Subsurface Oceans in the Outer Solar System

Version #3: The Search for Life

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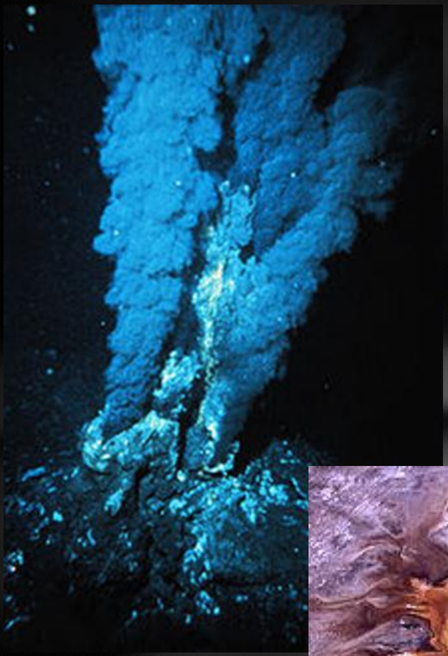
for Physics 596, Fall 2011

Introduction

- The search for life in the solar system – how does this relate to life on Earth?
- Basic questions to ask about life beyond Earth
- One type of possible environment for life: subsurface oceans in the solar system
- Examples of subsurface oceans
  - Europa
  - Enceladus
  - Titan & Triton
- Factors that keep oceans liquid
- What we hope to learn
- Future possibilities for exploration

The Search for Life

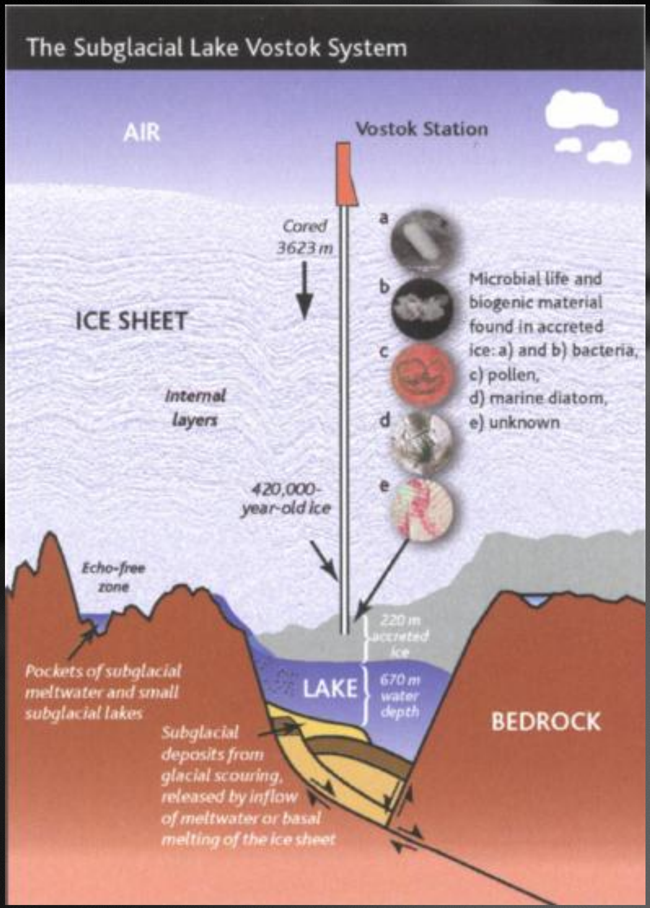
- The search for life in the solar system begins on Earth
  - What kind of environment do humans need?
    - Warm
    - Wet (surface water)
    - Sunlight
  - No other places like this in the Solar System!!
  - Extremophiles:
    - Exists in environments we find hostile
    - Extremes of temperature, pressure, acidity, complete darkness, etc.
    - Do environments similar to these extremes exist?
  - Cryophiles on Earth like cold temperatures around 260K



Take-away: the boundaries for life need to be established

Subsurface Lakes on Earth

- Subsurface Antarctic Lakes:
  - 4 km below the surface
  - Very cold by human standards
  - Under pressure
  - Isolated from the environment
- Questions to ask:
  - How similar to subsurface oceans on moons in outer Solar System?
  - Can we access it?
  - What technology is needed?
  - Can we investigate without contaminating the lake?



M. Inman, Science 310 (5748), 611-612 (2005).

Basic Questions for Life in the Solar System

- What kind of environments on Earth, like subsurface lakes, can translate into space?
- Are subsurface oceans common?
- Where are they located?
- What keeps them from freezing?
  - High temp?
  - High pressure?
  - Antifreeze chemicals like salt or ammonia?
  - Are conditions near the range of known extremophiles?
- Are they stable enough for life to form? Do they survive for billions of years, rather than thousands of years?
- Can they be accessed from the surface?
  - Do we have the technology?
  - How far below the surface?

Table 6
Results from the 3-layer model (ice thickness D, ocean thickness D_{oc}, core radius, relative core radius, rock-to-ice mass ratio, dimensionless axial moment of inertia, ammonia content within the ocean X, assumed initial ammonia content X_0)

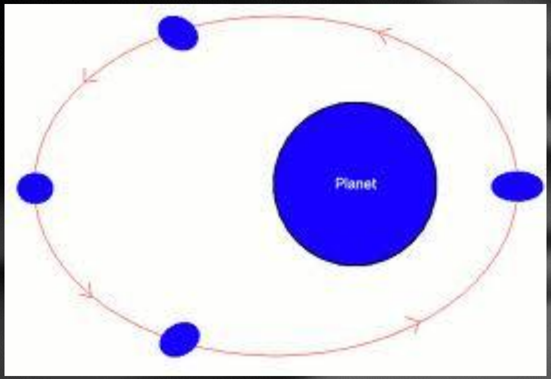
	D, km	D_{oc}, km	R_c, km	R_c/R_p	M_c/M_p	MoI	X, %	X_0, %
Europa	79.5	80.5	1405.0	0.90	0.92	0.346	2.1	1.0
	77.5	82.5	1405.0	0.90	0.92	0.346	6.1	3.0
	74.8	85.2	1405.0	0.90	0.92	0.346	9.9	5.0
	70.0	90.0	1405.0	0.90	0.92	0.346	14.9	8.0
	57.0	103.0	1405.0	0.90	0.92	0.346	24.2	15.0
Rhea	400.9	16.4	347.2	0.45	0.27	0.340	32.5	0.5
Titania	253.1	16.0	519.8	0.66	0.58	0.306	26.2	1.0
	229.7	39.4	519.8	0.66	0.58	0.306	30.6	3.0
	217.7	51.5	519.8	0.66	0.58	0.306	32.5	4.3
Oberon	264.4	16.0	481.0	0.63	0.54	0.307	28.7	1.0
	241.1	39.3	481.0	0.63	0.54	0.307	32.5	2.9
Triton	200.5	135.9	1017.0	0.75	0.72	0.310	3.0	1.0
	194.9	141.5	1017.0	0.75	0.72	0.310	8.5	3.0
	187.5	148.9	1017.0	0.75	0.72	0.310	13.4	5.0
	174.8	161.6	1017.0	0.75	0.72	0.310	19.5	8.0
	143.9	192.5	1017.0	0.75	0.72	0.310	29.8	15.0
Pluto	260.6	104.2	830.2	0.70	0.64	0.306	4.7	1.0
	248.7	116.1	830.2	0.70	0.64	0.306	12.4	3.0
	234.9	129.9	830.2	0.70	0.64	0.306	18.1	5.0
	214.5	150.3	830.2	0.70	0.64	0.306	24.5	8.0
	179.9	184.9	830.2	0.70	0.64	0.306	32.5	13.6

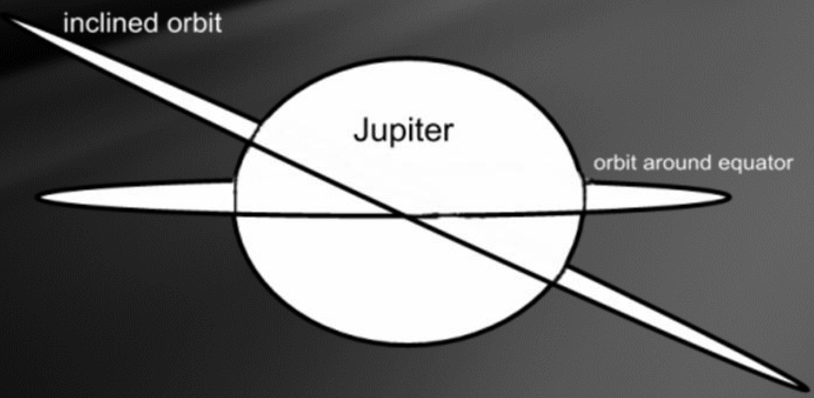
Notes. We considered X_0-values of 1, 3, 5, 8, and 15%. In cases where the peritectic composition of 32.5% within the ocean is reached for initial values smaller than 15%, we determined the initial concentration, for which a liquid layer close to the peritectic composition exists (e.g., $X_0 = 13.6\%$ for Pluto or 0.5% for Rhea). In such cases larger initial concentrations will lead to crystallization of solid ammonia compounds. We did not obtain solutions for the remaining satellites (note that we excluded the large icy satellites, Ganymede, Callisto, and Titan).

H. Hussmann, F. Sohl and T. Spohn, Icarus **185** (1), 258-273 (2006).

Factors That Keep Oceans from Freezing

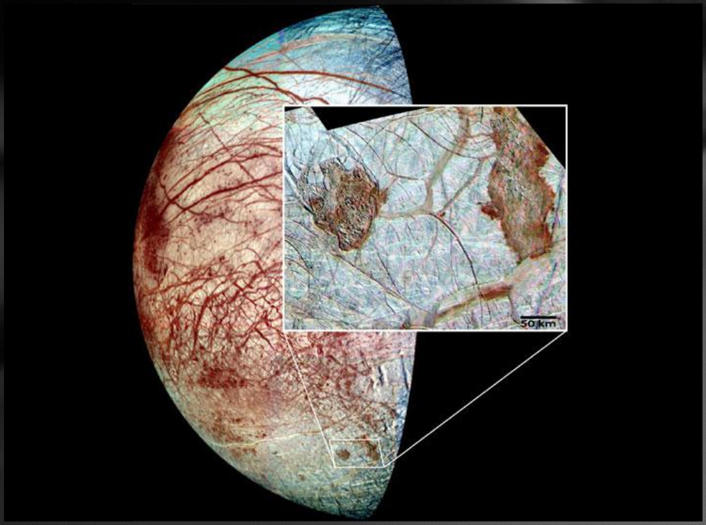
- Tidal heating
  - Occurs when the gravitational field experienced by a body changes either in location or magnitude
  - Most moons are tidally locked to their parent, so we are mostly concerned with magnitude changes
  - Magnitude changes can be induced by eccentricity and inclination (if the parent body is strongly oblate)
  - Decoupled surface and interior can increase the effect of tidal forces, both by making the surface easier to deform and by drag on the interior that allows it to tidally unlock slightly from the synchronicity
- Additives to ocean that act like antifreeze such as salts or ammonia which can lower the freezing temperature of the water
- Radiogenic heating from a large rocky or metallic interior





Detection of Subsurface Oceans

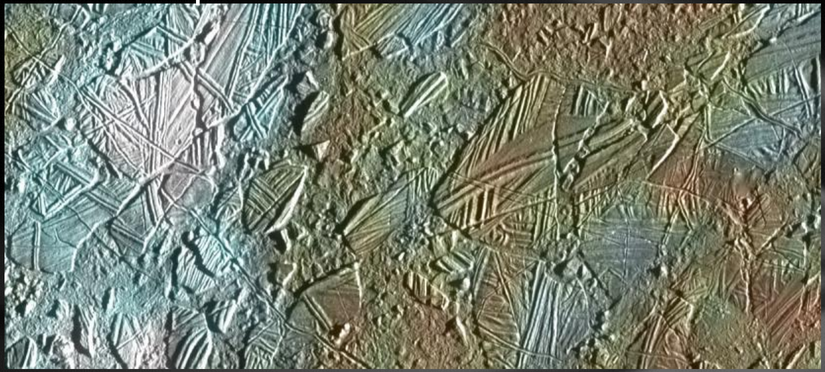
- Calculation of heat budget
- Young surface
- Evidence of cryovolcanism
- Electrical or magnetic field generated by moving charges in liquid layer
- Careful measurement over a long period can give values for tidal Love numbers
- Ejected material
- Direct detection



Europa

- Europa was first imaged close up by Voyager in 1979
- Images reminded scientists of ice floes in the Arctic/Antarctic leading to speculation about a subsurface ocean
- Young age of the surface further suggested recent resurfacing and some sort of geologic activity
- Colour changes on the surface likely due to organic molecules breaking down in Jupiter's radiation
- Weak magnetic moment confirms the likelihood of a salt water ocean under the surface

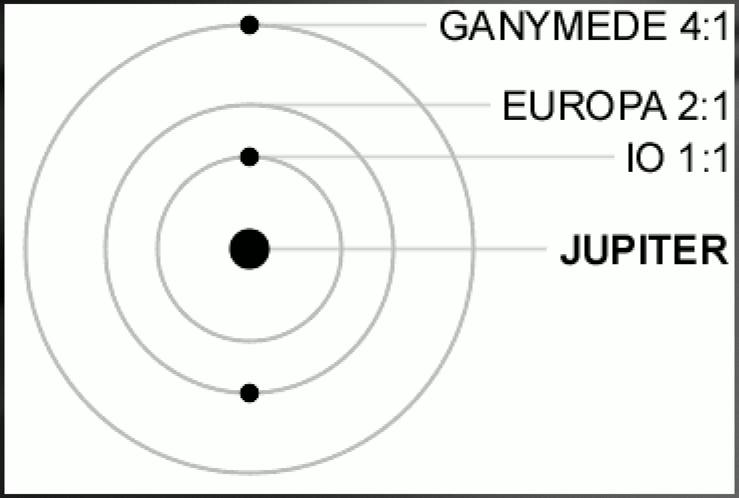
Europa



Antarctic ice floe

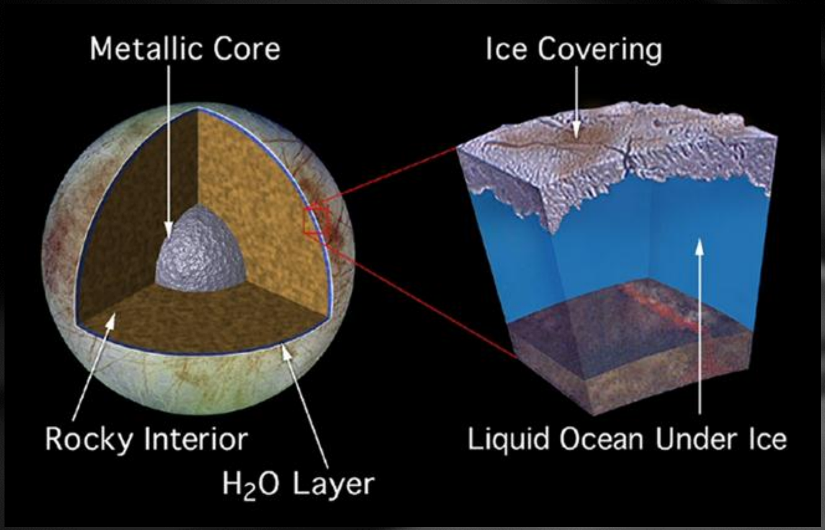
Europa

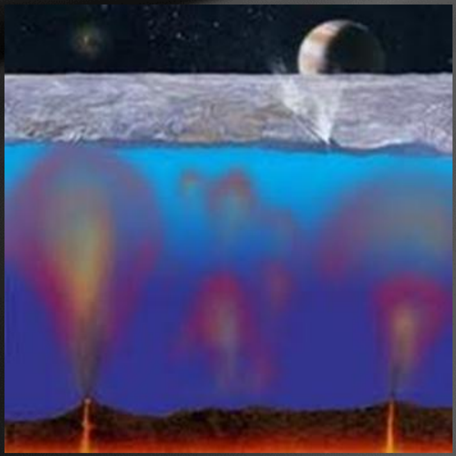
- Tidal heating keeps water ocean from freezing
- Laplace resonance with Io and Ganymede maintains eccentricity in orbit
- Tidal Love numbers are non-dimensional measures of the height of the tidal bulge and the associated induced gravitational quadrupole moment
- They can reveal if the interior is decoupled from the surface through careful measurement of surface and gravitational field
- Interior and surface may rotate at different rates if there is an ocean
- Inclination of orbit may also generate forces in the ocean that contribute substantially to total heat budget



Europa

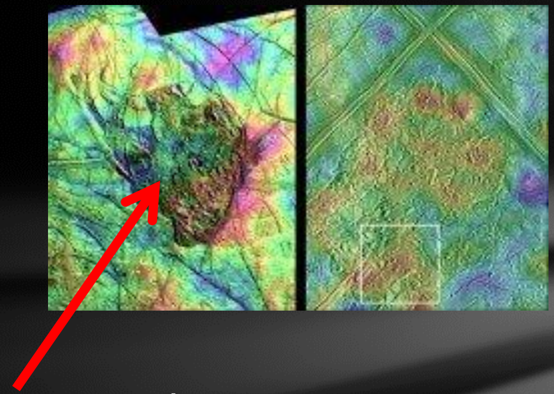
- Salts and ammonia may act as an antifreeze
- Radiogenic heat from the rocky interior and metal core could bubble up from the interior as on Earth at ocean rifts
- Ocean is stable over the long-term because of the Laplace resonance
- Most Earthlike of known subsurface oceans
- Icy surface may be as little as 3-4 km thick, about the same as the Antarctic ice sheet
- May represent best chance for Earthlike life





Europa – Flash Update 16 Nov 2011

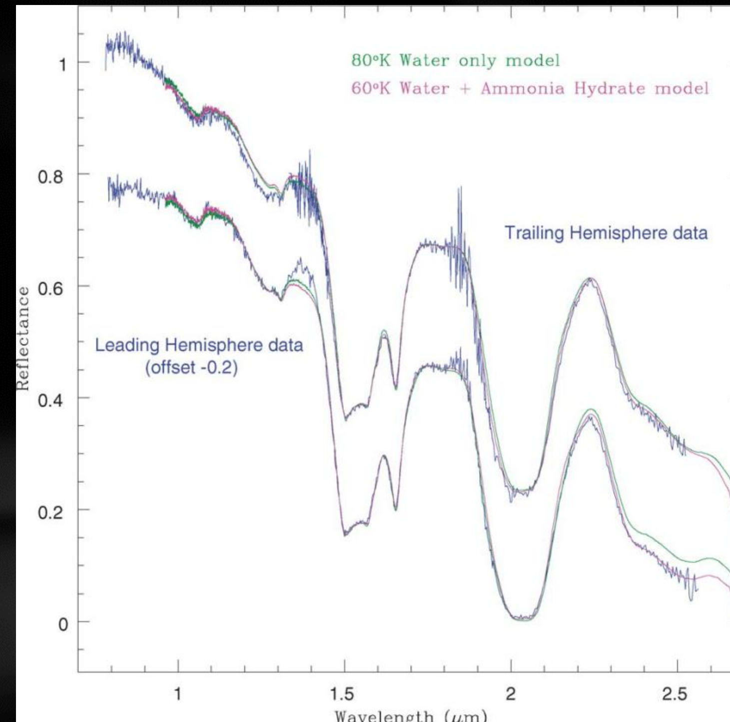
- A new article in *Nature*, according to the press release, argues that regions of chaos terrain harbor lakes, and provide for exchange between the surface and the subsurface ocean
- This brings liquid water much closer to the surface, and the sun, and would make it easier for a probe to access.
- Interaction between surface and subsurface could increase chances for life
- Video of the press conference available at: http://www.universetoday.com/91040/europas-hidden-great-lakes/

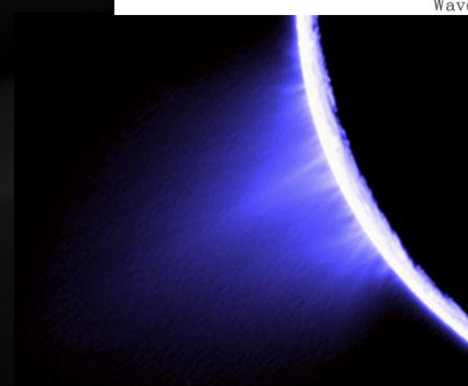


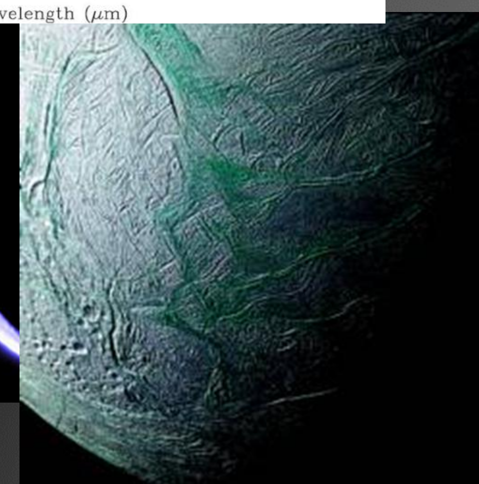
Chaos terrain

Enceladus

- Enceladus is a moon of Saturn
- Material ejected from its surface in the form of water ice geysers are responsible for forming faint E ring
- Spectroscopic analysis confirms the presence of water in jets
- Like Europa, the surface is extremely young and relatively crater free



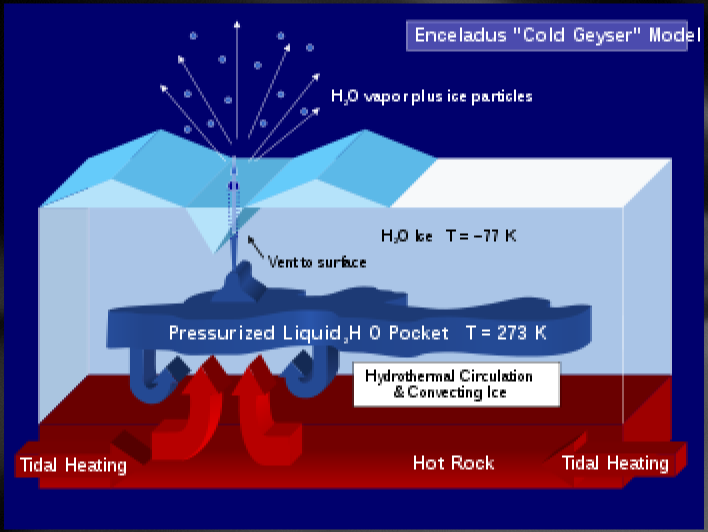


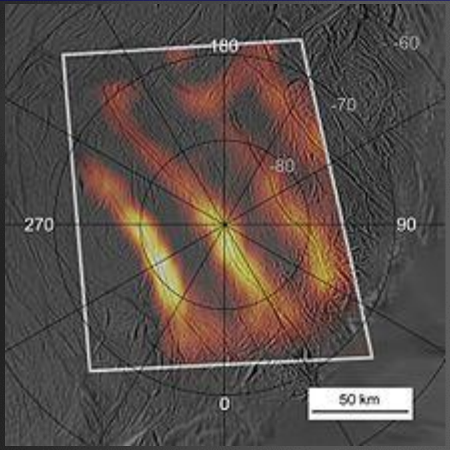


C. J. Hansen, L. W. Esposito, A. I. F. Stewart, B. Meinke, B. Wallis, J. E. Colwell, A. R.

Enceladus

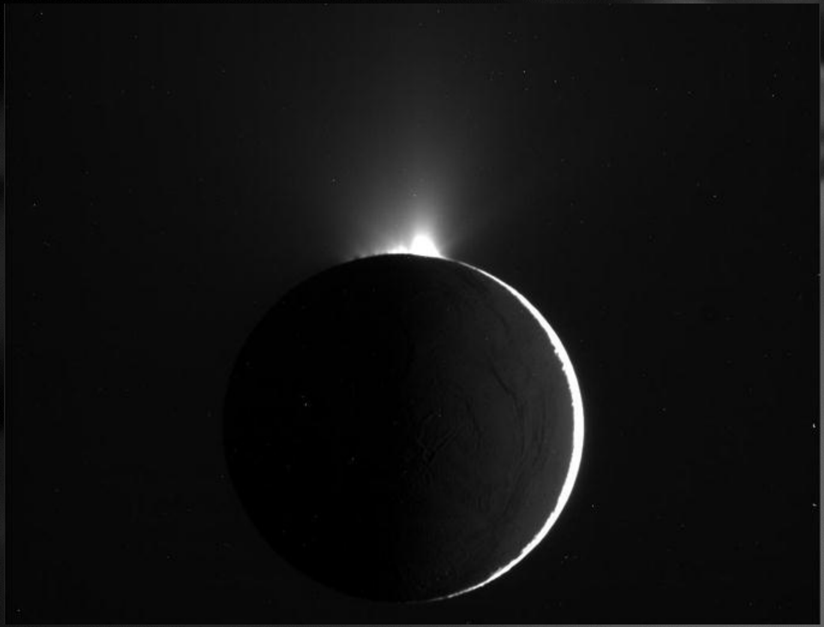
- Structure of the ocean may be substantially different than europan ocean
- There is a distinctive heat anomaly under the southern pole marked by the tiger stripes
- It is thought that the water has formed a diapir and is being forced to the surface by pressure and gravity
- Whether this is a remnant ocean that was once planetwide or if formed by some other heating event remains an open question





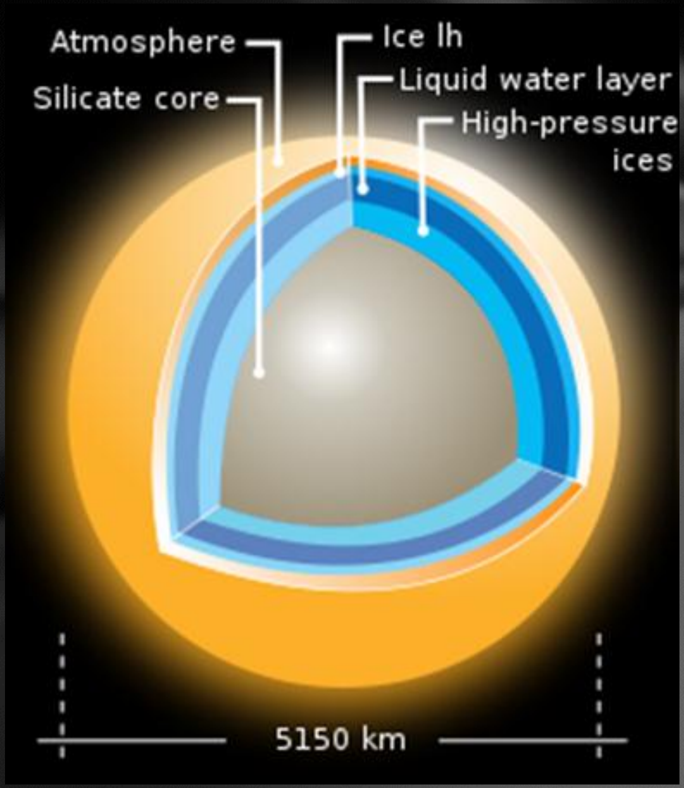
Enceladus

- It is thought to be too small to maintain a liquid ocean since formation
- Tidal heating maintains it now, as Enceladus drifts closer to Saturn
- Long-term stability is highly doubtful at this point
- Big open question is whether the ocean has been around long enough for life to form, and if so, how is it maintained
- However, because jets shooting into space, probably the easiest to access



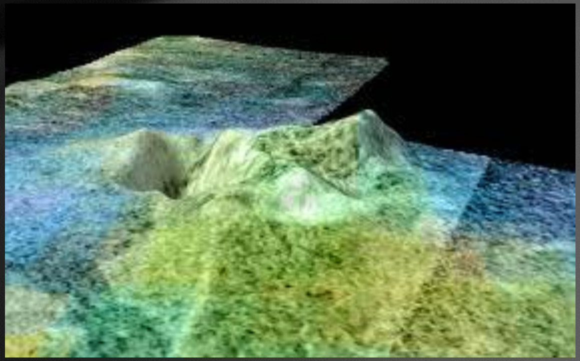
Titan & Triton

- Titan and Triton are probably quite similar in their water oceans
- Depth of the ocean will be more effected by the size of their rocky interiors which provide radiogenic heat than by surface conditions
- The ocean is thought to be sandwiched between low pressure ices on top, and high pressure ices just above the rocky core
- Ammonia acting as an antifreeze can allow for a deeper ocean
- Evidence for cryovolcanism on surface of both moons
- Both oceans will be under extremely high pressure



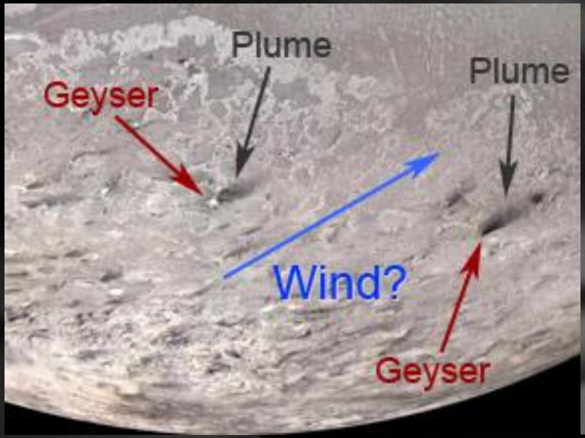
Titan

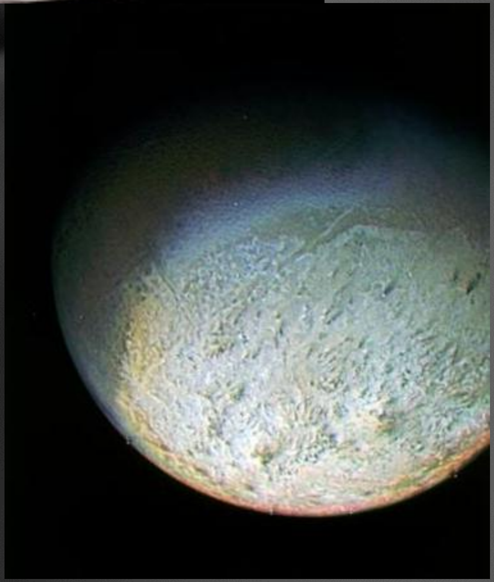
- Titan is a uniquely interesting body because it may have two environments for life: one on the surface (with a methane-based metabolism) and one in the ocean (with a water-based metabolism)
- Evidence that Titan's core is decoupled from surface and rotates at a slightly different rate.
- Electrical field detection interpreted as evidence for liquid ocean
- Cryovolcanic features may expel slushy water lava, building surface features out of ice as Earth does with rock
- Methane in atmosphere may be the result of gas exchange with interior



Triton

- May have the youngest surface in the solar system
- Mechanism for this resurfacing is unclear
- Voyager II photographed multiple geysers on the surface
- Black streaks downwind may indicate breakdown of organic molecules into carbon
- Large rock-to-ice ratio provides large radiogenic heat budget
- Capture process thoroughly melted interior
- High orbital inclination may continue to provide additional tidal heating





Current & Future Missions

- Juno is currently headed to Jupiter, but its focus is not on Europa
- Future missions to Europa and Titan are currently competing for funding and launch dates
- New Horizons is expected to arrive at Pluto in 2015 and may provide data on a possible Plutonian ocean
  - New Horizons will also be visiting other Kuiper Belt objects (TBD)
- Life may exist in many more places, and in many for forms, than we ever previously imagined.

Conclusion

- Subsurface oceans are important because they can potentially mimic environments on Earth that we know can sustain life
- Strong evidence for these subsurface oceans exists on at least three moons in the outer solar system: Europa, Enceladus, and Titan
- There is some reason to believe they could exist on still many more worlds
- Future missions to these worlds can help us to determine the number of subsurface oceans, and the kinds of environments they are
- Access and contamination of those oceans remains a major hurdle in exploring them directly

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