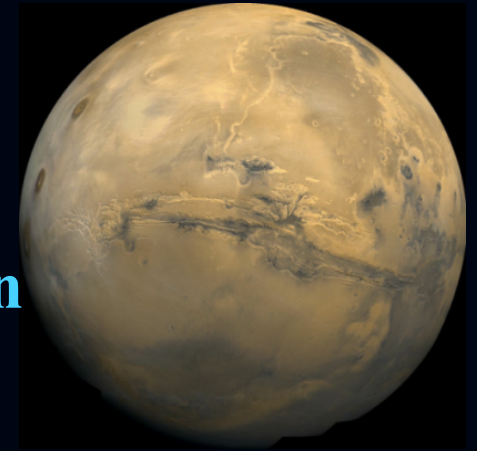
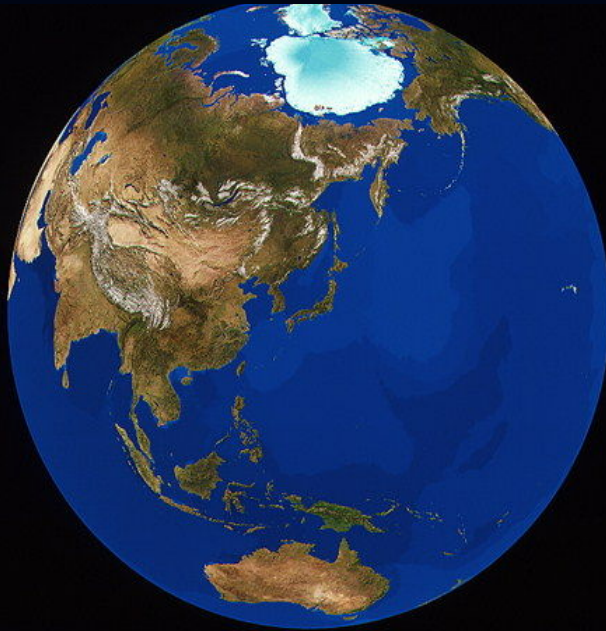


# HABITABLE TRINITY

James Dohm and Shige Maruyama (ELSI)



**I am truly grateful to have an opportunity to work with Shige Maruyama, importantly Shige is most significant to the new concept that I will present today, Kei Hirose, Shigeru Ida, and all of you to make this interdisciplinary and international ELSI effort most fruitful**

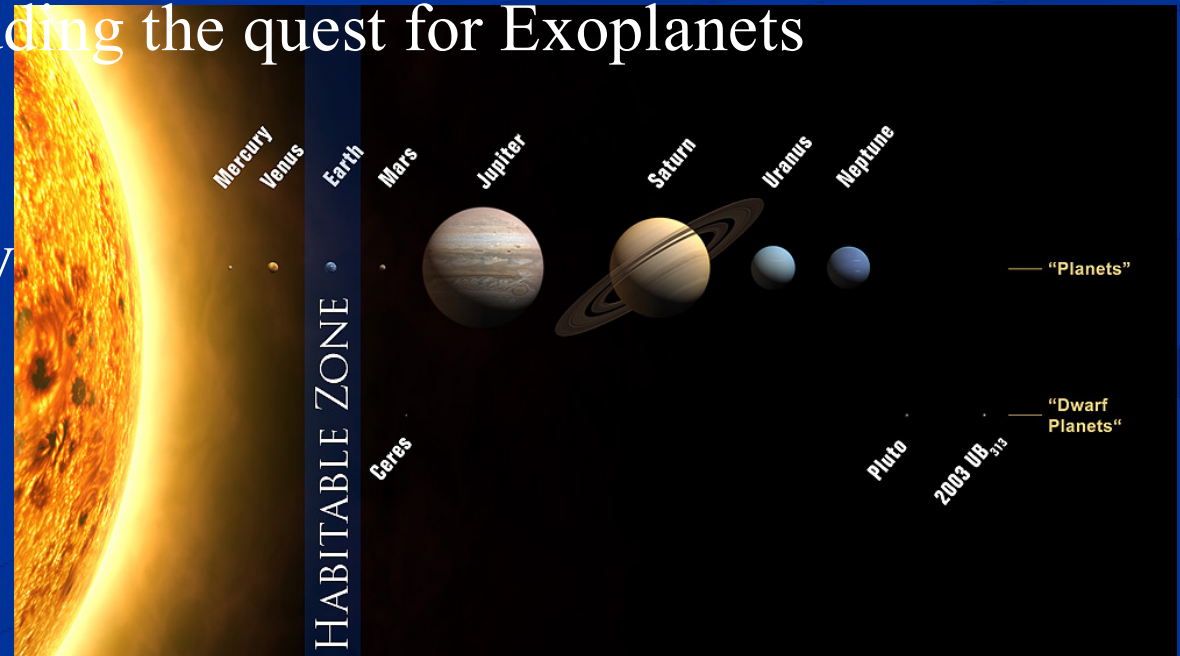
# Outline

1. Existing “Habitable” concept
2. New paradigm-changing concept is proposed, “**Habitable Trinity**”, to provide an index for identifying prime candidate life-containing targets beyond Earth including exo-solar planets
3. Application of the **Habitable-Trinity** concept to the solar planets and satellites of our solar system, examples including
  1. Earth - **HABITABLE TRINITY**
  2. Mars
  3. Venus
  4. Europa
  5. Titan
4. Application of the concept to the extrasolar planets
5. Conclusions - Implications concerning ELSI

# Existing “habitable” concept: Circumstellar Habitable Zone (CHZ)

- The CHZ, a well-known region around a star where a planet with sufficient atmospheric pressure to maintain liquid water on its surface, originated during the 1950s (e.g., Strughold, 1955; Huang, 1959).
- Since that time, a water-enriched planetary body is automatically assumed to be a habitable planet, even possibly metazoan-scale evolution of life. You may be familiar with the “**FOLLOW THE WATER**” approach including the quest for Exoplanets

- As was emphasized yesterday, water can actually be harmful to life.



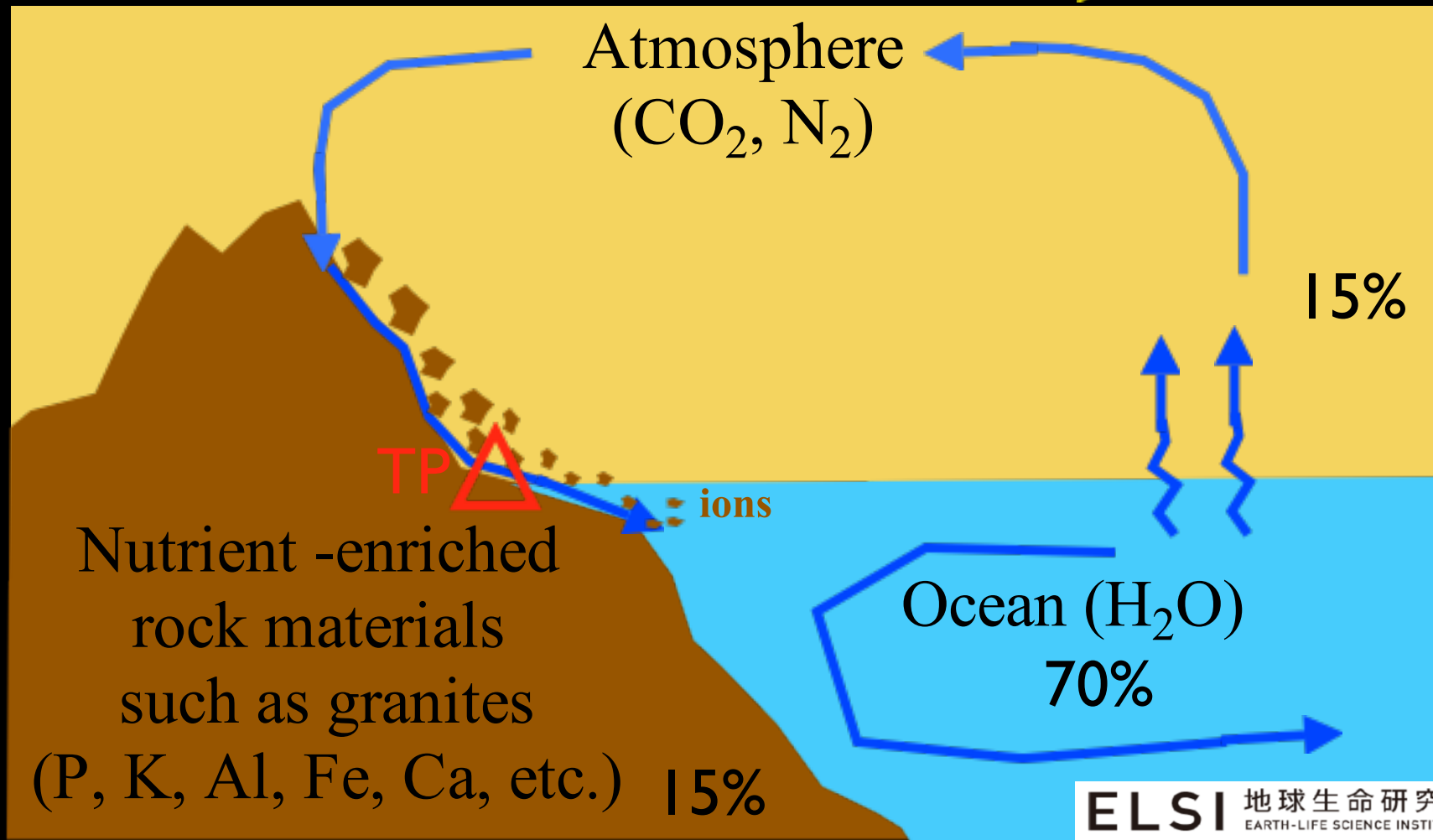
Element	Weight(Kg)	Wt%	Compose of
O	45.50	65.00	All
H	7.00	10.00	Ocean
C	12.60	18.00	Atmosphere
N	2.10	3.00	Atmosphere
Ca	1.05	1.50	Landmass
P	0.70	1.00	Landmass
Minor*	1.05	1.50	Landmass
Total	70.00	100.00	-----

- Elements of a 70 kg human being - **Life is not composed of only water** - all elements must be supplied from 3 components (ocean, atmosphere, and landmass)
- We therefore must go beyond the “follow the water” paradigm. All 3 components (**atmosphere, ocean, and landmass**) are critical to unraveling the origin and evolution of life, including a sufficient and continuous nutrient supply for embryos to develop, metabolisms to create energy for sustainability and evolution, and self duplication.

➤ We thus propose **Habitable Trinity** as the new concept of a habitable environment: 3 components with steady-state supply of energy for life cycled to each through the primary engine (the Sun)



➤ **without these 3 life cannot be born**

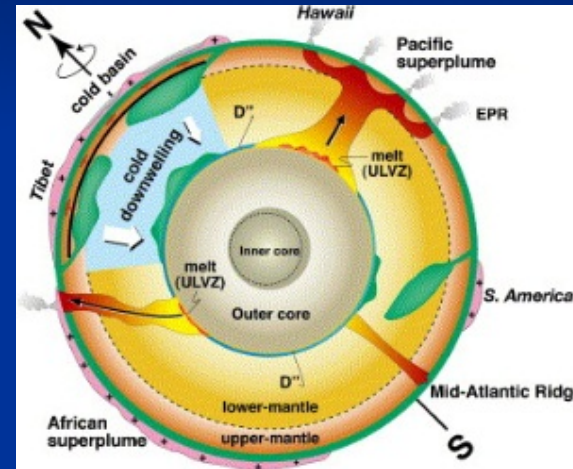


**Habitable-Trinity** environmental conditions do not remain constant due to:

impact events and orbital parameters such as obliquity and eccentricity) and endogenic activity such as superplume and plate tectonic activity (today's **Habitable-Trinity** environment is ever changing).



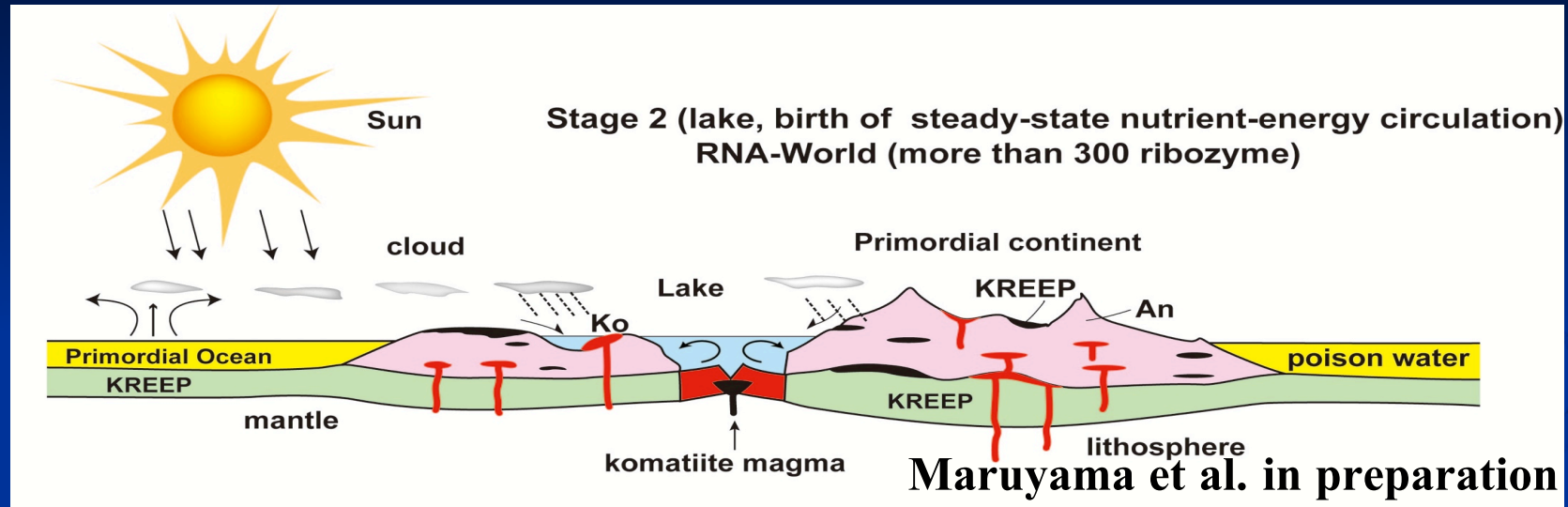
Text



Maruyama et al.

Our team ELSI effort will be unique to those that have come before in the quest of the origin of life and its possible existence beyond Earth through bringing together geology and biology at an optimal point, including their evolution, while incorporating the various disciplines as highlighted by Kei Hirose in the last few days. It has been common practice to use present-day conditions for experimentation. We will collectively go beyond this

The Hadean environment, for example, was distinct from today, as informed by Shige Maruyama. Collectively we must be mindful of this as we perform experimentation.

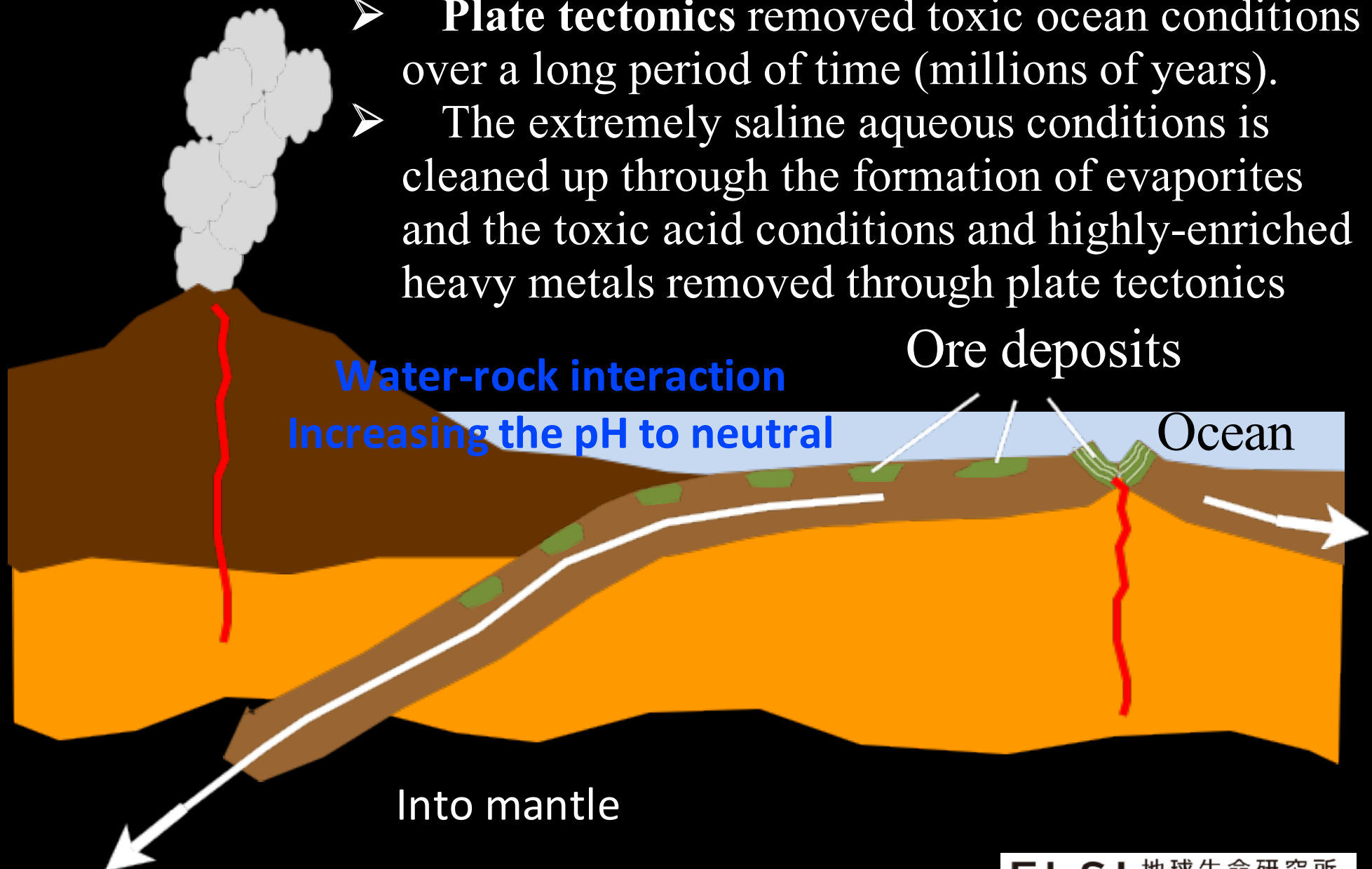


## Toxic conditions in the oceans existed during the Hadean

- 3 characteristics of poisonous ocean: ultra acidic, extremely saline, heavy metals (Halogen and sulfur leads to extremely toxic conditions)
- How then to clean up the toxic primordial oceans with ultra acidity, high salinity, and highly-enriched heavy metals (Cd, Cu, Pb, Zn, etc.)?

# Plate tectonics plays a critical role in a Habitable-Trinity environment

- **Plate tectonics** removed toxic ocean conditions over a long period of time (millions of years).
- The extremely saline aqueous conditions is cleaned up through the formation of evaporites and the toxic acid conditions and highly-enriched heavy metals removed through plate tectonics



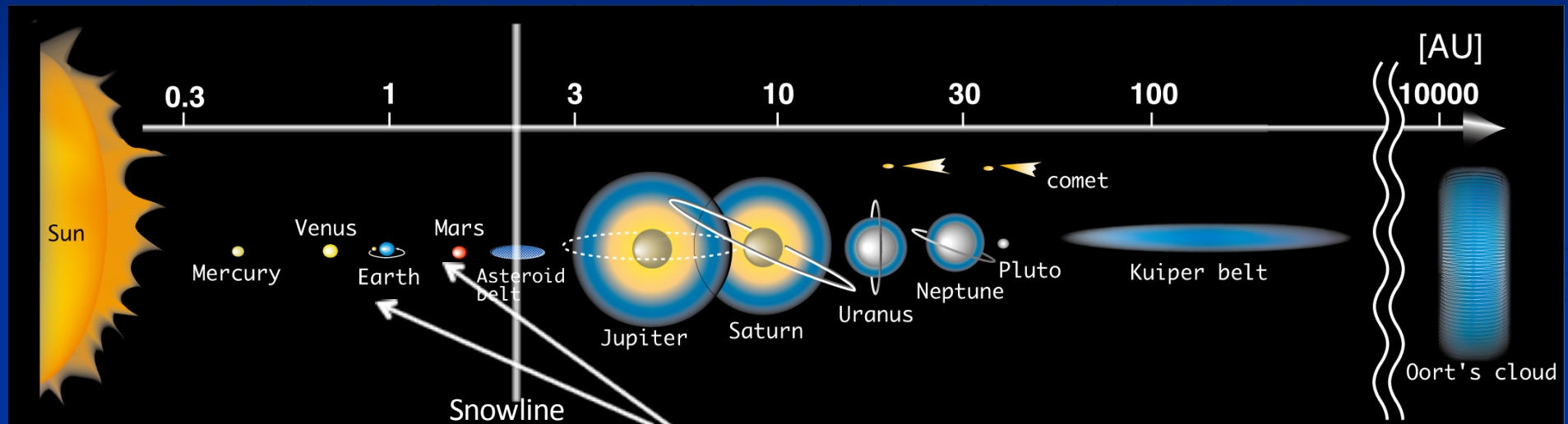


# Summary of Part 1 - New Concept

- Life requires the three components (ocean, atmosphere, and nutrient-enriched landmass), **Habitable Trinity**, to have originated and evolved - **without them life would not have originated**
- Thus, “follow the water” is not good enough in the search of life beyond Earth
- The 3 components with steady-state supply of energy for life cycled to each through the primary engine, the Sun
- Plate tectonics cleaned up the toxic primordial oceans
- During ELSI experimentation and laboratory analyses, we need to be thoughtful of the fact that **Habitable-Trinity** conditions of the ancient Earth, when life originated, was different from that of present-day

- now that that we have presented a new concept, how do we apply it?

## Application 1: Solar planets and satellites.



Ocean: 4km thick

Mechanism to deliver appropriate amount of water to rocky (naked) planet is a key (Maruyama et al., 2013).

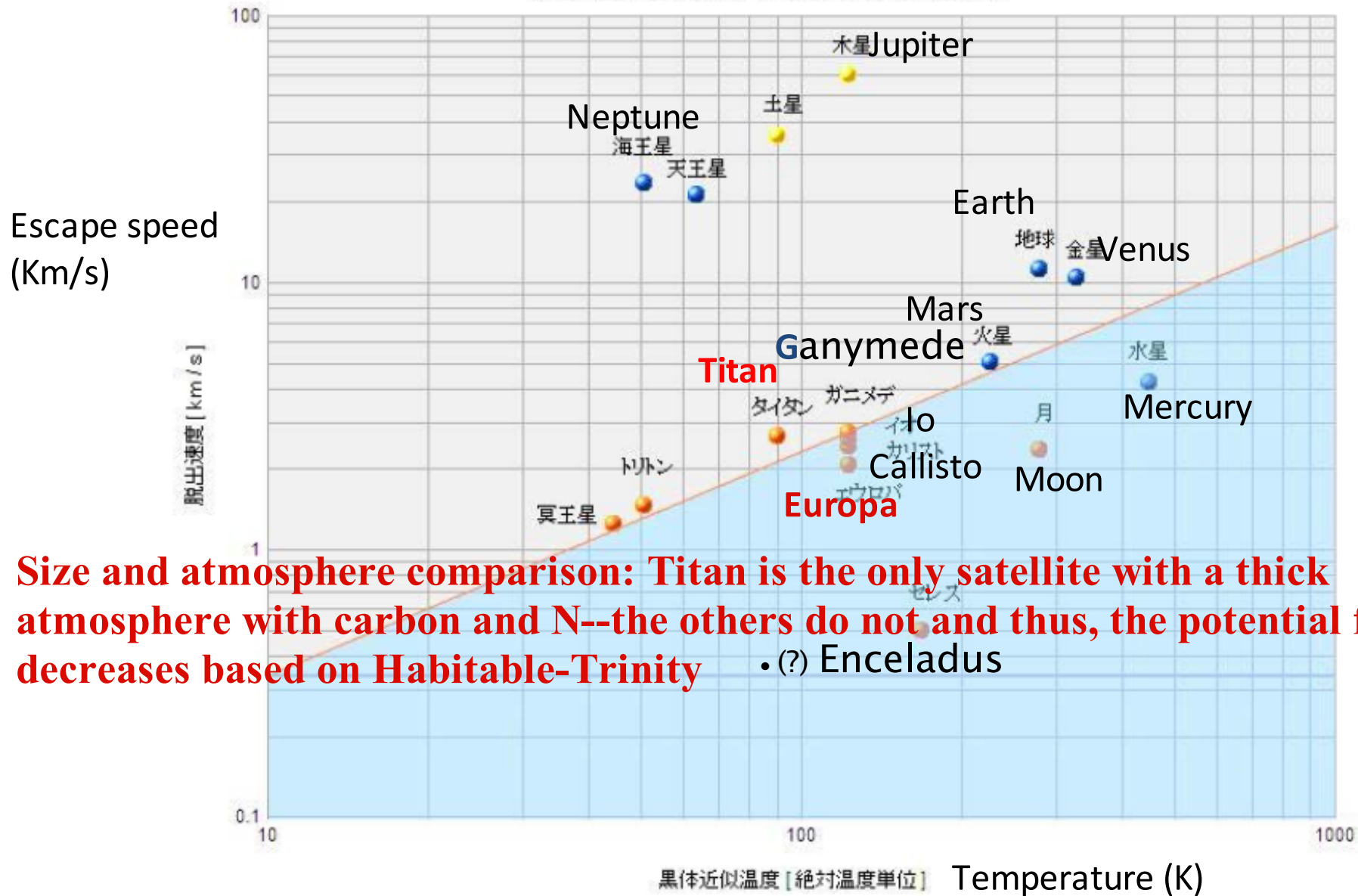


- Earth has an ocean, nutrient-enriched continental crust, atmosphere, plate tectonics, and solar radiation from the sun (trafficking)
- Early Mars had an ocean, nutrient-enriched continental crust, atmosphere, plate tectonics, and solar radiation from the sun (trafficking), making it a prime Habitable-Trinity target<sup>10</sup>

- habitable trinity is satisfied through Earth even as far back as the Pre-Cambrian based on the geologic record and possibly extending back to the Hadean as there is no record
- now that examples of the application of Habitable-Trinity to the rocky planets has been presented, now we will apply the Habitable-Trinity perspective to the outer planets and their satellites, specifically Europa and Titan

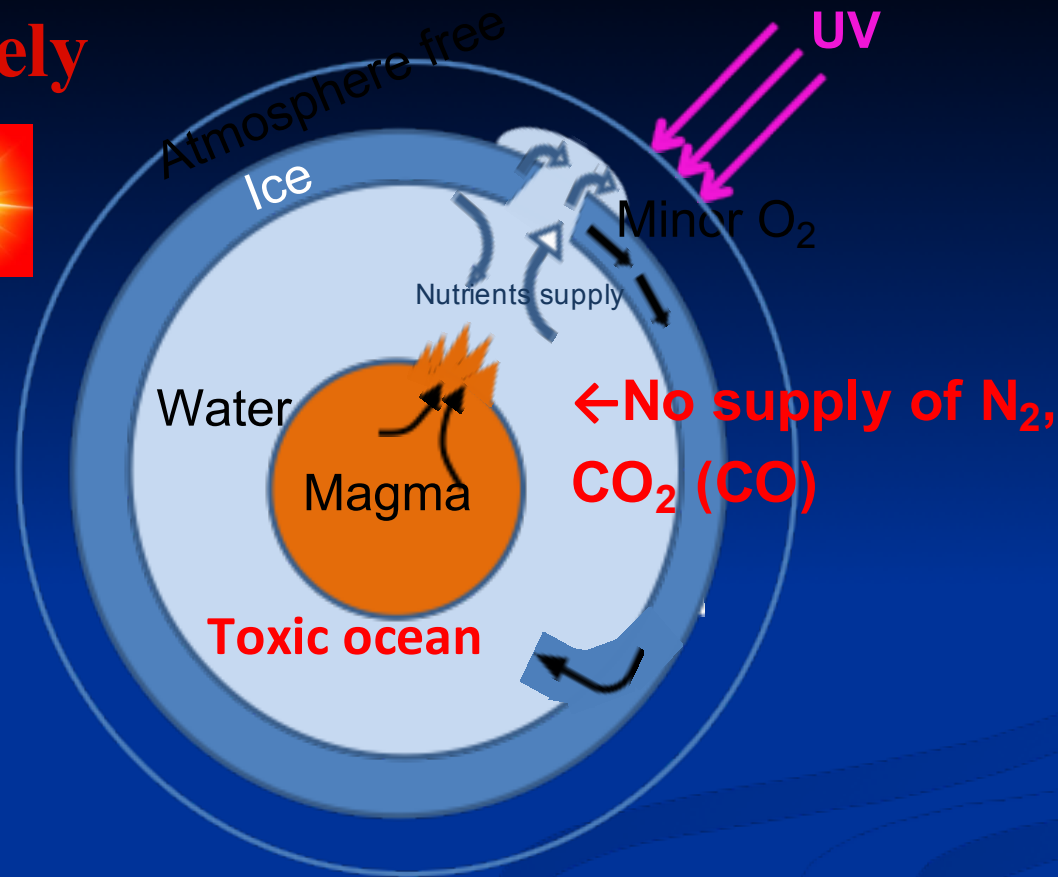
# Index to find life-sustaining planet.

Escape speed of atmosphere  
天体の黒体近似温度と脱出速度の関係



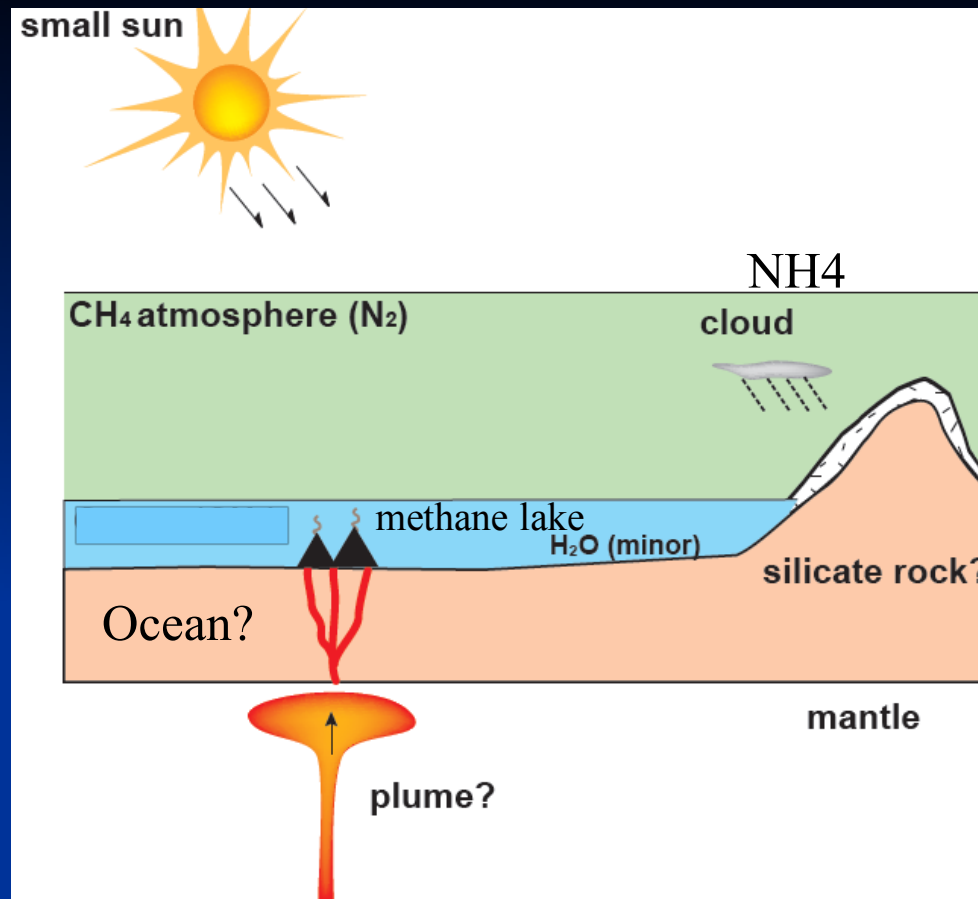
**Size and atmosphere comparison: Titan is the only satellite with a thick atmosphere with carbon and N--the others do not and thus, the potential for life decreases based on Habitable-Trinity** • (?) Enceladus

# Europa - life unlikely



- Europa has an ice-covered ocean, no nutrient-enriched continental crust, a tiny, tenuous atmosphere, no plate tectonics, and solar radiation from the sun
- difficult to make amino acids and protein due to the lack of atmosphere which contains nitrogen and carbon--no trafficking between atmosphere and ocean due to the lid of ice sheet//toxic ocean,, making it an unlikely Habitable-Trinity target

# Titan - life unlikely

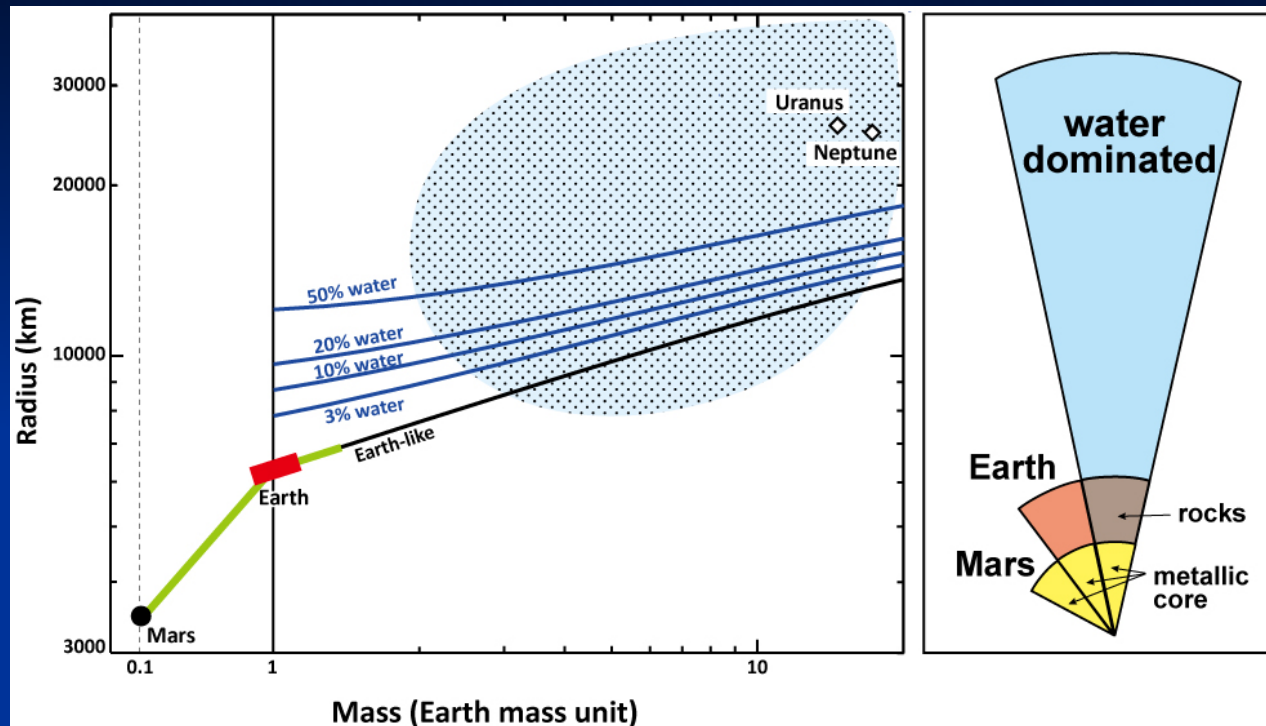


- Titan has methane lakes and a possible ocean at great depths with a solid methane and water-ice lid, no nutrient-enriched continental crust, a thick atmosphere, no plate tectonics, and solar radiation from the sun (no trafficking), making it an unlikely Habitable-Trinity target

## Application 2: Extrasolar planets

- $60/3600$ =habitable zone planet (2013)
- If **Habitable Trinity** is applied  
= how many left?

# Criteria to seek life-sustaining planet



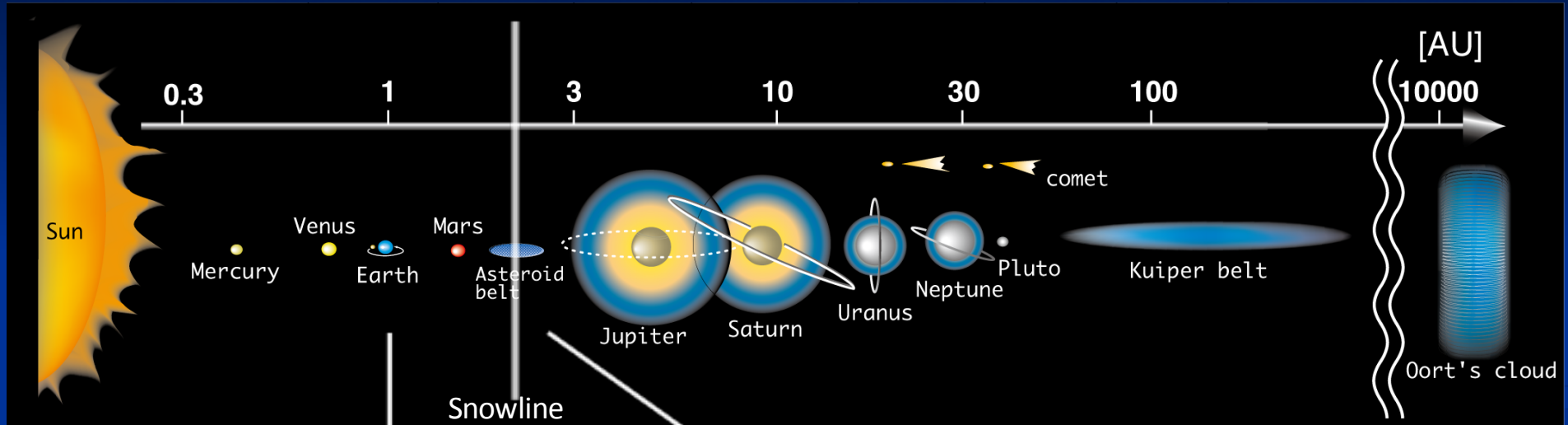
(Maruyama, Ikoma, Genda, Hirose, Yokoyama, 2013)

## Very narrow window to find life-sustaining exo-planet

- **Habitable-Trinity** is defined on the narrow line of Earth
- Super Earth's would plot into too much water (though could happen along the line)
- Super Earths are so large that they would readily destroy primordial crustal materials and granitic rocks even if plate tectonism was in operation
- Therefore **Habitable Trinity** is an excellent index for the search of life beyond Earth



**Extremely tight condition: ocean thickness must be 3-5km = Naked Planet (Maruyama et al., 2013); initial mass of ocean controls the fate of a planet.**



**Earth**



Ocean: 4km thick

**Another Earth**



Ocean: 1200km thick

Made from 10H<sub>2</sub>O% chondrite

Himalayas would be covered

# Conclusions

**HABITABLE TRINITY** (coexistence of atmosphere, ocean and landmass (**trafficking**)) is a paradigm-changing concept to optimize our search for prime life-containing objects (solar planets/satellites and extrasolar planetary bodies), including providing an an index for the life-hunt:

1. size of planet
2. mass of ocean
3. atmospheric composition
4. geochemistry of the landmass {{e.g., granite}}
5. snowline & origin of ocean

# Conclusions continued

## Habitable-Trinity provides:

- a new perspective and systemization of Astrobiology.
- the environmental inputs to our ELSI laboratory/experimental/super computing-based analyses (e.g., inputs to the work spearheaded by Ken Kurokawa). {{we must be thoughtful of the various past environmental conditions informed by the geologic record, consistent with what Ken Takai noted yesterday.}}

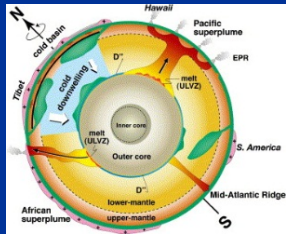
# ELSI: Interdisciplinary and International Effort

Biological System I (Origin)

Planetary Geology



Earth History

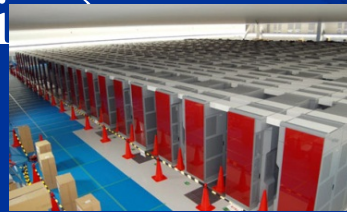


Planetary Science

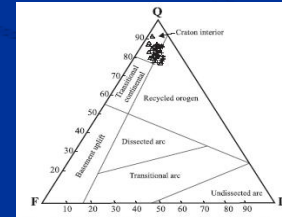
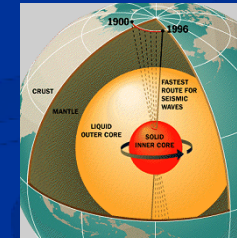


**Habitable-Trinity**

Biological System II



Solid Earth



We, ELSI, have an opportunity to set an example for the rest of the world, by bringing together our various disciplinary expertise at an optimal point and through channeling our efforts collectively and thoughtfully in support of ELSI led by Kei Hirose

This is a golden age of exploration, multidisciplinary and international effort, education of our youth (as emphasized by Ken Takai yesterday), and discovery. I look forward to having the opportunity to work with all of you on the ELSI effort to produce most significant fruit.

We certainly have been given a unique opportunity through the Japanese government and tax payers - a significant step for mankind in the words emphasized by Dr. Hiroshi Kitazato of Japan Agency for Marine-Earth Science and Technology.



Mars Sunset

**Special thanks to colleague, Reiko Hattori**