DARES Focus Area #4

Comparative planetology of habitable worlds, opportunities for Earth exploration connecting to the next generation of astrobiology exploration of the solar system and beyond

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Summary: Employ and improve comparative planetology, including our own planet Earth, as part of the next phase of understanding and search for life in the universe.

Image: Google Gemini

Overview (findings)

What is this Focus Area about?

1. Planetary exploration bridges our evolving understanding of Earth to other bodies in the solar system and beyond
2. Field studies on Earth can be vital to developing the needed technologies, and they also present synergies with studies of our own planet
3. Planning should begin now for ocean access

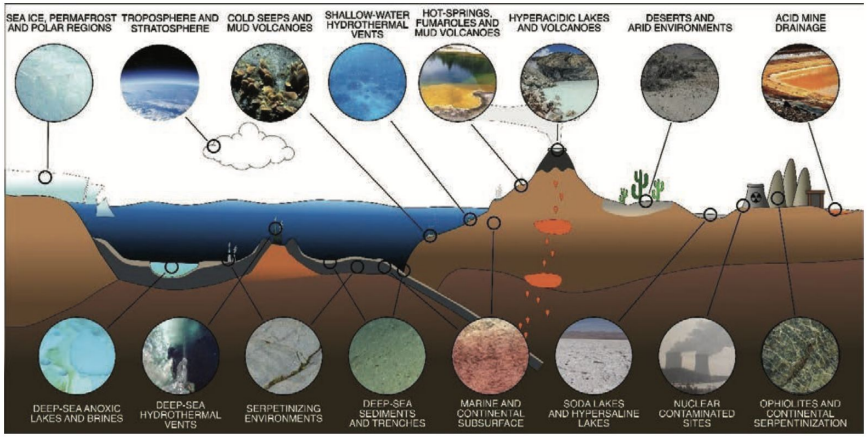
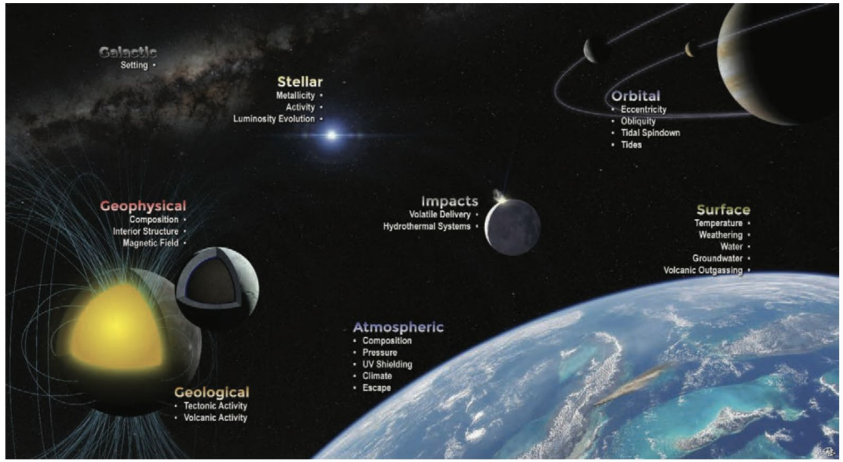
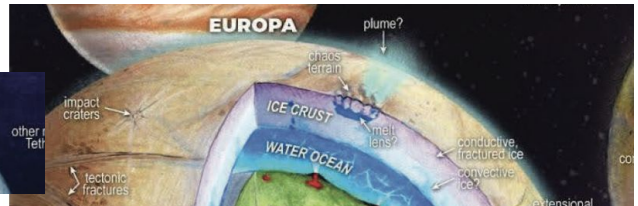


FIGURE 12-4 Representative idealized cross section of Earth's crust showing the diversity of so-called extreme habitable environments and their approximate location. SOURCE: Merino et al. (2019), CC BY 4.0.

from OWL Planetary Decadal





Overview

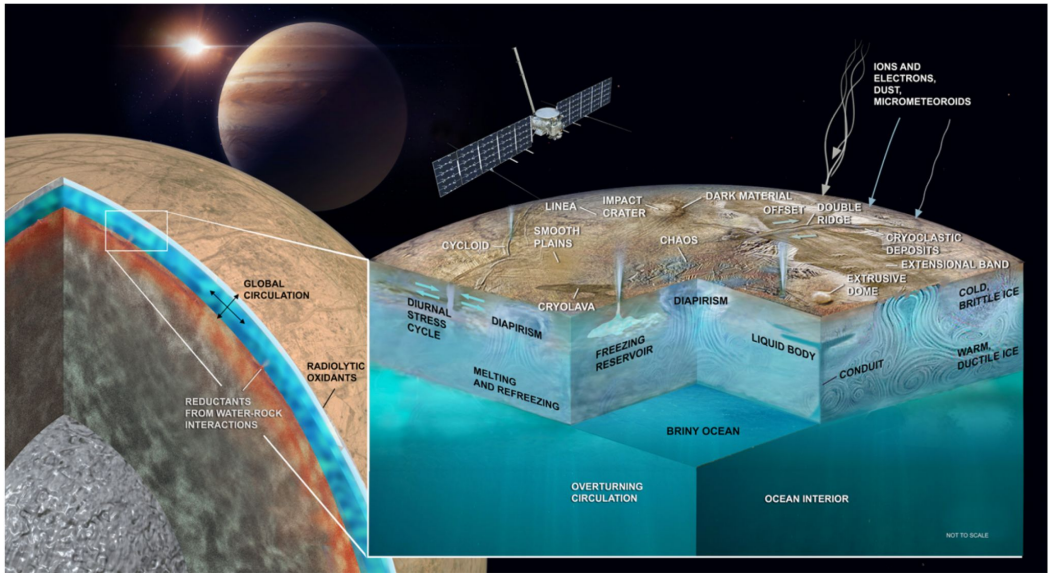
Why is this Focus Area important to NASA Astrobiology?

- NASA's Astrobiology program is a nexus for **comparative planetology**, including the continued study of our own planet
- Opportunities may exist for stronger partnerships between NASA directorates and science agencies
- 2019 NASEM, 2023 "Origins, Worlds, Life" Planetary Decadal Survey emphasize dynamic habitability, understanding the coevolution of worlds and life (see Focus Area 3)
- Stronger partnerships with e.g. NSF will address this topic while meeting other agency goals
- E.g., Integrated Ocean Drilling and NASA Science Workshop Report

Overview

Why is this Focus Area important to NASA Astrobiology?

Missions: The next generation of planetary missions focused on habitability life detection demands greater fidelity of understanding dynamic habitability and environments, strengthening the tie to the detailed exploration of our home planet



Vance et al. 2023

Key Findings from RFI Synthesis

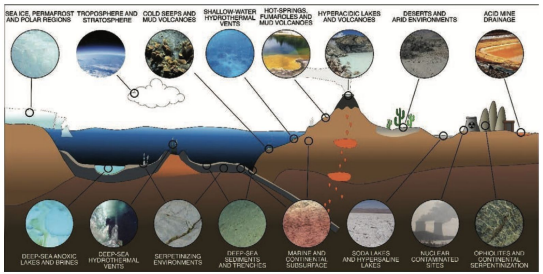
Finding 1: ***Planetary exploration bridges our evolving understanding of Earth to other bodies in the solar system and beyond***

- The **outer solar system and ocean worlds** continue to be important for astrobiological study
  - past ocean worlds—e.g., Ceres, Callisto—and current ocean worlds (e.g. Europa, Enceladus, Ganymede, Titan)
  - OWL priority Uranus Orbiter and Probe would reveal the workings of ice giants relevant to exoplanets while also exploring five potentially habitable mid-sized icy moons
  - Next flagship priority Enceladus Orbilander provides a real chance to search for life
  - Possibility to access oceans directly following Europa Clipper, Juice, and Dragonfly
  - These missions often look back at Earth, providing key information relevant to exoplanet characterization efforts
- Terrestrial planets are key to understanding Earth in context, and exoplanets different from Earth
  - Planned **lunar exploration** offers a chance for rapid development of technology and knowledge of planetary processes
  - Earth's earliest history might be recorded in ancient ejecta strewn across Moon's surface. The Moon could serve as a biorepository for Earth, and a strategic site for large telescopes
  - Interiors of Mars and Venus remain mysterious, but both hold clues to how their habitability evolved through time
  - Venus holds clues to Earth's thermal evolution, fate of water, potential life in the atmosphere
- Astrophysical observations, especially from JWST and HWO, are key to understanding our solar system, in synergy with characterizing habitable planets around other stars
  - Earth spectra and earthshine are key to understanding exoplanet signatures of life, as is the study of Earth's evolution

Key Findings from RFI Synthesis

Finding 2: ***Field studies on Earth can be vital to developing the needed technologies, and they also present synergies with studies of our own planet.***

- Dedicated access to planetary analogues for Mars, Venus, and ocean worlds:
  - High deserts, volcanic settings, caves, dune fields
  - ice covered regions: Antarctica (NASA-NSF partnership), Greenland, Alaska, Svalbard…
  - autonomous under-ice and ocean exploration
  - workings and geology of the seafloor through mapping, sampling
  - ocean drilling—combine NSF and NASA datasets, address Earth's climate; redox fluxes and limits to life; impacts, plate tectonics, and geohazard prediction; volcanism



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Atacama Desert, Chile

NASA scientist Mary Beth Wilhelm collects soil samples to analyze. Studying ancient life in the driest places on Earth helps us to understand conditions on Mars. Credit: NASA

Key Findings from RFI Synthesis

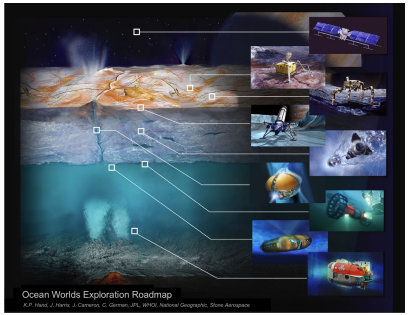
Finding 2: ***Field studies on Earth can be vital to developing the needed technologies, and they also present synergies with studies of our own planet.***

- Partner in these efforts with NSF, NOAA, international space and geoscience agencies/organizations

From the 2024 IODP-NASA Workshop report: *synergies between scientific ocean drilling as presented in the 2050 Science Framework and research emphases within NASA Earth Science and Planetary Science divisions.*

	Division	Research Emphasis	Ocean Drilling Research: 2050 Science Framework
NASA Science Mission Directorate	Earth Science	Climate Variability & Change	FI: Ground Truthing Future Climate Change; SO: Earth's Climate System
		Carbon Cycle & Ecosystems	SO: Global Cycles of Energy & Matter
		Earth Surface and Interior (including natural hazards)	FI: Probing the Deep Earth; FI: Assessing EQ & Tsunami Hazards; SO: Natural Hazards Affecting Society
	Planetary Science	Origin & Evolution of Life	FI: Exploring Life & it's Origin; SO: Habitability & Life on Earth
		Origin & Evolution of Planetary Bodies	FI: Probing the Deep Earth; EE Terrestrial to Extraterrestrial
FI = Flagship Initiative; SO = Strategic Objective; EE = Enabling Element			

Key Findings from RFI Synthesis



Cwik, KISS Accessing Ocean Worlds 2017

Finding 3: ***Planning should begin now for ocean access***

- Preparing to explore ocean worlds is a generational challenge that needs active investment now: NASA should prioritize addressing the challenges to ocean access and the technology requirements for in situ sampling in the search for biosignatures if they are to happen in the coming decades
    - Technology is needed for landing, drilling through and operating in ice, and for transitioning to operating in the ocean. Previous NASA investments (ICEE, COLDTech, PSTAR, ASTEP, SESAME) jump-started this work, and it needs to continue
    - Concepts of operations for these missions also need further development in concert with tech development NASA Astrobiology can ensure future ocean access missions by supporting a coherent strategy for ocean world exploration similar to NASA's Mars Exploration Science Goals
    - Continued investment in Research and Analysis, Technology. E.g. instrumentation, facilities, the next generation of habitability analysis merging geology, geochemistry, geophysics
    - Strategic agency partnerships—e.g. NOAA, NSF, JAXA, ESA

Why this Focus Area now?

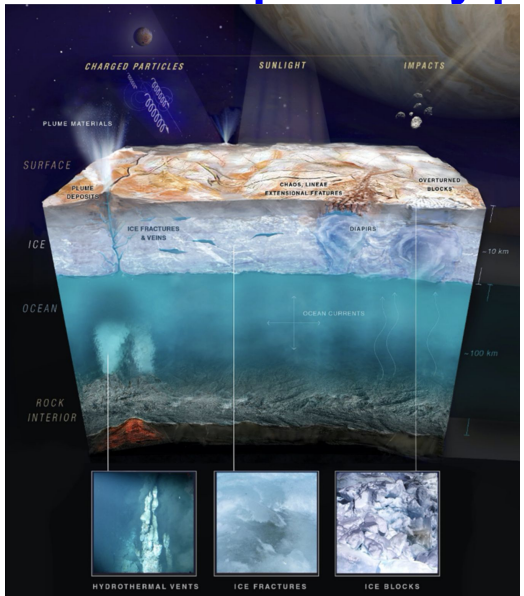
Differences from the 2015 Astrobiology Strategy

- Touches on topics 4,5,6 of the 2015 Astrobiology Strategy: coevolution of life-environment, habitability and biosignatures, constructing habitable worlds
  What is different: stronger integration across NASA Divisions, stronger coupling between new generation of missions and telescopes, Earth exploration
- Expanding on the directive of the 2015 Astrobiology Strategy to ***consider / characterize organic distribution in the solar system and beyond. JWST and HWO enable that to a greater degree. Planetary missions since 2015, including those yet to begin, dramatically improve organic detection and characterization.***

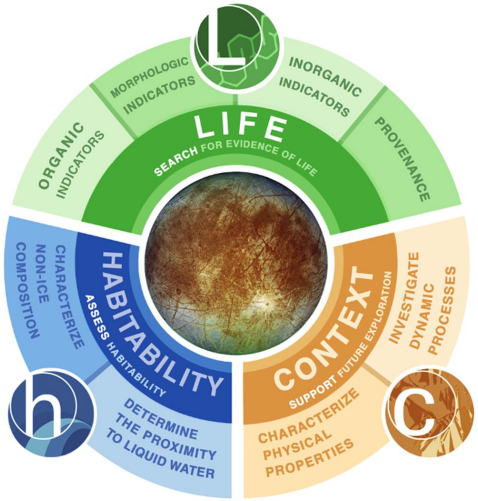
Why this Focus Area now?

Differences from the 2015 Astrobiology Strategy

2016 Europa Lander study (e.g. Hand et al. 2022), Ladder of Life Detection (Neveu et al. 2018) have refined approach to habitability and life detection linked to planetary processes



Hand et al. 2022



Neveu et al. 2018

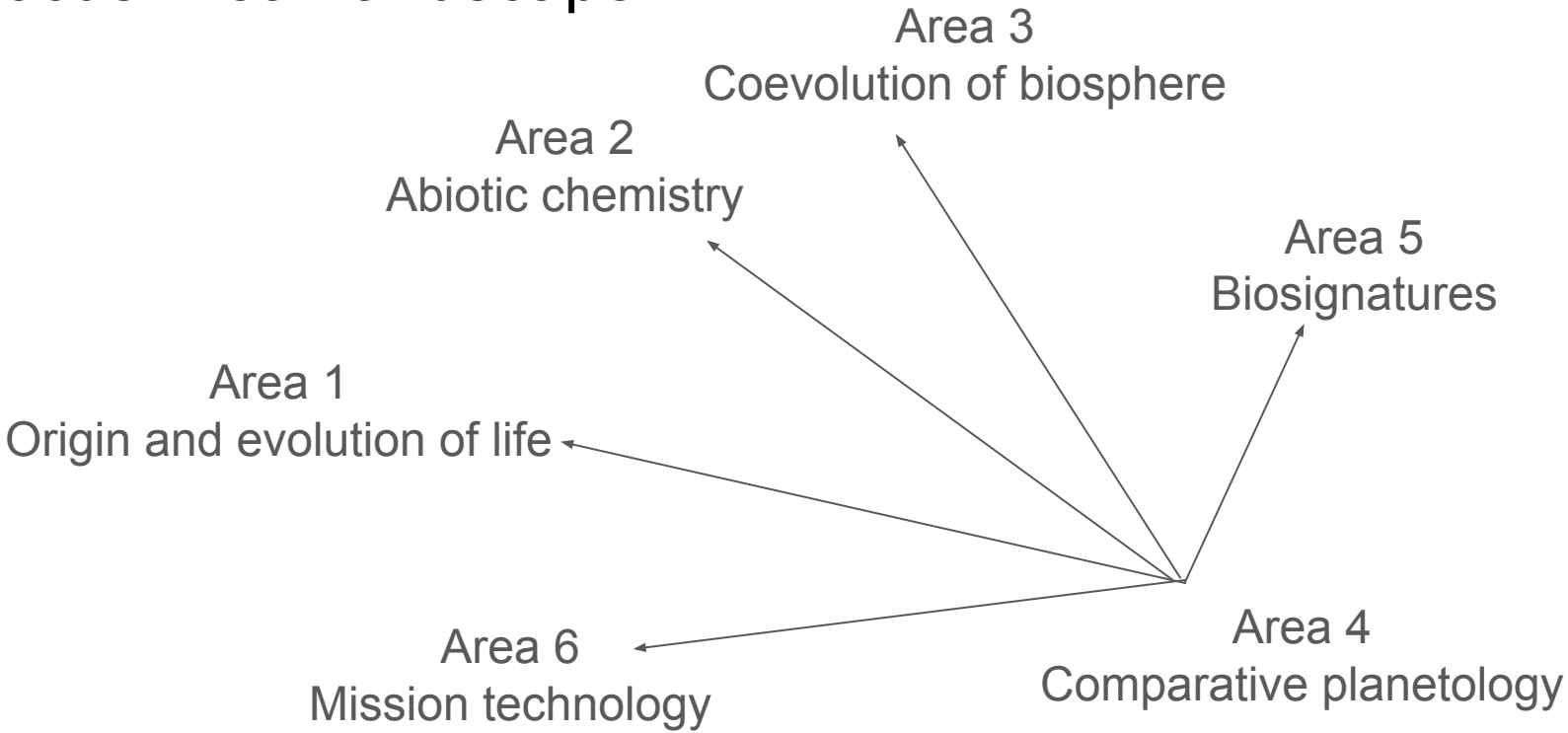
Feature	Permutations A	B	C
Morphologies	0	0	1
Isotopic fractionations	0	1	1
Mineralogical evidence	0	0	0
Large enantiomeric excess	1	1	1
Complex organics	1	1	1
Patterns in organic mixtures	0	0	0
Life Detection Result	1	1	1

If A is 1 then B and C are 1

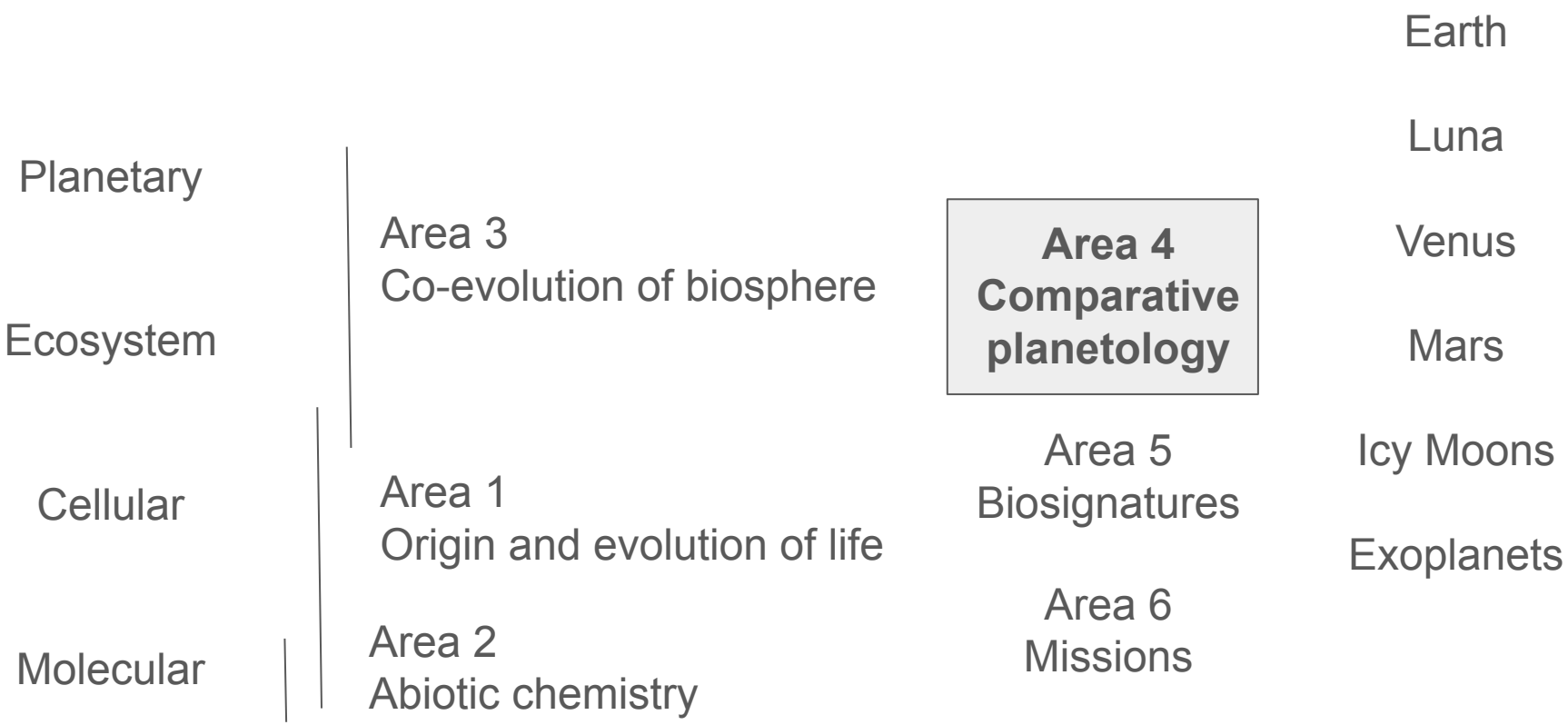
Focus Area Landscape

- Key research areas, NASA science divisions/mission directorates, planetary environments, technologies, missions, communities, etc.
- (Consider visuals like tables or venn diagrams)
- Opportunity to present uncertainties that came up during TF1 that require additional attention during discussion

Focus Area Landscape



Focus Area Landscape



Focus Area #4 Summary

- Comparative planetology is our bridge between Earth and other worlds, including the Moon, Venus, Mars, outer solar system, and icy bodies
- Field studies on Earth are opportunities for astrobiology technology development and for synergies with other areas of astrobiology
- Effective astrobiology missions to the outer solar system require long-term planning now
- Integration across NASA divisions and partnerships with other agencies are essential