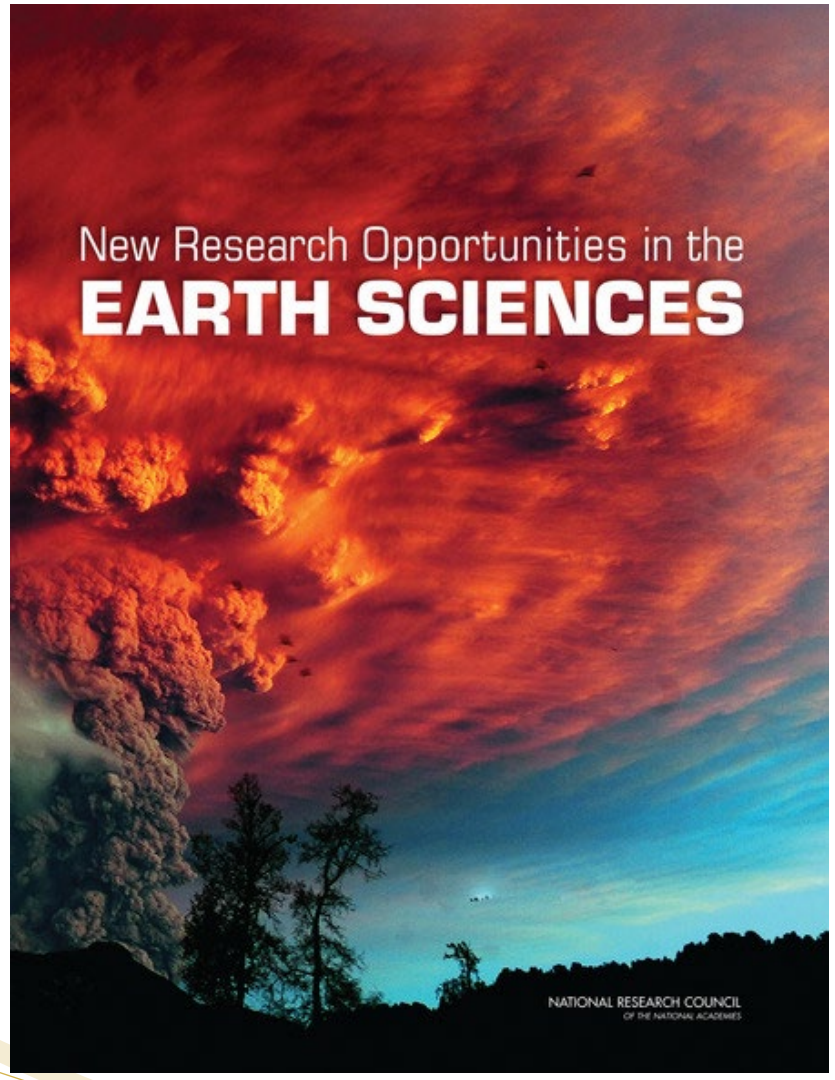
NASEM Decadal Survey on Biological and Physical Sciences Research in Space 2023-2032

The study will generate consensus recommendations to implement a comprehensive strategy and vision for a decade of transformative science at the frontiers of biological and physical sciences research in space.

Steven L Goldstein
Senior Science Advisor
Directorate for Geosciences

National Research Council 2001



Finding 1:

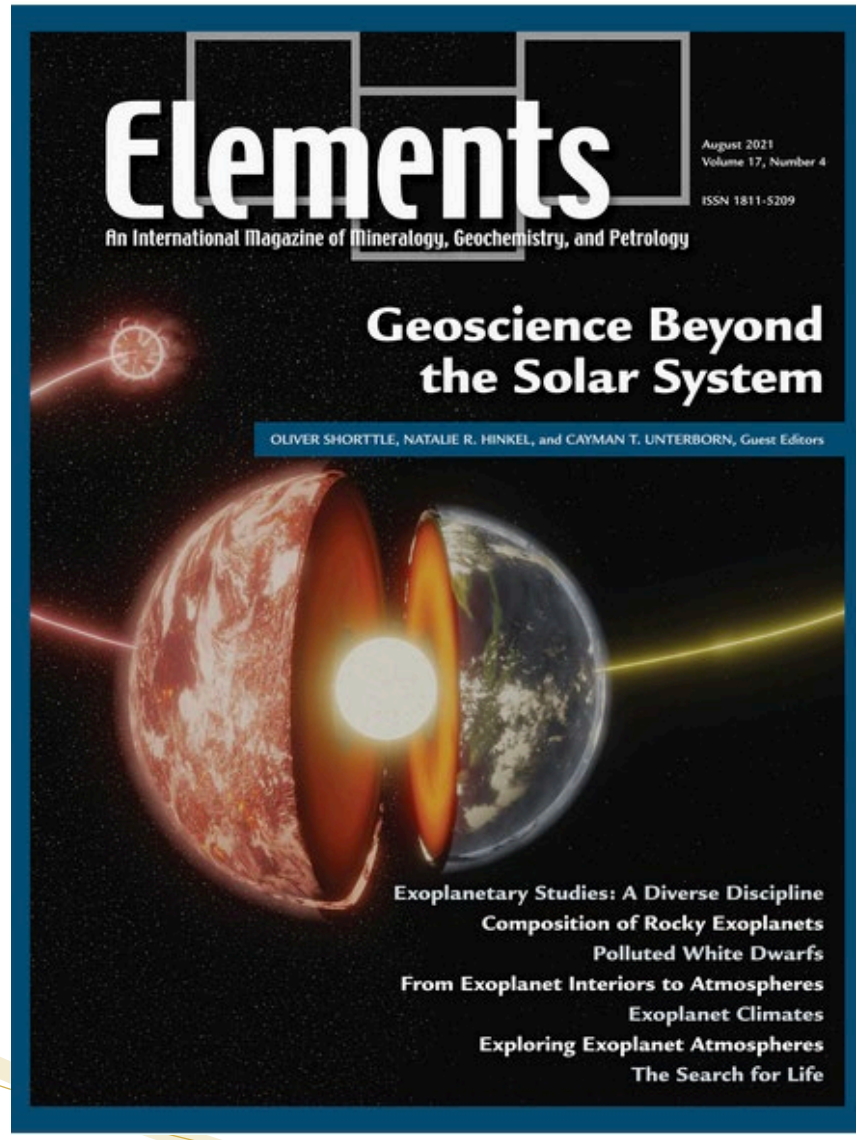
"Advances can come from collaborations with astronomy, astrophysics, planetary science, exoplanet detection and characterization, and astrobiology …

… coordination with the research efforts of [NASA] is particularly relevant, because NASA supports research on *detection and comparison with exoplanetary systems; origins of life and biological materials in our solar system; meteorite, asteroid, and solar system dust sampling; and large-scale modeling of planetary system formation."*

https://www.nap.edu/catalog/13236/new-research-opportunities-in-the-earth-sciences

August 2021

Elements – published by the major geochemistry, mineralogy, petrology societies



http://elementsmagazine.org/past-issues/geoscience-beyond-the-solar-system/

NSF/GEO Support for Space Analog Research

NSF 22-032

December 17, 2021

Dear Colleague Letter: Geoscience Lessons for and from Other Worlds (GLOW)

"GLOW" DCL: *NSF GEO/AGS, GEO/EAR, MPS/AST*

- *use other worlds to broaden understanding of the Earth;*
- *use geoscience knowledge to understand the environments of other worlds;*

Driven by increasing interest in exoplanets in both the Geosciences and Astronomy

Science drivers include:

- *What can the study of other worlds reveal about:*
  - *… Earth's past and future climate?*
  - *… interactions between the Earth and space environment?*
  - *… environments and processes that shape other worlds?*
  - *… possibility of life on other planetary bodies*

- How can our basic science understanding of Earth processes and systems guide the identification of other habitable worlds?

Exoplanet analogs – Life in Extreme Environments on Earth

Parameters that limit life:
temperature, pressure, water activity/salinity, acidity/alkalinity, radiation

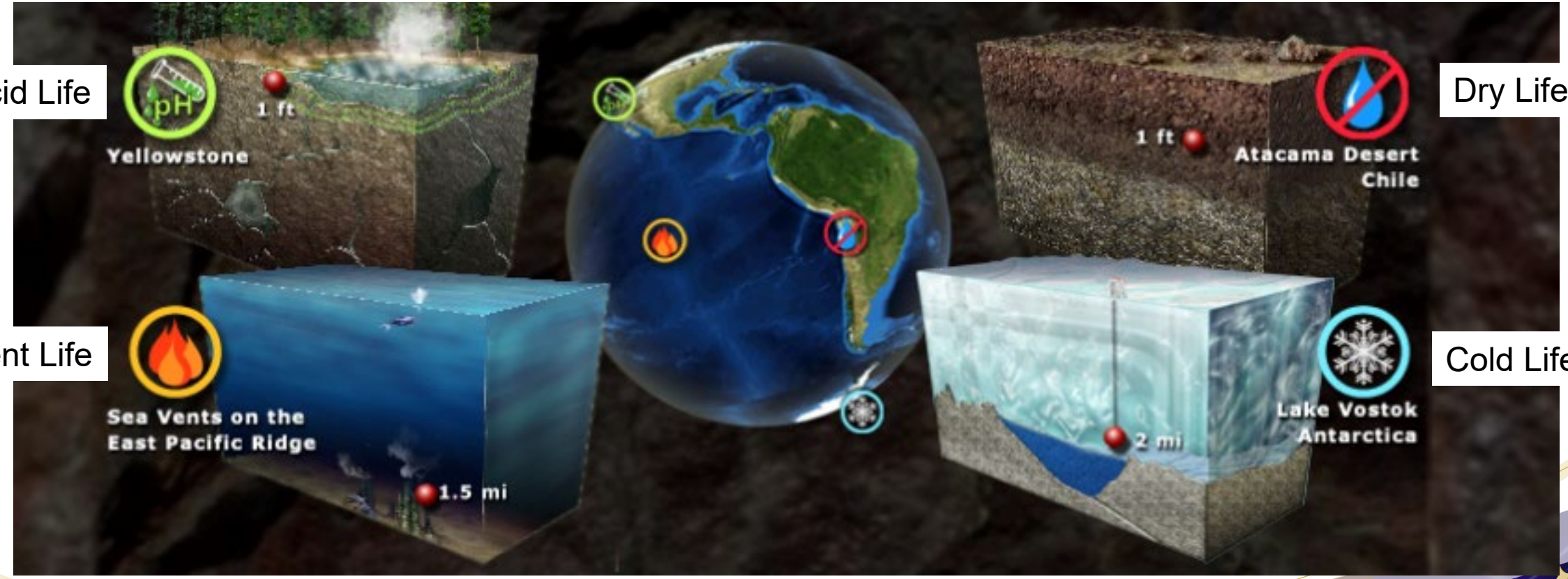
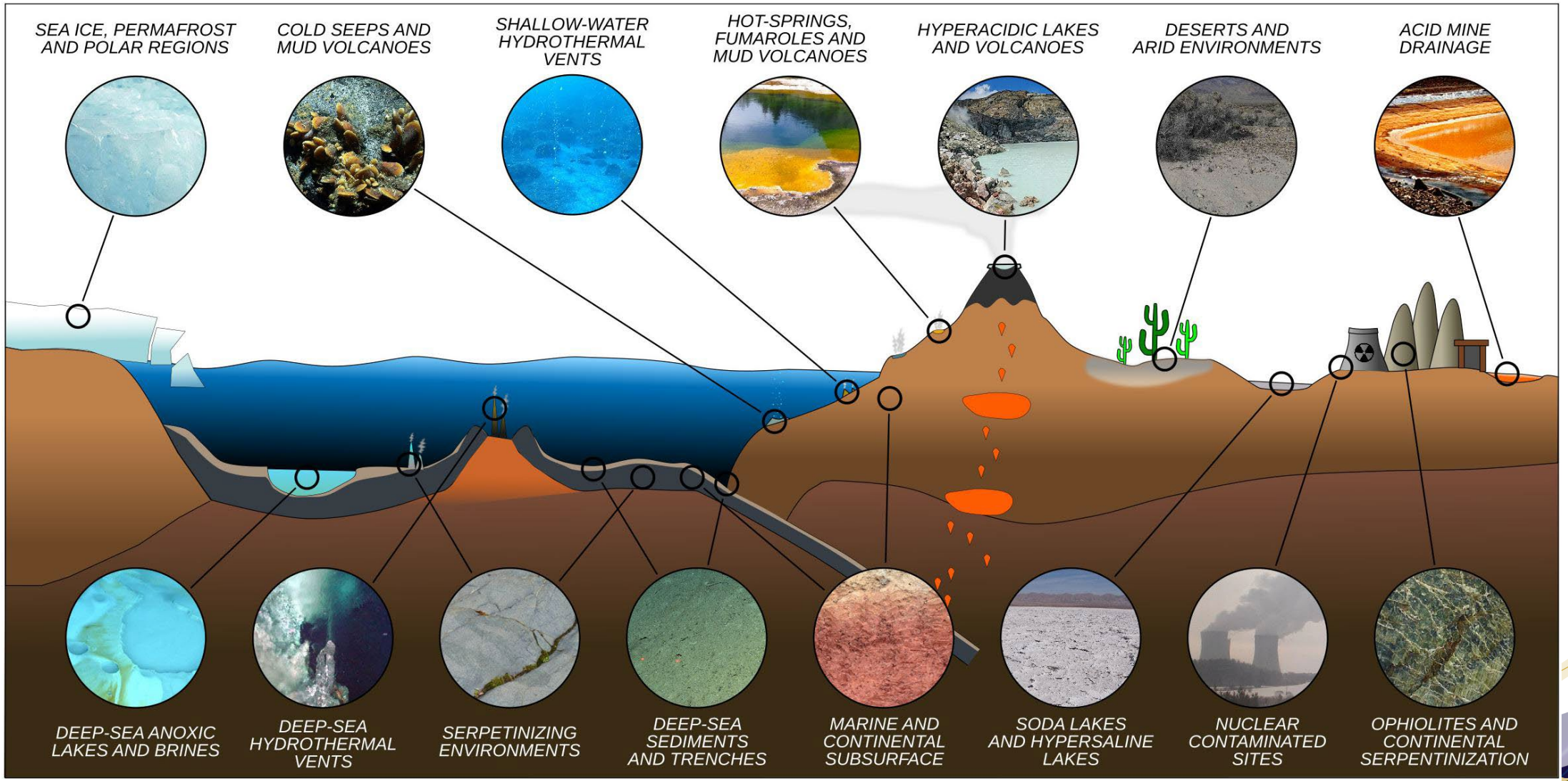


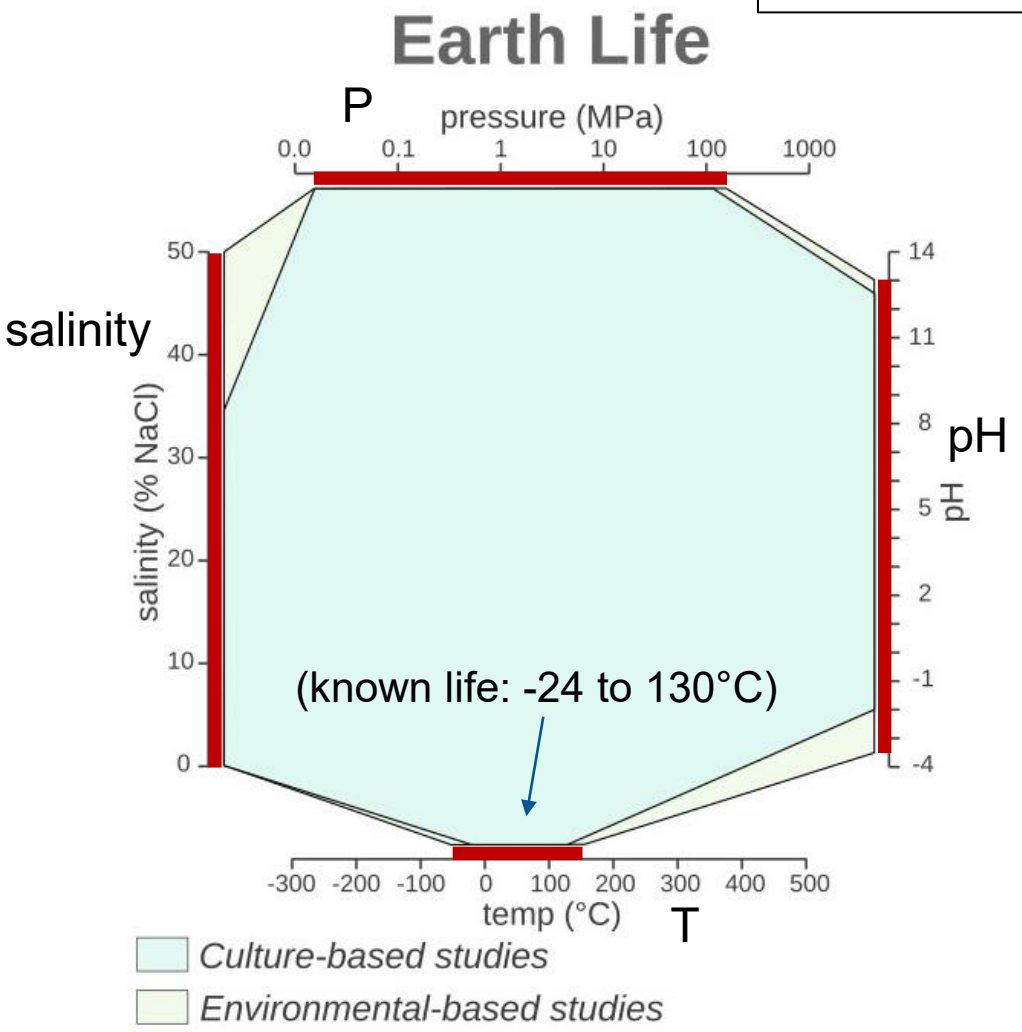
Figure from: https://www.nsf.gov/news/special_reports/microbes/index.jsp

Exoplanet analogs – Life in Extreme Environments on Earth



From Merino et al., *"Living at the Extremes: Extremophiles and the Limits of Life in a Planetary Context"*, Frontiers of Microbiology, 2019

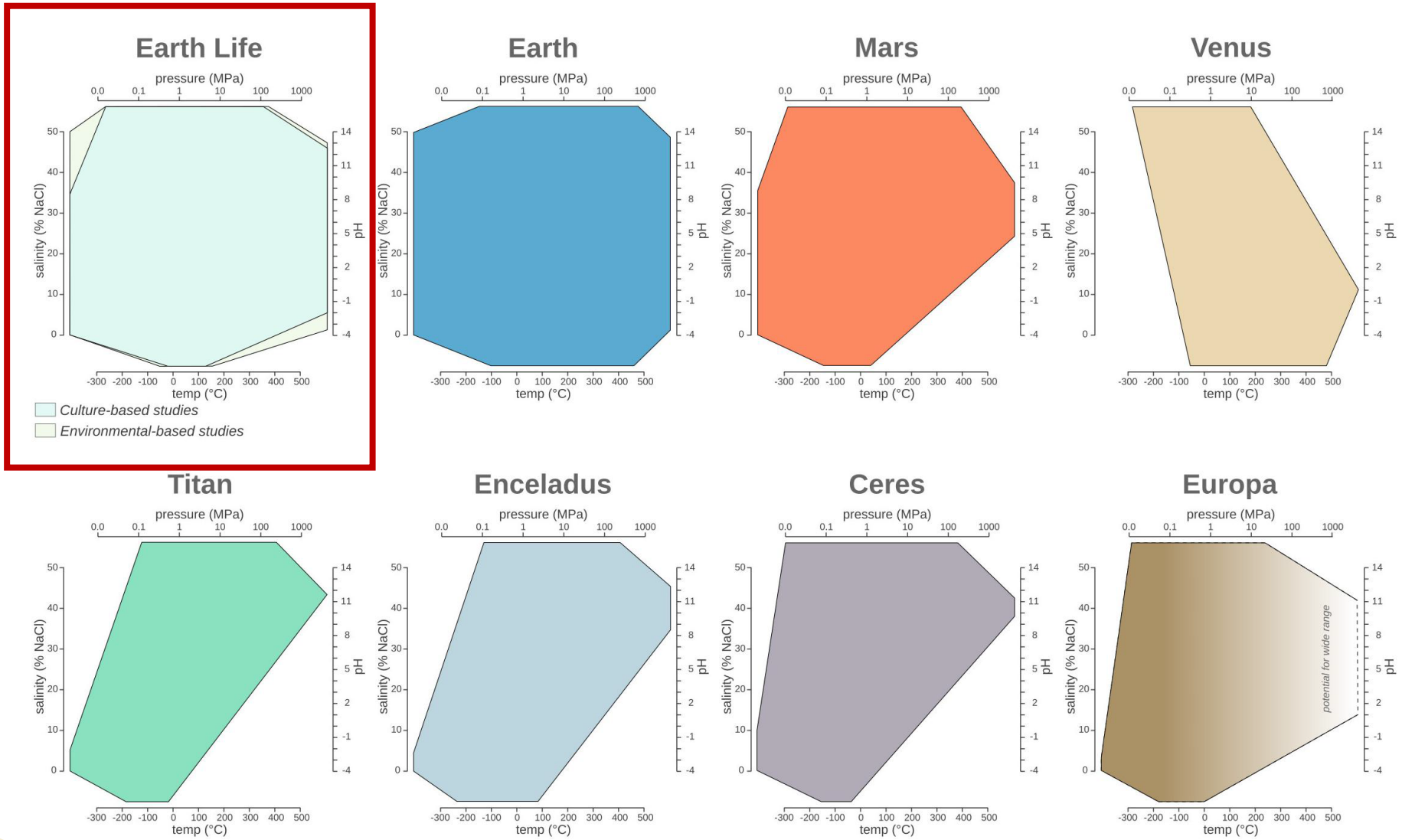
Limiting Conditions of life on Earth



- Parameters that limit life: ***temperature, pressure, salinity, pH, radiation***
- Axes ranges cover a large portion of conditions observed for the *atmosphere, surface, and shallow subsurface*
- Red lines show limits of tolerance for observed natural and cultured life – *covers most of the range of Earth conditions (except T, but still a huge range)*

From Merino et al., *"Living at the Extremes: Extremophiles and the Limits of Life in a Planetary Context",* Frontiers of Microbiology, 2019

Atmosphere, surface, and subsurface conditions of planetary bodies



All of these planetary bodies show overlaps with conditions on Earth ***where life exists***

From Merino et al., *"Living at the Extremes: Extremophiles and the Limits of Life in a Planetary Context"*, Frontiers of Microbiology, 2019

Radiation tolerant organisms

Radiation sources: radioactive decay, UV radiation, X-rays, gamma rays, cosmic rays.

Earliest life had to be resistant to intense UV radiation and ionizing radiation.

- First half of Earth history, lack of atmospheric O_2, no ozone layer;
- 200–300 nm wavelength range - several orders of magnitude higher than present.

Some microorganisms can survive exposure to extreme radiation (range of kGy), ***including space conditions for hundreds of days***

Radiation-resistant microorganisms have been shown to resist up to 30 kGy of gamma radiation.

(Note: Wikipedia “Gray” - whole body exposure to 5 Gy usually leads to death within 14 days)

NSF/GEO Support for Space Analog Research

NSF Program, 1997-2003 - LExEn: Life in Extreme Environments:

"A strong emphasis … on environments that are near the extremes of conditions on earth."

"Funding will also support research about our solar system and beyond, to help identify possible new sites for life beyond earth."

Initiated by GEO (participation by all GEO units); funding by BIO, ENG, GEO, MPS (AST), OISE.

Resulted in 92 NSF awards. Total: >$24.5M.

2017-present: 11 NSF** awards with "life in extreme environments" in title or abstract, mainly by core programs in GEO, AST, EHR, ENG. **Total: ~$6.2M.

NSF/GEO Support for Space Analog Research

NSF 16-570, June 7, 2016

NSF BIO and GEO Directorates and NASA Astrobiology

Purpose: *"generation and execution of innovative research projects aimed at identifying and funding … research to address grand challenge questions in the origin of life."*

Aimed at *"stimulating creative thinking and new research on the earliest events leading to life on early Earth … and inform our search for life on other worlds."*

NSF since 2017: *60 awards totaling ~$23.8M by BIO, ENG, GEO, MPS (AST, CHE, PHY) with "origin of life" or "origins of life" in title or abstract*

CENTER for DARK ENERGY BIOSPHERE INVESTIGATIONS

NSF-GEO-OCE-funded Science and Technology Center (STC)
Since 2010 - $47.6M

C-DEBI mission: to explore life beneath the seafloor:

- determine what organisms exist and where,
- how long they've been there,
- how they are related to organisms elsewhere,
- how they contribute to critical global biogeochemical cycles.

C-DEBI has supported deep biosphere research at over 45 institutions in nearly 110 projects including about 55 graduate student and postdoctoral research fellowships.

NSF/GEO Support for Space Analog Research

Keywords in title or abstract: **awards 2017-present**

"Exoplanet"*: 136 NSF awards, mainly by MPS/AST.* ***Total: >$99.1M****.*
Over that time GEO has funded 11 such awards. ***Total: $3.76M****.*

"extremophile" or "thermophile" or "limits of life*": 62 NSF awards, mainly by core programs in GEO, AST, BIO, ENG.* ***Total: ~$31.0M***

"Astrobiology"*: 32 NSF awards by BIO, GEO, MPS (AST, CHE, PHY), SBE.* ***Total: >$14.3M***

"Life in extreme environments"*: 11 NSF awards, mainly by core programs in GEO, AST, EHR, ENG.* ***Total: $6.2M.*** ***(LExEN program 1997-2003, 92 awards, >$24.5M)***

NSF/Polar Programs and NASA Cooperation

2021 - NSF and NASA: new joint agreement to advance Space, Earth, Biological, Physical Sciences (Release 21-001).

- NSF and NASA - long collaboration history in Antarctica and Greenland through NSF-managed stations and facilities.
- NSF and NASA in Antarctica - environment of extremes:
  - Earth's best analog to the Martian environment before it lost most of its atmosphere;
  - *Cold life* – microbial life found In places never suspected of harboring life, e.g. beneath perennially ice-covered lakes.
- NSF and NASA – jointly support human health research in polar environments representing analogs to space flight.
  - Example: immunological changes from deployment to extreme environments, prolonged isolation, periods of 24h darkness.
- NSF and NASA support ***Icefin***, an underwater oceanographic robot that helps scientists explore ice-covered oceans, which ***may deploy on future trips to Europa***.

NSF Geosciences - Division of Atmospheric and Geospace Sciences (AGS)

Ionosphere disturbances disrupt radio propagations in the ionosphere, affecting Global Navigation Satellite Systems and communications.

- GEO/AGS with NOAA supports observation, modeling, and improving operational forecasting of these disruptions due to atmospheric disturbances from below and abrupt change of solar energy input from above.

Human exposure to intense radiation and high energy particles in space and at high latitude - greatly increased during geomagnetic storms - are mostly created by sun disturbances such as solar flares

- GEO/AGS supports research on the generation and propagation of solar events and their impacts on Earth's magnetosphere-ionosphere system.

Geomagnetic storms greatly change thermosphere density, altering spacecraft drag and their orbital dynamics (e.g., the recent SpaceX launch event)

- GEO/AGS supports atmosphere modeling and observation of thermosphere response to predict these changes and help spacecrafts to adapt and minimize their impact.

NSF/GEO Support for Space Analog Research

Some take-aways:

NSF/GEO:

- *Major source of funding for studies of Earth environments; many support extreme life and also are proxies for extraterrestrial bodies.*
- *Major source of funding for Geospace studies affecting GNSS, spacecraft, and human health*
- *When NSF encourages a theme, PIs will follow (LExEn, Origins of Life)*
- *Last 5 years – less interest seen in GEO, possibly reflects large NASA Astrobiology Program for these studies*
- *Origins of Life: benefited from NASA/NSF cooperation, generated significant PI interest*

Next 10 years:

NSF PIs are entrepreneurial; special programmatic themes generate PI responses

NSF responds to the community – prioritize important program themes

NSF-NASA cooperation benefits science and the science community