Ocean Worlds Explorer. J. Crouch[1,] J. H. Waite[1], K. Reh[2], S. Bolton[1], R. D. Lorenz[3], K.P. Hand[2], C. Glein[1] and C.R. German[4], [1]Southwest Research Institute,, [2]NASA Jet Propulsion Laboratory (JPL), [3]Johns Hopkins APL, [4]Woods Hole Oceanographic Institution (WHOI)

Introduction: These are the themes of the conference that this abstract focuses on:

ORIGINS — understanding the formation of icy satellites within the Saturn system from what appears to be rather pristine ices [1] and determining the origin of the materials forming the Galilean satellites.

WORKINGS — understanding the thermal evolution of the interior of Enceladus and the subsequent coupled geophysical and geochemical modification that ensued to produce an interior ocean.

LIFE — understanding of the origin and evolution of life; sequence the microbes if you find them; are they similar to Earth microbes or completely different?

Ocean Worlds have been recently identified by NASA as an important destination in looking for life in the outer solar system. NASA's Europa project is underway to send a reconnaissance spacecraft to fly by Europa over forty times in search of information regarding its habitability [2]. Titan and Enceladus have recently been added to the New Frontiers list of candidate targets due to their unique ocean characteristics – methane oceans at Titan [3] and an abundance of organics [4] and a global subsurface ocean at Enceladus [5], [6] complete with hydrothermal systems linked to the interior [7] and again an abundance of organics [1]. To date we know more about the ocean of Eneladus than any ocean outside of Earth due to the gas and ice grains that pour forth in abundance from the south polar "Tiger Stripes" (*Science special volume 311*, 2006). From this material we can deduce the pH [8] and look for basic volatiles that might provide chemical energy sources for life, such as H_2. However, our search for life will remain limited until such time as we can deploy a submersible spacecraft to investigate those oceans' interior – a lesson we have learned from Earth in the exploration for seafloor fluid flow and Ocean World-relevant chemosynthetic systems [9-11]. Our earth experience has already given us some preliminary direction on what instrumentation will be needed. Maturing these instrumentation ideas is a parallel task that is being actively pursued in Earth's ocean with NSF funding. This presentation will explore how this type of Submersible Explorer (SE) can be extrapolated to provide direct sampling of the basic chemistry, habitability, and potential life in the oceans of the outer solar system.

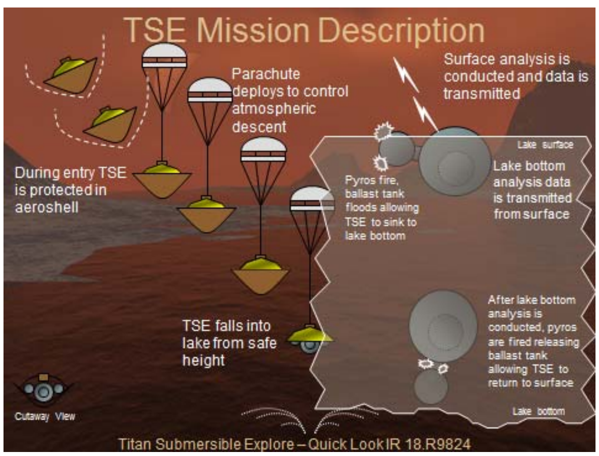
Motivation for a Submersible Probe: Southwest Research Institute (SwRI) has been designing, fabricating, and testing custom submersibles for more than five decades. These unique vehicles were often designed and built out of non-standard materials or were intended to be used in relatively severe environments. In the 50's, SwRI provided the preliminary design for an aluminum submarine (Aluminaut) to demonstrate the capabilities of aluminum in harsh conditions. In the 70's we designed and built an experimental vehicle out of acrylic for the US Navy (NEMO) to demonstrate the ability to form and operate a spherical pressure hull using a transparent material. In the 80's we built the US Navy's largest autonomous vehicle, a ¼-scale SEAWOLF SSN21, out of high yield steel (LSV 1 "Kokanee"). And, in the last 10 years, SwRI has designed, fabricated, tested and delivered the US Navy's one-of-a-kind pressurized submarine rescue vehicle out of a high yield steel (Falcon) and their deepest diving titanium submersible sphere (Alvin) capable of diving in >80 % of the earth's oceans.

In 2008, to determine the feasibility of an SE concept, SwRI performed the Titan Submersible Exploration (TSE) concept study. This TSE study was conducted as an internal research and development (IR&D) project. Preliminary results were presented to JPL and APL. The concept was also presented to the European Space Research and Technology Center (ESTEC) at an event that was held in Noordwijk, the Netherlands on the 21st and 22nd of July, 2008. Follow submersible design work was carried out during the Decadal study with Team X personnel from JPL The value of and interest in missions of this sort has been underscored by a recent NASA Innovative Advanced Concepts (NIAC) study on a Titan Submarine [12].

Research conducted in these studies demonstrated that a SE concept is indeed feasible. In order to insure the highest probability of success, an SE concept would enable utilization of multiple proven technologies and a low risk overall design approach. The low risk, high reward, nature of a SE mission should ensure consideration as a viable mission element for any future Ocean World mission.

This presentation uses the findings of the TSE, the JPL Team-X, and the NIAC studies and previous work on scientific exploration of the Earth's oceans to outline the utility of a SE for exploration of Ocean Worlds. The Titan Submersible Explorer (TSE) is a simple concept that, when implemented, would enable scientists to investigate the depths of one of Titan's lakes. Similar to the Huygens probe, the TSE would be targeted by a Saturn Orbiter, released to enter Titan's atmosphere, and descend into one of the larger lakes. Once in the lake, the battery (or nuclear) powered TSE would accomplish two primary tasks: 1) evaluate chemistry at the surface of the lake, and 2) evaluate chemistry at the bottom of the lake. Evaluating chemistry at the lake's bottom is important due to potential interaction from material from an interior water ocean.

This venting could provide an environment that supports formation of organic compounds. Once the TSE has completed bottom analysis it will release its buoyancy control module and return to the surface of the lake. On the surface it will transmit its data back to the orbiter.



The challenges are great on Titan, but our study found that they are manageable. The temperature extremes, requisite data transfer, energy requirements, and the sequenced pyrotechnics envisioned have all been faced before. These difficulties, however, would be added to on Europa, Enceladus, or other icy worlds. 1) The challenge of penetrating a deep layer of ice to access a liquid ocean adds complexity to a mission like this. 2) The need to maintain a communication channel while operating below the ice layer would require additional solutions. 3) Of critical importance and a prime candidate for development is a very high level of autonomy that would allow the vehicle to operate independently for long periods without the need for telepresence or telecommunication. Such an approach is already being investigated, in its infancy, in a cooperation between WHOI and JPL [http://web.whoi.edu/oases-for-life/] and is recognized as a pre-requisite for the outer solar system where light times are prohibitively long.

We will present the science rationale for the submersible approach based on Earth experience. The simple TSE concept will be presented and expanded upon [12]. The presentation will also show how this simple concept can be generalized to other ocean world environments at Europa and Enceladus. Finally we will focus on near long term developments that are needed to make this technology viable by 2050: drilling through the ice core and autonomous systems.

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