Ocean Worlds Analog Systems in the Hadal Ocean: Systematic Examination of Pressure, Food Supply, Topography, and Evolution on Hadal Life. T. M. Shank[1], C. German[1], C. Machado[1], A. Bowen[1], J. Drazen[2], P. Yancey[3], A. Jamieson[4], A. Rowden[5], M. Clark[5], T. Heyl[1], D. Mayor[4], S. Piertney[6], and H. Ruhl[7]
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All known Ocean Worlds except Earth host their liquid water oceans beneath a thick ice crust. The seafloor of Europa (currently NASA's highest priority for exploration) experiences pressures only found in the depths of Earth's hadal trenches, troughs, and troughs, areas of the ocean virtually unexplored due to their inaccessibility. The hadal zone encompasses these deep troughs and trenches on earth and extends across nearly half of the ocean's depth range, from 6,000 to 11,000 meters (20,000 to 36,000 feet). The hadal zone represents the deepest marine habitat on Earth, accounting for the deepest 45% of the global ocean. The geomorphological heterogeneity of these habitats has provided settings where environmental conditions (hydrostatic pressure and food supply) differ greatly from the majority of the deep sea and hypothesized to result in high levels of endemism at hadal depths.

In 2012, a new initiative, the Hadal Ecosystems Studies (HADES) Program was launched to determine the composition and distribution of hadal species, the role of hadal pressures, food supply and depth/topography on community structure within deep-ocean trenches in comparison to neighboring abyssal plains using the hybrid remotely operated vehicle "*Nereus*" in conjunction with full-ocean depth imaging landers (Hadal-Lander). The HADES program began in 2014, with studies along the Kermadec Trench involving PIs from 7 institutions to examine megafaunal community structure and the relationship between POC and benthic bacterial biomass, as a function of depth and location, by systematic high-definition imaging and sediment/faunal sampling transects from abyssal to full trench depths. Population genomic approaches are providing levels of genetic divergence and evolutionarily independent lineages to assess the role of depth and topography in promoting the formation of species diversity. Physiological constraints are being investigated via in-situ respiration of selected fauna and tissue concentrations of such protein stabilizers as trimethylamine oxide (TMAO), and the structural adaptations of macromolecules.

Following the loss of *Nereus* at 10,000m during this expedition, a series of engineering trade studies and science and engineering workshops have combined to usher in the Hadal Exploration Program (HADEX), aimed at determining the composition and distribution of hadal species, the role of pressure, food supply, physiology, depth, and topography on deep-ocean communities and evolution of life. In addition, a primary goal of the HADEX Program is to develop an armada of new full-ocean depth autonomous underwater "drone" vehicles. These are being designed and constructed to facilitate comparative investigations of hadal and abyssal life forms throughout the global network of hadal environments on earth as well as to serve in the development of vehicles for the exploration of the ice-covered ocean of Europa. This program was born via a new partnership between the Woods Hole Oceanographic Institution and NASA's Jet Propulsion Laboratory to advance the exploration and detection of life in oceans known to exist in our solar system.

The HADEX-JPL/NASA partnership comes together under the new program "Pathways to Ocean Worlds" and brings together world leaders in ocean and space exploration to harness convergent technologies and methodologies that will benefit deep-ocean exploration of all ocean worlds. The development of advanced robotic technology will allow pursuit of the foremost questions in hadal research as well as all parts of the ocean, from the ice-covered poles to the deepest trenches.

Figure 1. Engineer rendering of a new full-ocean depth autonomous underwater "drone" vehicle, capable of examining deep-ocean ecosystems via multiple landings and transits on and over deep ice-covered and hadal seafloor.