Ocean Worlds Working Group Update

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“Recommendation: NASA should develop scientific exploration strategies, as it has for Mars, in areas of broad scientific importance, for example, Venus and ocean worlds that have an increasing number of U.S. missions and international collaboration opportunities.”

- Origins, Worlds, and Life (p. 568)

“Response: NASA does not concur with this recommendation and asserts that specific scientific exploration strategies should be community-generated by bodies such as the Analysis Groups, advisory committees, and NASEM’s standing boards and commissioned studies.”

- NASA’s 90-Day Response to the 2023-2033 Decadal Survey (p. 20)

The OWWG was founded by OPAG, SBAG, and NOW to “create an actionable ocean worlds exploration strategy.”

Approach:

Utilize previous community efforts to define prioritized science questions and identify the technology development necessary to answer them.

Activities:

- Community review of relevant literature (Decadals, White papers, peer-reviewed lit.)
- Organization and prioritization of key science questions
- Identification of required measurements and critical technology

Actions:

- Community Q&A session at LPSC (March)
- Working meetings of subgroups in February and April
- Joint meeting in June
  - Groups working on science – technology traceability

Expected Outcomes:

- A limited set of prioritized science questions that link directly to necessary technology development.
- A limited set of missions that address these prioritized questions, fit within NASA's existing structures, and are prioritized for additional study.
- A strong, diverse, and welcoming Ocean Worlds community.

Community review of relevant literature

Shared with me › OWWG_Science Goals › Literature › Reviews Draft

Type | People | Modified

Name	Owner	Last modified	File size
Geochemistry	amarusiak	Apr 9, 2024 amarusiak	—
Geophysics (Deep interior)	wingwong2007@u.north...	Mar 27, 2024 wingwong200...	—
Geology	mfz3@nau.edu	Mar 27, 2024 mfz3@nau.edu	—
Spectroscopy	andreas.riedo@gmail.com	Mar 25, 2024 andreas.riedo...	—
Geophysics (Shallow)	himani.tanish@gmail.com	Mar 24, 2024 himani.tanish...	—
Astrobiology	srb558@nau.edu	Mar 24, 2024 srb558@nau....	—

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Name	Owner	Last modified	File size
Summary_DecadalSurvey_Question5	anton.i.ermakov@gmail.c...	Apr 19, 2024 anton.i.ermak...	7 KB
Summary_Cockell+2024	anton.i.ermakov@gmail.c...	Apr 19, 2024 anton.i.ermak...	2 KB
Summary_ermakov_21.docx	wingwong2007@u.north...	Apr 10, 2024	290 KB
Summary_RoadMapToOW_Hendrix_2019	Joe Renaud	Apr 9, 2024	5 KB
OPAG goals-03-18 annotated.pdf	james.h.roberts@gmail.c...	Apr 5, 2024 james.h.robert...	13.4 MB
Summary_Cartwright21	james.h.roberts@gmail.c...	Apr 4, 2024 james.h.robert...	4 KB
Summary_german_22.docx	wingwong2007@u.north...	Mar 27, 2024 wingwong200...	21 KB
Summary_vance_17.docx	wingwong2007@u.north...	Mar 26, 2024 wingwong20...	16 KB

- Let individuals build familiarity with existing work
- Crowd source the monumental task of "summarizing the literature"

Summary

Of German et al. 2022 (Ocean system science to inform the exploration of ocean worlds, *Oceanography*, 35(1):16-22.)

The Summary is prepared by Teresa Wong

This Summary contains gathered ideas, notes, quotes, and rephrased statements relevant to the Science Goal part of the *Strategic Plan for Ocean Wolds Exploration* developed by the *Cross-AG Ocean Worlds Working Group*.

Notions: German et al. 2022 = Ger22; Red font is used for suggested insets to the Strategic Plan; Blue font is used for quote references.

Short information about the article: Ger22 discusses avenues of research for ocean worlds, including Earth's ocean and oceans on other planetary bodies. This article addresses the questions of sources of chemical energy available for life from geophysical and geochemical processes, and the transportation and modification of biosignatures to be detected. (Ger22-p2, l-col, fig-1)

"In brief, we advocate for applying ocean systems science to the future investigation of ocean worlds beyond Earth." (Ger22-p1, r-col) (Motivation/Terrestrial analog section with reference)

Quotes:

"Earth's ocean scientists, however, have a wealth of expertise in understanding how geophysical processes within a planet's interior can influence both heat flux and the possibility of lateral variability in the character of an ocean world's seafloor." (Ger22-p3, m-col) (Motivation/Terrestrial analog section with reference)

- "The material properties of this rocky component of an ocean world will also be important in controlling the hydrology of any fluids that circulate through, extract heat from, and react chemically within the subseafloor environment." (Ger22-p3, m-col)
- "…residual topography in a submarine environment can impart lateral differences in pressure or heat flow at the seafloor that could be sufficient to support subseafloor fluid circulation." (Gerr22-p3, m-col)

"The physical regime of an ocean world will determine the reaction conditions at which ocean-derived fluids and the rocks that those fluids cycle through interact; pressure, temperature and flow rate are all important in dictating the products generated from any set of reactants." (Ger22-p3, r-col)

- "Combining the spectrum of possible reactant compositions with the pressure, temperature, and flow rate for subseafloor fluid flow allows a wide array of possible chemical reactions to be anticipated that can generate varying concentrations and fluxes of reaction products that can be released back to the overlying ocean." (Ger22-p3, r-col)
- "Theoretical modeling can be used to predict the cumulative outputs of such chemical reactions, together with their potential energy yield" (Ger22-p4, l-col) (Methodology section with reference)
- "…under conditions where the energetics to support life are predicted to be particularly favorable, laboratory experiments to simulate the same reactions can be conducted both to test the model predictions and to investigate how kinetically controlled processes permit the

Organization and prioritization of key science questions

Expertise Group	Submitted Science Questions
Shallow Geophysics	What are the major geophysical processes that have influenced ocean world surfaces/subsurfaces? How have these evolved over solar system history?”
Astrobiology	Is there a chiral signature for molecules in the subsurface oceans of icy moons like Europa and Enceladus? What does the presence of these molecules imply about potential extraterrestrial life? What are the key molecular signatures ejected from plumes on ocean worlds like Enceladus? How can past or present life be detected on ocean worlds? How can they be used to distinguish between biotic and abiotic processes, and what are the implications for the origin of these molecules?
Geology	How does geological features help indicate an ocean environment? What features should we be in search of to help support these possible oceans? What geological surface features indicate an ocean environment How do those features indicate geophysical processes and how moons evolved over time

TABLE S-1 The Twelve Priority Science Questions

Scientific Themes	Priority Science Question Topics and Descriptions
(A) Origins	Q1. *Evolution of the protoplanetary disk.* What were the initial conditions in the solar system? What processes led to the production of planetary building blocks, and what was the nature and evolution of these materials?
	Q2. *Accretion in the outer solar system.* How and when did the giant planets and their satellite systems originate, and did their orbits migrate early in their history? How and when did dwarf planets and cometary bodies orbiting beyond the giant planets form, and how were they affected by the early evolution of the solar system?
	Q3. *Origin of Earth and inner solar system bodies.* How and when did the terrestrial planets, their moons, and the asteroids accrete, and what processes determined their initial properties? To what extent were outer solar system materials incorporated?
(B) Worlds and Processes	Q4. *Impacts and dynamics.* How has the population of solar system bodies changed through time, and how has bombardment varied across the solar system? How have collisions affected the evolution of planetary bodies?
	Q5. *Solid body interiors and surfaces.* How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?
	Q6. *Solid body atmospheres, exospheres, magnetospheres, and climate evolution.* What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states?
	Q7. *Giant planet structure and evolution.* What processes influence the structure, evolution, and dynamics of giant planet interiors, atmospheres, and magnetospheres?
	Q8. *Circumplanetary systems.* What processes and interactions establish the diverse properties of satellite and ring systems, and how do these systems interact with the host planet and the external environment?
(C) Life and Habitability	Q9. *Insights from terrestrial life.* What conditions and processes led to the emergence and evolution of life on Earth; what is the range of possible metabolisms in the surface, subsurface, and/or atmosphere; and how can this inform our understanding of the likelihood of life elsewhere?
	Q10. *Dynamic habitability.* Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time?
	Q11. *Search for life elsewhere.* Is there evidence of past or present life in the solar system beyond Earth, and how do we detect it?
	nets. What does our planetary system and its circumplanetary systems of satellites and about exoplanetary systems, and what can circumstellar disks and exoplanetary systems ut the solar system?

- Origins, Worlds, and Life

Hendrix et al. (2019): The ROW	Identify Ocean Worlds		Characterize Oceans		Assess Habitability		Search for Life
	Energy Sources	Ocean Signatures	Solvents	Rock/Ocean Interface	Energy for Life	Physico-chemical Conditions for Life	Biomarkers

Identification of required measurements and critical technology

Science Question 1 for OWWG

Science Questions	Science Goals	Science Objectives	Measurements	Enceladus	Europa	Ceres	Titan	Triton	Pluto	Uranus (UOP)
				Architecture / Instruments / Observations by Target						
Do water oceans exist in the interiors of outer solar system bodies? Which bodies have oceans today?	**Reveal interior structures of icy worlds**	Determine ice thickness and ocean thickness	reflections off ice-ocean and ocean-rock layers	orbiter: radar sounder; lander: seismometer	orbiter: radar sounder; lander: seismometer	orbiter: radar sounder; lander: seismometer	orbiter: radar sounder; lander: seismometer	orbiter: radar sounder; lander: seismometer	orbiter: radar sounder; lander: seismometer	
			in situ inversion of multiple geophysical waves	lander or penetrator: network of seismometers	lander or penetrator: network of seismometers	lander or penetrator: network of seismometers	lander or penetrator: network of seismometers	lander or penetrator: network of seismometers	lander or penetrator: network of seismometers	
			measure induction response	could work due to Enceladus eccentricity, but complexities due to plume. Magnetometer could detect from orbit; signal would be stronger from surface. (True for all) depends on conductivity/salt content	orbiter: magnetometer; lander: magnetotellurics	could use solar magnetic field? https://iopscience.iop.org/article/10.3847/PSJ/acaf6a/meta		probably would work depending on amplitude? orbiter: magnetometer; lander: magnetotellurics		induction would work great at Uranus system, especially for inner moons
			measure obliquity, and libration over several tidal cycles	orbiter: Stereo imager, InSAR, optical imager, laser altimeter	orbiter: Stereo imager, InSAR, optical imager, laser altimeter		orbiter: SAR imaging	orbiter: Stereo imager, InSAR, optical imager, laser altimeter		
			Determine regional and local topography	orbiter: laser altimeter, radar altimeter	orbiter: laser altimeter, radar altimeter	orbiter: laser altimeter, radar altimeter	would a radar altimeter work on Titan?	orbiter: laser altimeter, radar altimeter	orbiter: laser altimeter, radar altimeter	
			Measure h2	orbiter: Optical imager, laser altimeter, radar altimeter	orbiter: Optical imager, laser altimeter, radar altimeter	orbiter: Optical imager, laser altimeter, radar altimeter	would this work?	orbiter: Optical imager, laser altimeter, radar altimeter	orbiter: Optical imager, laser altimeter, radar altimeter	
			Measure k2, measure degree-2 gravity field	orbiter: gravity / radio science	orbiter: gravity / radio science	orbiter: gravity / radio science	orbiter: gravity / radio science	orbiter: gravity / radio science	orbiter: gravity / radio science	
		Are there lateral heterogeneities within the ice shell and ocean? (OR split this to have physics vs. chemistry, ice shell vs. ocean)	Measure density / gravity anomalies within the ice shell	orbiter: gravity ranger	orbiter: gravity ranger	orbiter: gravity ranger	orbiter: gravity ranger	orbiter: gravity ranger	orbiter: gravity ranger	
			Search for variations in seismic arrival times and waveforms	Lander / subsurface penetrator: seismometer	Lander / subsurface penetrator: seismometer	Lander / subsurface penetrator: seismometer	Lander / subsurface penetrator: seismometer	Lander / subsurface penetrator: seismometer	Lander / subsurface penetrator: seismometer	

Current and future activity

- OWWG leadership is finalizing top leveling wording (for community feedback)
- Science Goals subgroup is working to build out key measurements based on these questions
- Technology subgroup is identifying critical technology development based on the measurements

Get Involved!

- All of the material is open and available
- OWWG Mailing List at www.lpi.usra.edu/owwg
- Join us on Slack