Expeditions to the world's deepest serpentinite-hosted seep system, the Shinkai Seep Field, the southern Mariana forearc

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A serpentinite-hosted cold seep and associated ecosystem in the southern Mariana forearc near the Challenger Deep [Ohara et al., PNAS, 2012] was serendipitously discovered as a massive vesicomyid clam colony site during a DSV Shinkai 6500 dive for mantle peridotite mapping in September 2010. Although seeping fluids were not observed during the dive, the presence of a massive clam colony strongly indicated the presence of reduced fluid seepage. The site was therefore named the Shinkai Seep Field (SSF).

Serpentinite-hosted systems are believed to be significant incubators and habitats of early life on Earth as well as for extraterrestrial life such as on Saturn’s moon Enceladus. The SSF is the fourth known major location of such a serpentinite-hosted system in the ocean, following the Lost City hydrothermal field in the Mid-Atlantic Ridge, South Chamorro Seamount in the Mariana Forearc, and the Prony Bay hydrothermal field in New Caledonia. Among these, the SSF is the world’s deepest, located ~5700 m below the surface. In this contribution, we will outline past SSF expeditions and some research progress.

Following the SSF discovery, three JAMSTEC expeditions with DSV Shinkai 6500 (YK13-08, YK14-13 and YK15-11 cruises) and a single NSF-funded US expedition with a deep-towed side-scan sonar IMI-30 (TN273 cruise) investigated the SSF. These follow-up expeditions further discovered brucite and carbonate chimney sites and another vesicomyid clam colony sites [Okumura et al., G3, 2016], and a new species of *Provanna* (Gastropoda: Abyssochrysoidea) [Chen et al., J. Marine Biol. Assoc. UK., 2016]. In spite of many trials during the past expeditions, seeping fluid has not been observed. However, growth of chimneys and active biota from year-to-year indicates continued fluid flow [Okumura et al., G3, 2016].

The SSF formed in the southern Marianas, which is young and tectonically active. This tectonic setting differs from the Mariana forearc to the east, which has been stable for much longer, allowing large serpentinite mud volcanoes to grow. In contrast, SSF is very young and disorganized. SSF appears to be located just below the Moho and in a region with recent basaltic volcanism [Stern et al., Island Arc, 2014]. Based on the observations from the past expeditions, we estimate that the areal extent of the SSF is approximately 500 m by 300 m. However, this estimation is based on the shipboard multibeam bathymetry of R/V Yokosuka, which has the grid size of ~50 m. Therefore, our understanding of the spatial relationships of chimneys and clam colonies is not as well-constrained as it could be, hindering to discuss the subseafloor hydrological structure and geological background of the SSF.

In order to sample the seeping fluid and understand the detailed spatial relationship between SSF chimneys, a JAMSTEC expedition with ROV Kaiko Mk-IV (KR16-14 cruise) was performed in 2016. The expedition obtained the first *in situ* alkaline fluid sample (pH = 9.9) from the SSF. During the expedition, the Kaiko employed a multibeam sonar system, SeaBat 7125, obtaining the first near-bottom high-resolution bathymetric data with grid size of ~1 m. These new data and observations from KR16-14 cruise will help us understand the structure and evolution of the SSF, and provide avenues for further discoveries in the region.

Keywords: Shinkai Seep Field, Mariana forearc, serpentinite, brucite, carbonate, vesicomyid clam

Dynamics and Exploration of Titan's Seas

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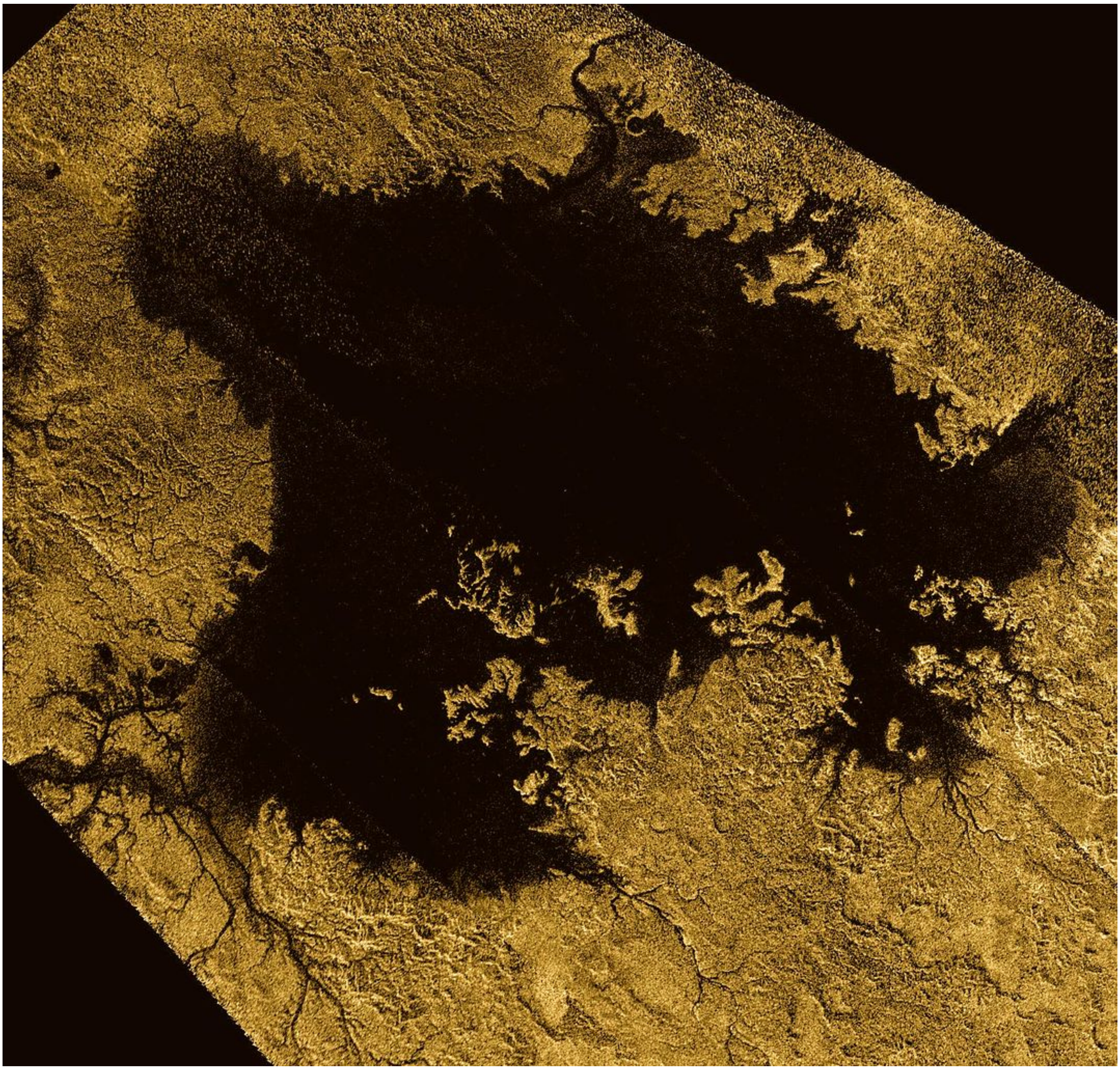
Saturn's moon Titan has seas of liquid hydrocarbons that are an important target for future exploration. The largest of these seas, Ligeia Mare and Kraken Mare, are ~400km and ~1000km in extent, respectively, and are composed of liquid methane at ~94K, with likely traces of ethane and other organic compounds. Titan's seas represent a novel laboratory for air:sea exchange and other hydrological and oceanographic processes.
Observations from the Cassini spacecraft, in particular its radar instrument, have measured the depth of Ligeia Mare to be ~160m, consistent with terrestrial basins of similar size. The tidal amplitudes have been predicted to be some tens of centimeters, and as surface windspeeds grow to 1-2 m/s as we approach northern summer in 2017, waves are expected to form. Cassini observations of sunglint and with radar/radio generally show the sea surface to be flat up to now, but some time-variable patches of reflectivity show that dynamic processes are active, and perhaps that waves are just beginning to form. The final observations of Titan's seas by Cassini in April 2017 are eagerly anticipated and a brief report may be made at this meeting.
During Titan's rainy summer, 10m or more of liquid may be added to the seas by rainfall. Some initial model results on the seas' response to this input will be presented –Ligeia may overflow rather quickly through the channel Trevize Fretum into Kraken.
Several proposals have considered future missions to Titan's seas, including a floating capsule, the Titan Mare Explorer (TiME). This envisaged a radioisotope-powered capsule in Ligeia Mare in 2023, which it would traverse over several weeks blown by the wind. More recently, the NASA Institute for Advanced Concepts (NIAC) has sponsored a study of a robot submarine to explore Titan's seas circa 2040. Aspects of these and other future exploration concepts will be discussed.

Keywords: Titan, Seas, Exploration



Microorganisms involved in the formation of distinctive iron oxide in deep-sea environments of Earth and even in extraterrestrial bodies

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It has been suggested that iron is one of the most important energy sources for photosynthesis-independent microbial ecosystems in the ocean crust of Earth. Iron-metabolizing chemolithoautotrophs play a key role as primary producers in anoxic-oxic interface environments, but little is known about their distribution and diversity, and ecological roles, particularly iron-oxidizers. Recently, many iron-dominated flocculent sediments have been discovered at the deep-sea hydrothermal fields in the world. These sites are excellent place for studying iron-utilizing microbial communities and their mineralization of Fe-(oxy)hydroxides associated with deep-sea hydrothermal activities. Indeed, it is still unclear how such microbial populations are involved in iron-dominated flocculent deposit formation. In this study, we analysed iron-dominated sediments from various deep-sea hydrothermal environments in the Western pacific by using culture-independent molecular techniques and X-ray mineralogical analyses. The SEM-EDS analysis and X-ray absorption fine structure (XAFS) analysis reveal chemical and mineralogical signatures of biogenic Fe-(oxy)hydroxides species as well as the potential contribution of iron-oxidizing bacteria to the *in situ* production. These key findings provide important insights into the mechanisms of both geomicrobiological iron cycling and formation of iron-dominated sediments in deep-sea hydrothermal fields. In addition, the formation and preservation mechanisms of biological produced iron-dominated sediments point to the possible microbial metabolisms and functions in the fossil records of iron oxide deposits such as banded iron formation (BIF) in the past Earth. Now, many peoples know that iron-oxide mineral deposits are also present in extraterrestrial bodies of our solar system such as Mars and Jupiter’ s moon Europa. The formation mechanisms of these extraterrestrial iron-dominating mineral deposits are highly unknown. However, if in situ observations and sample-return-based analyses in future astrobiological exploration of these extraterrestrial red-orange deposits will find certain specific iron oxide structures such as helical, twisted and stringing shapes associated with organic materials, the specific iron oxide structures will be significant bio-markers and will be useful for further detail exploration planning and strategy.

Dragonfly: Exploring Titan's Prebiotic Organic Chemistry and Habitability

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Titan offers abundant, complex, diverse carbon-rich chemistry on an ocean world (e.g., Raulin et al. 2010; Thompson & Sagan 1992), making it an ideal destination to study prebiotic chemistry (e.g., Neish et al. 2010) and document habitability of an extraterrestrial environment. Moreover, Titan's dense atmosphere and low gravity provide the means to access different geologic settings 10s - 100s of kilometers apart via exploration by an aerial vehicle.

It has long been recognized that Titan's rich organic environment provides a unique opportunity to explore prebiotic chemistry (e.g., CSWG on Prebiotic Chemistry in the Outer Solar System (Chyba et al. 1999; Lorenz 2000)), and development of mobile aerial exploration was considered a next step after Cassini-Huygens. Studies include airships, balloons, and fixed-wing vehicles (e.g., Leary et al. 2008; Barnes et al. 2012), but access to surface materials for analysis presents a challenge; and, while multiple in situ landers could address Titan's surface chemical diversity, multiple copies of instrumentation and sample acquisition equipment would be necessary.

A more efficient approach is to convey a single instrument suite to multiple locations using a lander with aerial mobility. Given Titan's atmospheric density (4x Earth's) and low gravity (1.35 m/s^2), heavier-than-air mobility is highly efficient (Lorenz 2000, 2001), and improvements in autonomous aircraft make such exploration a realistic prospect. A multi-rotor vehicle (Langelaan et al. 2017) is mechanically straightforward, as the proliferation of terrestrial quadcopter drones attests. Thus, the Dragonfly mission concept is a rotorcraft lander designed to take advantage of conditions on Titan to be able to sample materials in different geologic settings and understand how far prebiotic chemistry has progressed in environments that provide known key ingredients for life. Areas of particular interest are impact-melt sheets (Neish et al. 2017) and potential cryovolcanic flows where transient liquid water may have interacted with the abundant photochemical products that litter the surface (Thompson & Sagan 1992).

Bulk elemental surface composition can be determined by a gamma-ray spectrometer (Lawrence et al. 2017). Surface material can be sampled (Zacny et al. 2017) into a mass spectrometer (Trainer et al. 2017) to identify the chemical components available and processes at work to produce biologically relevant compounds. Seismic sensing can probe subsurface structure and activity. And meteorology (Wilson & Lorenz 2017) and remote sensing measurements can characterize Titan's atmosphere and surface.

Dragonfly is a revolutionary concept providing the capability to explore diverse locations to characterize the habitability of Titan's environment, investigate the progression of prebiotic chemistry, and search for chemical signatures indicative of water- or hydrocarbon-based life.

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Keywords: Titan, Prebiotic chemistry, Habitability

In Situ Sample Analysis and Sample Return Exploration from Deep Habitats of the Ocean Worlds

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Disocovery of sub-surface water reservours of icy bodies in the Solar System has revolutionalized a concept of the habitable zone. Now potential deep habitats like Europa and Enceladus have received rigorous exploration mission studies from space agencies, scientists and engineers worldwide. In particular, present icy plumes from the southern polar region of Enceladus, a Saturnian satellite of 500 km in diameter, has yielded chemical composition of the global ocean water containing organics, salts, and minerals implying hydrothermal activities at its sea floor, thanks to the investigations by the Cassini spacecraft.
Together with a new launcher with a great delta V like NASA's SLS rocket soon to be launched in 2018 or so, "Ocean Worlds" exploration is a next logical step for astrobiology-driven robotic space explorations in 2020's to the mid 21st Century. The main scientific objectives are understanding the habilility conditions of these deep habitats and life detection in these "eco systems". To do so, a number of innovative exploration strategies are essential, including life detection instruments, sample collection and analysis methods, as well as planetary protection countermeasures of the collected samples.
In this presentation, we discuss a possible game changing strategy of sample return science for "restricted Earth return" samples, by employing synergy between lessons learned from terrestrial deep sea exploration and sample handling and current developments of next generation sample collection and analysis instruments in deep space missions.

Keywords: Deep Sea Exploration, Subsurface Ocean, Icy Plumes

Oceanus: A New Frontiers orbiter concept to study Titan's potential habitability

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Cassini has demonstrated that Titan is an organic world of two oceans: surface hydrocarbon seas [1,2] that cover part of the north polar region and a deep water ocean [3] that decouples the outer ice crust from an inner core likely composed of hydrated silicates [4]. The Cassini mission also demonstrated that Titan's reduced nitrogen-rich atmosphere operates as an organic factory [5] where heavy organic molecules are produced by a series of reactions starting by the photolysis of methane [6,7]. Oceanus is a proposed orbiter concept that would follow up on Cassini's amazing discoveries and assess Titan's habitability. By following the organics and the water, this Titan orbiter carries a straightforward payload and will (i) Determine the chemical processes producing the heavy organic molecules in Titan's upper atmosphere, (ii) Follow the transport of organics at the surface as climate has evolved, (iii) Determine if organics and water have mixed in the crust, and (iv) Determine whether geological processes have allowed for the transport of organics into Titan's subsurface ocean.
The New Frontiers 4 AO includes the theme "Ocean Worlds (Titan and/or Enceladus)" focused on the search for signs of extant life and/or characterizing the potential habitability of Titan and/or Enceladus. The Titan's science objectives are (i) Understand the organic and methanogenic cycle on Titan, especially as it relates to prebiotic chemistry; and (ii) Investigate the subsurface ocean and/or liquid reservoirs, particularly their evolution and possible interaction with the surface. Oceanus would not only address these two science objectives but would also be responsive to a large number of the important science questions defined by the 2011 Decadal Survey.
Oceanus would provide the data that can shed light on the organic chemistry that operated on Earth when life emerged 4 billion years ago [8]. At that time Earth was a 'pale orange dot' that eventually became the living planet we know today. That "pale orange dot" version of Earth had plenty of liquid water in its oceans and energy in the form of sunlight. However, we do not know the roles that carbon chemistry played to enable the development of an Earth's biology. Given how active tectonics has erased the geologic record of Early Earth, information about how those processes has been lost. Oceanus would provide that information.
Oceanus would address these questions with three high-heritage instruments that address the potential habitability of Titan: an infrared camera that would acquire 25 m pixel size images of Titan's surface at 1500 km altitude, a radar altimeter that would provide a global topography and measurements of the time-dependent deformation of Titan's surface, and a mass spectrometer capable of characterizing the processes that build the heavy molecules fabricated in Titan's upper atmosphere as well as determining

their building blocks. In addition, information on the gravity field would be obtained from the Doppler shift of the microwave carrier used in the radio link to the ground.

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