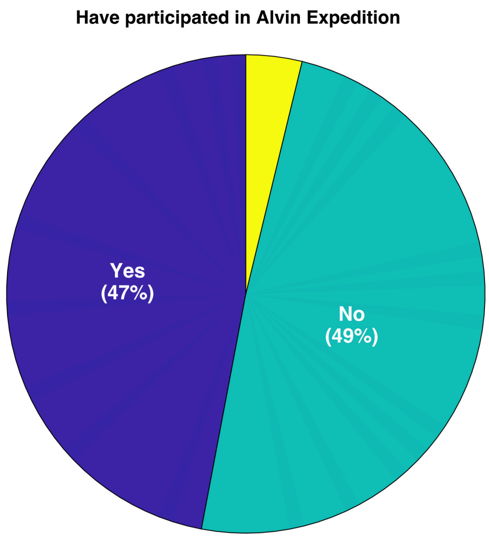
WHO PARTICIPATED?

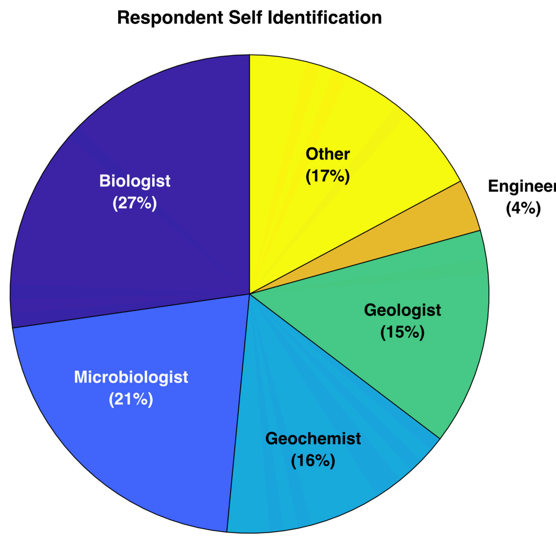
The participants were mostly from the US, with representation from 34 states, along with a small number of international respondents. Roughly half of the respondents have had experience with HOV Alvin operations and most of those experiences (~2/3) are recent, within the last 5 years. Of those that have not had experience with HOV Alvin, more than half have had experience with other deep submergence assets. In fact, the list of deep submergence vehicles that respondents have used collectively is incredibly comprehensive ranging from HOV Turtle or ROV Subastian.

Respondents self-identified their area of expertise, with biologist (27%) and microbiologist (21%) representing more than half of the responses, geochemists (16%) and geologist (15%) together representing about one third of the responses, along with a smaller number of engineers (4%), and a sizable group of 'other' (17%). Approximately one-third of respondents included 'Professor' in their title and 20% included either 'student' or 'postdoc' in their title.




*Distribution of US respondents to Abyssal Science Workshop survey. State colors indicate number of respondents with yellow indicating >20 and grey indicating 0. A total of eight respondents were international.*




*Roughly half of the collected respondents have had experience using HOV Alvin. Of those that have not, half of them have had experience with other deep submergence vehicles. The respondents self identified their field of expertise, led by biologists and microbiologists.*

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|---|---|---|
| HOV Pisces IV, V | Comanche | Schilling UHD |
| ROV Deep Discoverer | Mohawk | HOV Sea Cliff |
| ROV Hercules | HOV Triton 3300 | ROV Icefin |
| AUV Eagle Ray | ROV Kraken II | HOV MIR |
| ROV Global Explorer | ROV Deepworker | ROV Lu'ukai |
| ROV Odysseus | ROV Ropos | ROV Oceaneering |
| HOV Nautile | AUV ABE | ROV Aegir6000 |
| ROV Jason | AUV Puma | HOV Turtle |
| ROV Tiburon | AUV Jaguar | DSL-120 |
| ROV Ventana | ROV Little Hercules | MR-1 |
| ROV Subastian | ROV Quest4000 | ROV Yogi |
| HOV Shinkai | UHD-34 | ROV Quest |
| HOV Johnson Sea Link | ROV Nadir | ROV SRI |
| AUV REMUS | TowCam | HOV Limiting Factor |
| HROV Nereus | Camper | AUV Hugin |
| AUV Sentry | AUV MBARI | ROV Victor |
| NR-1 | HOV DeepRover | ROV Jago |
| AUV Mesobot | ROV Isis | HOV Nautile |

*The list of deep submergence vehicles that the respondents have used covers nearly every available platform in the US and most of those operated abroad.*

AREAS OF INTEREST

Respondents were asked to list areas of interest for abyssal research. A huge variety of responses were listed that included both general descriptions (e.g., seamounts) and specific locations (e.g., Puerto Rico Trench). Among the most repeated were trenches, including Puerto Rico, Marianas, Cascadia, Hellenic, Dominica, Tonga, Java, Aleutian. Other types of sites all received roughly equal attention. Sites of seafloor fluid flow including general references to hydrothermal vents, serpentine hosted vents, and cold seeps as well as specific references to the Rainbow vent field, GOM seeps, Mid-Cayman Rise, Shinkai Vent field. Transform faults in all ocean basins were also listed as targets as well as bare rock sites at mid-ocean ridges, seamounts, and trenches. There were also mentions of marginal canyons and abyssal plains with the CCZ, North Pacific, Silver, and West Pacific.

OPPORTUNITIES

Respondents offered a huge range of scientific opportunities in abyssal environments. Many of the opportunities refer specifically to the *environmental conditions*, such as metabolism of organisms under high pressure, and limits for life in energy-limited environments. Other opportunities refer to the *features present at these depths* including deep hydrothermal vents and seeps, petit spot volcanism, and magmatism at ridge-transform intersections. Some of the opportunities seek specifically to look at *processes that operate at all ocean depths* including larval recruitment, earthquake activity, and microbial biogeochemistry, and hydrothermal geochemistry. In some cases. the *comparison of shallow and abyssal sites* was called out specifically. A subset of opportunities are specifically aimed at '*societally relevant*' processes including impacts of marine mining, plastics in the abyssal ocean, and carbon budgets and cycling in the deep ocean. A full listing of the suggested opportunities are listed at the end of this document.

CHALLENGES

Respondents were asked to list challenges to abyssal research in general and for HOVs in particular. Many of the responses are applicable to deep sea research at all depth ranges including the desire for greater funding, greater access to vehicles and ships, and more opportunities for student/post-doc participation in expeditions.

For abyssal reserach, respondents comments fall broadly into two categories: access and technology. In terms of access, there were multiple comments about the limited availability of platforms rated to abyssal depths. Further, respondents noted that long deployment and recovery times (for vehicles as well as elevators and other over-the-side deployments) was a challenge. In a similar vein, the prospect of limited bottom time because of the depths for HOVs was noted. More broadly, the limited knowledge of abyssal benthos including locations of study sites (e.g., outcrops, seeps, vents) and high-resolution maps was noted.

In terms of technology, it was noted that navigation at these depths can be a challenge, especially in the absence of well-documented sites. The difficulty in testing sensors of all types at abyssal pressures was also noted multiple times. Similarly, it was noted that recovering biological samples from these depths and keeping them in good shape (e.g., for genetic analysis) might be a problem. For HOVs in particular, questions were raised about battery power and its ability to deliver reasonable dive durations for abyssal depths. If extended dive times are possible, it was noted that diver fatigue may be a problem.

Full list of respondent-provided abyssal science opportunities

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| Connectivity across depth regimes |
| Energetic limits of life |
| Alternative energy sources other than photosynthesized organic matter |
| global biogeochemistry |
| microbiology adaptations |
| Adaptation to low energy |
| Chemoautotrophy in an abyss |
| Biological zonation at the transition between the abyssal plane and seamounts |
| Colonisation |
| impacts of deep-sea mining on ecosystem services at seamounts |
| biogeochemistry of biologically produced calcite |
| Ecology and biogeochemistry of isolated geologically active abyssal seamounts |
| underwater volcanoes |
| Genetic variation and structure at the bottom of the ocean |
| Fore-arc basement structure and composition |
| Volcanism spots |
| petit spot volcanism, uncluding microbial interactions with rocks/fluids |
| microbial metabolism under high pressure |
| Support infrastructure |
| limitations of life |
| hadal ecosystems (lots of questions) |
| community ecology |
| Adaptation to high hydrostatic pressure |
| benthic decomposition of organic matter in hadal trenches |
| Better coverage of subsurface sampling - we're missing anything covered by tall water columns. |
| Serpentinite hosted hydrothermal biology |
| Communities structure |
| fish species habitat associations |
| Relationship between subduction inputs and microbiological activity |

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| Diagenesis |
| pressure biological adaptations |
| Carbon cycling |
| in situ microbial activity |
| ambient microplastic density & composition |
| habitability at low energy availability |
| deep sea coral ocean current paleoceanography |
| deep sea corals and sponges (ecology and adpatation) in this unexplored depth range |
| heat/ energy production |
| microbial adaptation to extreme conditions (e.g., pressure, scarce resources) |
| lifeforms in abyssal regions |
| Access deep ocean methane seeps and the life they support |
| Processes controlling Fe-Mn nodules chemical composition |
| Diversity and community structure |
| sediment microbiology |
| novel microbes in deep-sea and medically- and industrially-relevant new metabolites |
| Water mass flows through deep topography |
| Serpentinization of ultramafic rocks exposed at seafloor |
| Loihi Seamount, specifically the FeMO deep site |
| deep-sea invertebrate metabolism |
| Microbial diversity and metabolic adaptations |
| Hydrothermal geochemistry |
| Use of microbial symbionts as a adaptation mechanisms for larvae |
| Species richness at deep sites |
| global patterns of speciation in abyssal vs shallower environments |
| hydrothermal origins of life |
| bottom water pathways |
| Paleoclimate |
| Microbial and viral adaptation to ultradeep hydrothermal vents |
| Serpentinization processes |
| Molecular adaptation to high pressure |
| organic carbon burial and remineralization |

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| microbial biogeography |
| geochemistry of deep hydrothermal systems |
| fast-spreading MOR core complex features- do they exist at the Wilkes microplate? |
| Organic matter chemistry coupled with biological adaptation to scarce resources |
| Tanaid biodiversity |
| Microbe-mineral interactions in "extreme" conditions |
| Comparison of microbial food web dynamics from >4500m to <4000m and <1000m depths (pressure tolerances) |
| Abyssal and hadal biogeography |
| Genomic Adaptations to life in the deep sea |
| unknown biodiversity of deep pelagic ocean |
| Animal/ecosystem adaptation to low energy |
| connectivity |
| Manganese Nodule resources and assoc. biota on the abyssal plains |
| I work from imagery, so any dive is an opportunity for me |
| hydrostatic adaptation |
| Tectonic windows, eg PRT |
| What quantity and quality of carbon and other elements are trenches shuttling to the lithosphere? |
| microbial biogeography |
| ocean island bases |
| Adaptation to high hydrostatic pressure |
| Novel organisms and metabolisms |
| macrozooplankton |
| Deepest parts of seamounts and petit spot volcanism |
| earthquakes |
| Speciation, barriers to dispersal |
| Buttom boundary current |
| biological adaptation to low energy (subtropical gyres) |
| Chemolithotrophic energy in "extremophilic" microbes |
| bnenthic ecosystem structure and food supply |
| Biogeochemical cycling |
| Biological and physiological adaptation |
| earthquake activity (e.g. deployment and retrieval of seismometers) |

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| biological adaptation to pressure |
| Downgoing slab hydrogeology close to/in trenches (CORKs) |
| (Micro)biological ramifications of hydrocarbon seepage in >4500 meters |
| Fluid circulation and metamorphism in older crust and sediments |
| Biological adaptation to pressure |
| Animal-microbe symbiosis |
| population connectivity |
| chemical water composition (estimated from photographs) |
| Piezophile microbial activity |
| Trophodynamics |
| Fluid exchange between crust and ocean |
| Serpentinization and weathering of ultramafic rocks |
| Speed and timing of gametogenesis where food is sporadic or limiting |
| Rift propagation |
| Mass budgets |
| Microplastics |
| Changes in abundance and composition in AABW |
| evolution and ecology under limited energy availability |
| Biological adaptation to depth |
| genetic connectivity across fragmented habitats (e.g. trenches separated by shallow regions) |
| Deep-sea associations |
| Crustal structure |
| Hard substrate megafauna species composition, distribution, abudnace, etc |
| Food limitation on ecosystem persistence |
| bottom water pathways |
| Genetic adaptations to extreme environments |
| Unique deep ocean climate time series from shells of long-lived organisms |
| off-axis volcanism |
| Scarce resources |
| coral adaptation to low $CaCO_3$ saturation states |
| Acoustic communication |
| General site characterization |

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| transform faults |
| finding money |
| Impacts of seabed mining |
| Deep chemosynthetic habitats |
| Microbe-mineral interactions with minimal surface input |
| ocean response to global warming and acidification |
| Mechanisms of diversification |
| Habitat connectivity |
| impacts of deep-sea mining on ecosystem services in manganese nodule areas |
| impacts of OMZ spreading |
| In situ SIP (or other incubation) experiments at extreme oligotrophic abyssal ecosystems |
| deep sea life |
| Adaptions to genetic and cellular deep enviornments |
| Magmatism & hydrothermalism of ultraslow-spreading oceanic pull-apart basin |
| Microorganisms in the Puerto Rican Trench |
| warm and cold seeps+rock generalization in trenches |
| microbial  degradation of organic matter |
| in situ measurement of biological processes |
| trenches as carbon syncs |
| species distribution (range and depth) |
| Biogeochemical cycling at subduction zones |
| Trenches are the first part of subduction zones, this is essential to sample. |
| Deep ocean methane seeps |
| biological adaptation |
| fish behavior |
| Geologic scale interaction between microbiology and geological processes |
| Deep Carbon Cycling |
| Microscopic life forms |
| habitat based microbial diversity and function |
| climate records of the deepest oceans areas from long-lived organisms (skeletons) |
| phylogenetic novelty |
| marine debris distribution |

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| Population connectivity |
| microbial adaptations to hyper salinity, anoxia, and pressure |
| Mixing over rough topography |
| Diversity and competition at chemosynthetic communoties |
| Fungi diversity |
| Weathering of oceanic crust |
| Symbiosis |
| Comparative studies with shallower sites |
| relative influences of vents, seeps, and surface sources in supplying carbon to abyssal ecosystems |
| geothermal pre-biotic chemistry |
| abyssal water property changes |
| Genomic underpinnings of microbial metabolism at depth |
| Hydrothermal alteration |
| ridge transform intersection tectonics and magmatic processes |
| Benthic organic matter |
| gene adaptation in crustaceans at depth |
| Identifying biogenic influence on hydrothermal vent mineralogy |
| Occurrences of symbiosis between eukaryotes and prokaryotes |
| benthic biodiversity at extreme depths |
| Marine Symbiosis |
| behaviors, orientations, fine-scale distribution of deep pelagic fauna |
| Animal/ecosystem adaptation to high pressure |
| chemosynthetic ecosystems |
| Evaluation of near-term marine mining sites in the CCZ |
| larval dispersal |
| baseline assesments to forecast human impacts in abyssal depths |
| long Hawaiian lava flows |
| Biogeochemical cycling at subduction zones |
| Information transfer (chemical signaling & communication) |
| ctenophores |
| Transform and fracture zone deeps - plutonic/ mantle exposures |
| trait adaptations |

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| Interaction of Topography with buttom water current |
| biological adaptation to extremely low levels of hydrothermalism |
| Energetic limits of life |
| biological diversity and physiological adaptations |
| Connectivity/dispersal |
| fluid expulsion and associated chemosynthetic ecosystems |
| extent and diversity of obligate piezophiles |
| Understanding polymetallic nodules & their formation (CCZ) |
| Accretionary wedge hydrogeology |
| Marine invertebrate larvae |
| biodiversity assessment in areas subject to mining exploration |
| Serpentine microbial communities |
| Biogeochemical cycling |
| Biological dependence on fluid exchange (i.e. vents) |
| Recruitment mechanisms |
| Transform faulting |
| Opal burial |
| Environmental DNA |
| Bathymetry of the Southern Ocean/broader Antarctic continental shelf break region |
| relative roles of carbon sources |
| Bentho-pelagic behavior of organisms |
| osmotic adaptation to extreme hydrostatic pressure |
| Sensory Adaptation |
| Igneous petrology |
| Impact of climate change on deep-sea communities |
| abyssal water property changes |
| Lipid genes in deep sea crustaceans |
| Chemistry of the deepest abyssal spring systems |
| microbial adaptation to extreme pressure |
| Tectonics |
| metabolic rate scaling with depth |
| Acoustic monitoring |

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| deep-ridges |
| Nutrient scarcity shaping microbial community |
| Adaptations to pressure |
| Anthropogenic influence |
| ocean crust deep biosphere |
| quantifying the role of deep-sea in Carbon Cycling |
| Ecology and biogeochemistry of metal nodules containing sediments |
| impacts of cables, etc. construction to sea floor |
| Meiofaunal community structure |
| Petit-spot volcanism and hydrothermalism |
| geology and slope stability of deep roots of Pacific seamounts |
| carbon transport and characterization at abyssal depths |
| distribution of vents & rare earths |
| Hadal biogeography |
| Hydrothermal vent island geobiology |
| environmetal factores influencing community structure |
| interspecific interactions fish vs fish, fish vs prey |
| Access to ultra-deep hydrothermal vents |
| Trace Metal Cycling |
| Nitrogen, Phosphorous, sulfur cycling |
| wierd deep ocean cold crust seep environments |
| role of benthic microbiology in biogeochemical cycling / rates of organic matter remineralization |
| affect of marine debris on organisms |
| Food webs, trophic modeling, carbon remineralization |
| protist and fungal activities in trenches and adaptations |
| Location and spreading of abyssal waters |
| dee-sea mining |
| Energy flows and nutrient cycling |
| Trace metal cycling between oceanic crust and seawater |
| Larval transport |
| Videography of deep water species (behavior documentation) |
| piezophilic microbiology |

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| limits of life in oceans |
| abyssal physical/chemical/biological dependencies |
| ultra slow spreading MOR volcanic and hydrothermal processes |
| Seep organic matter biogeochemical processes |
| Energetic limits of life in non-standard temperature and pressure |
| Host-associated microbiomes (and their impact on biodiversity, evolution, ecology) |
| groundtruth use of ship-mounted deep-sea sonar systems to detect/observe deep pelagic fauna |
| Temporal dynamics and seasonality |
| disturbance and recovery times |
| Exploration of seabed mineral resources and endemic communities in western Guam and CNMI |
| parasite ecology |
| Hadal biogeography |
| Transdisciplinary Science (integrated geo-phys-biol-chem collaboratories) |
| biodiversity |
| geochemical influence on ocean chemistry of low temperature hydrothermalism in deep flanks of seamounts |
| Mineral formation influenced by chemolithotrophs |
| genomic adapations to abyssal/hadal habitats /pressure |
| food-fall scavengers |
| Do hydothermal vents exist at deeper depths that we couldn't access before? |
| Biological adaptation |
| physical oceanography |
| Chemical budget from fluid exchange |
| Larval dispersal within and among trenches |
| Hydrothermal processes in transform faults and propagating rifts |
| C burial |
| Phylogeography |
| Changes in CDW circulation and heat content at depth |
| biodiversity patterning and process |
| fundamental taxonomy / species discovery |
| Biodiversity discovery |
| low-T forearc vents |
| Function of reducing habitats at deeper depths |

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| abyssal physical/chemical/biological dependencies |
| Pigmentation and bioluminescence in deep sea crustaceans |
| trophic dynamics in sediment-dominated abyssal settings |
| in situ technology testing for space exploration |
| trends in biodiversity with depth + distance from shore |