Ongoing need for a 6500m-rated HOV

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Introduction:
This document outlines the ongoing need for a 6500m-rated HOV. We summarize a number of reports generated from community-based workshops in the past that have addressed this need. We also summarize recommendations from three recent workshop reports that reaffirm the desire for a 6500m-rated HOV and we report on an informal survey of deep-submergence vehicle users that provide additional insight into the potential uses of a 6500m-rated HOV.

The general recommendation of previous reports is that the current 4500m-rated HOV *Alvin* does not entirely meet the needs of the scientific community and that a 6500m-rated HOV would satisfy that need by providing the flexibility required to study nearly all of the ocean basins via human-occupied submersible. Development of a 6500m-rated *Alvin* would bring the US in line with other nations that operate deep-diving human-occupied submersibles (i.e., China, Japan, Russia, France). The clear desire for a 6500m-rated HOV, however, is balanced by caution that the costs for such an upgrade should not unduly consume the resources that would fuel the anticipated scientific advances.

Based on our reassessment of the potential use cases for a 6500m-rated HOV as expressed by the community, we conclude that the scientific justification and desire for a 6500m-rated HOV remains strong.

Table 1: Reports used in the generation of this white paper (publicly available reports are linked)

Report Name	Author/Sponsor organizations	Date published
DESCEND2	DeSSC/NSF	Pre-publication
The SZ4D Initiative	IRIS/NSF	Pre-publication
ERUPT	NAS/(NSF,USGS,NASA)	March 2017
Sea Change	(OSB,NRC,NAS)/NSF	2015
Alvin Upgrade Project Execution Plan	WHOI	2010
DESCEND	DeSSC/NSF	2009
Future Needs in Deep Submergence Science	(OSB,NAS)/NSF	2004

Note: The relative merits of ROVs and HOVs for deep submergence science is largely subjective and some members of the scientific community hold strong preferences for one platform type over another. Determining the value of the two vehicle types is beyond the scope of this report, but we will note that HOVs and ROVs are often used interchangeably and thus the availability of a 6500m-rated HOV would provide the scientific community with greater access to these depth ranges. We will not presume to assign scientific objectives to one platform over another and instead summarize the regions and research areas that would benefit from any deep-diving vehicle.

Scientific use cases for 6500m-rated *Alvin*:
An increased depth range from 4500m (current) to 6500m would provide access to an additional 33% of the seafloor (by area) and ~45% (by volume) of the overlying water column to be investigated by HOV *Alvin*, bringing the total accessible seafloor to 98% of the ocean basins. Previous community surveys have identified research areas that will benefit from an increased depth rating for HOV *Alvin*, and below we summarize those earlier findings drawing largely from the summaries in the *Alvin* Upgrade Project Execution Plan.

Mid-Ocean Ridges: Mid-ocean ridge crests deeper than 4500m are common on ultra-slow spreading ridges and present on slow spreading ridges. Ridges of this type make up at least half of the global mid-ocean ridge system. Key research avenues on deep mid-ocean ridges include studies of exposed lower crust and mantle rocks, deep hydrothermal vents (which can yield higher fluid temperatures), and chemosynthetic ecosystems with extremophile species that contain potentially important industrial or biomedical substances.

Ridge-flank Hydrothermal Processes: Significant thermal advection and mass exchange occurs in vast aquifers within the upper oceanic crust. Fluid flow through these aquifers may control the thermal state of the lithosphere and are projected to contain the largest biological province on the planet. The sites of fluid ingress and egress for these aquifers are located on the abyssal plains, commonly at depths greater than 6500m.

Subduction Margins: Convergent margins surround significant portions of the ocean basins, especially the Pacific. Here, dense oceanic crust is subjected beneath the continents creating deep trenches. These regions are critical areas to study in order to understand deformation cycles leading to large earthquakes, fluid exchange including the subduction of water that drives arc volcanism and enables mantle flow as well as return flow that drives mud volcanism and supports forearc seeps and associated ecosystems.

Biodiversity in Marine Ecosystems: The vast 3D volume of the oceans is severely undersampled with respect to biomass, biodiversity, and organism function. Much of the benthos lies below 4500m. These as well as the overlying water column are inaccessible to *Alvin* (due to regulations that limit dives to areas where the seabed is within the depth rating). Key areas of scientific enquiry include how organisms adapt to extreme isolation and food limitation and how genetic exchange occurs across the ocean basins.

Two additional scientific use cases identified in the original assessment of scientific need outlined in the *Alvin* Upgrade Project Execution Plan, but not discussed here, are Deep Sea Corals and Methane Hydrates. In our view, these topics fit as sub-categories of *Subduction Margins* and *Biodiversity in Marine Ecosystems* described above. Below we describe two emerging research areas to previous listings of >4500m scientific use cases, *Marine Mining* and *Transform Faults*.

Marine Mining: Large tracts of the seafloor have been claimed by nations for mining rights, and it is anticipated that extracting metals from those sites will become economical in the coming decades. Policy makers, regulators, and ocean conservation advocates are actively discussing best practices for site characterization and monitoring. Deep submergence tools that can access the deepest of these sites (e.g., Clarion-Clipperton Zone) will be critical in the development of the fundamental knowledge needed to effectively characterize and monitor these sites.

Transform Faults: Transform faults are among the most prominent geologic features in the oceans and commonly exceed 4500m depth, even on fast- and intermediate spreading rate ridges. Transform faults are sites of highly focused deformation that extends from the seabed to the upper mantle. They expose thick sections of the oceanic crust and upper mantle and are thought to be sites of extensive serpentinization. Intra-transform spreading centers provide a unique picture of upper mantle melting and host isolated and unique chemosynthetic ecosystems. The level of investigation within transform faults has been largely limited to dredging and geophysical studies, in part due to their significant depths.

Expressions of interest from community groups:
Above, we summarize the wide range of research targets within the proposed expanded HOV *Alvin* depth range (4500-6500m) that are topical, on the cutting edge of marine science, and relevant to society. Below we summarize recent workshop findings and discussions with members of the US marine science research community regarding their needs for deep diving (i.e., 6500m) submersibles.

DESCEND2: The most recent community meeting discussing deep submergence needs, DESCEND2 Workshop, was held in January 2016. Among the key recommendations from the workshop relevant to a deeper diving HOV are: 1) increased access to hadal regions (>6000m), which are noted as among the least-explored places on Earth; 2) increased access to the mid-water, which comprises the bulk of the habitable volume of Earth (and would require an increased depth range for *Alvin* in many places); 3) better understanding of the linkages between geological processes and geochemical fluxes, such as at MORs.

ERUPT: The Eruption Response and Unrest. "Monitoring of submarine volcanoes, repeat high-resolution bathymetric surveys with autonomous vehicles, sampling submarine deposits with human-occupied and remotely operated vehicles, and ocean drilling would expand our understanding of the history and nature of submarine volcanism." An expanded depth range to 6500m would provide access to more of the volcanic features within the ocean basins.

SZ4D: The Subduction Zone Observatory workshop gathered the trans-disciplinary researchers interested in the geology of convergent margins. The preliminary findings from this workshop are that there is a pressing need to understand subduction zones given the significant hazards they pose from large earthquakes and explosive volcanic eruptions. The workshop report recommends access to deep submergence vehicles for instrument deployment/recovery and direct observation. As described above, vehicles capable of 6500m operation are well suited to subduction zone investigations.