Subsurface Oceans in the Outer Solar System

Version #2: The Search for Life

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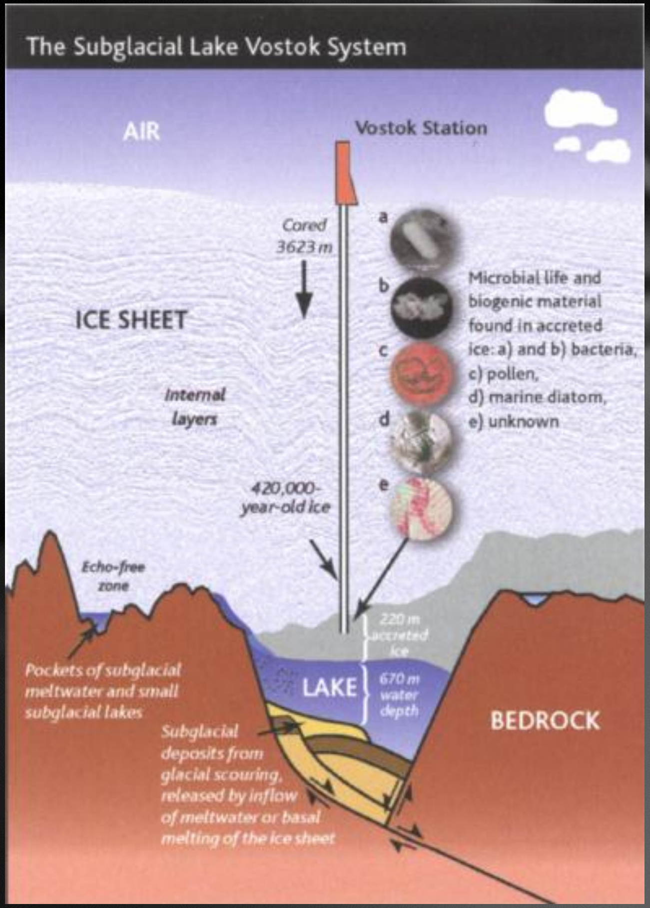
for Physics 596, Fall 2011

Introduction

- The search for life in the solar system begins on Earth
  - Extremophiles:
    - How exotic can life on Earth be?
    - What kinds of extreme environments can harbor life here?
    - Are there similar environments in elsewhere in the Solar System?
  - Subsurface Antarctic Lakes:
    - How similar to subsurface oceans on moons in outer Solar System?
    - Can we access it?
    - What technology is needed?
    - Can we access the lake without contaminating it?



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

Basic Questions

- How common are subsurface water oceans in the outer Solar System?
- Where are they located?
- What keeps them from freezing?
- Are they stable enough for life to form?
- Can they be accessed from 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)

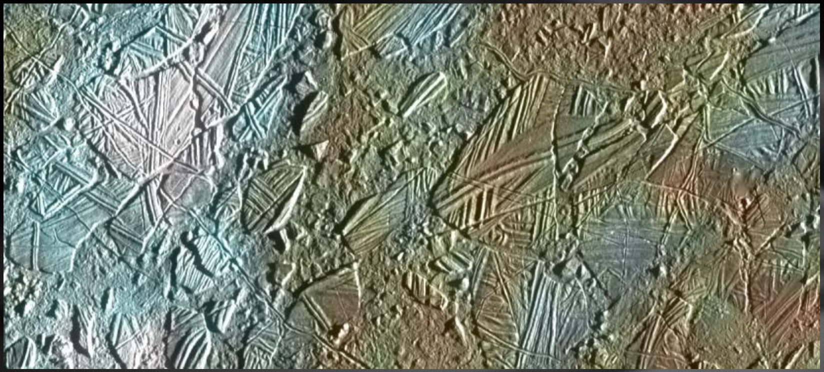
	D, km	D_{oc}, km	R_c, km	R_c/R_p	M_c/M_p	MoI	X, %	X_0, %
Europa	79.5	80.5	1405.0	0.90	0.92	0.346	2.1	1.0
	77.5	82.5	1405.0	0.90	0.92	0.346	6.1	3.0
	74.8	85.2	1405.0	0.90	0.92	0.346	9.9	5.0
	70.0	90.0	1405.0	0.90	0.92	0.346	14.9	8.0
	57.0	103.0	1405.0	0.90	0.92	0.346	24.2	15.0
Rhea	400.9	16.4	347.2	0.45	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).

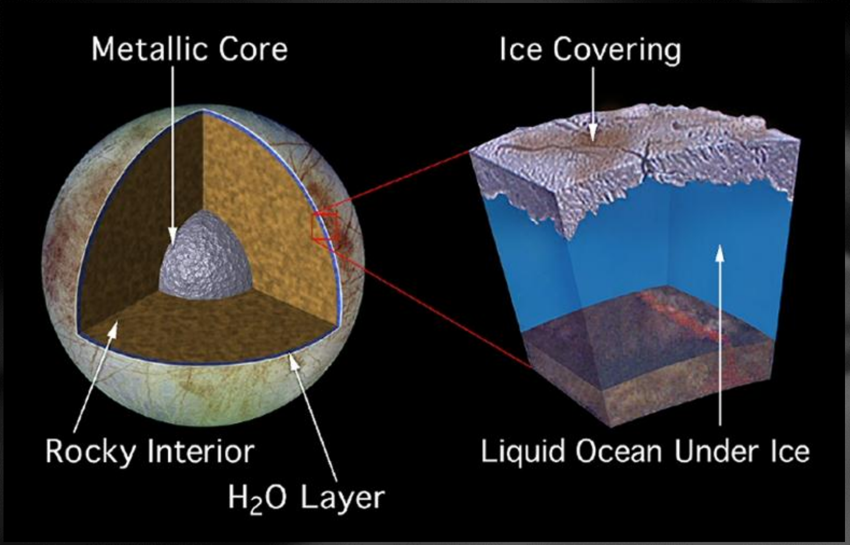
Europa

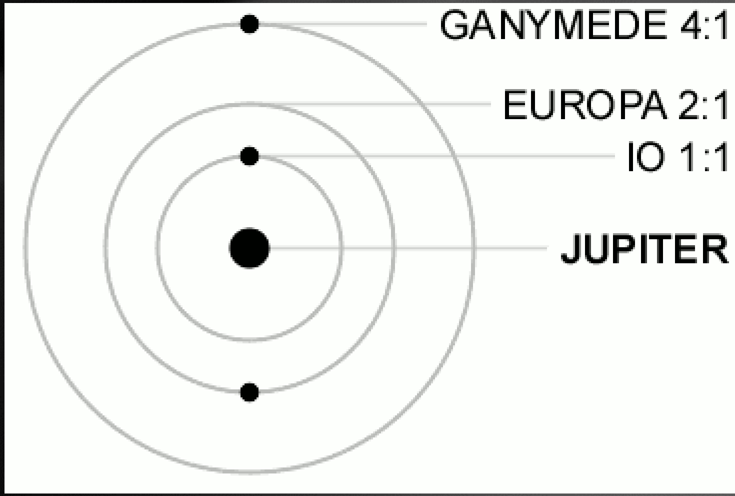
- Europa was first imaged close up by Voyager in 1979
- Images reminded scientists of ice floes in the Arctic/Antarctic leading to speculation about a subsurface ocean
- Young age of the surface further suggested recent resurfacing and some sort of geologic activity
- Colour changes on the surface likely 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

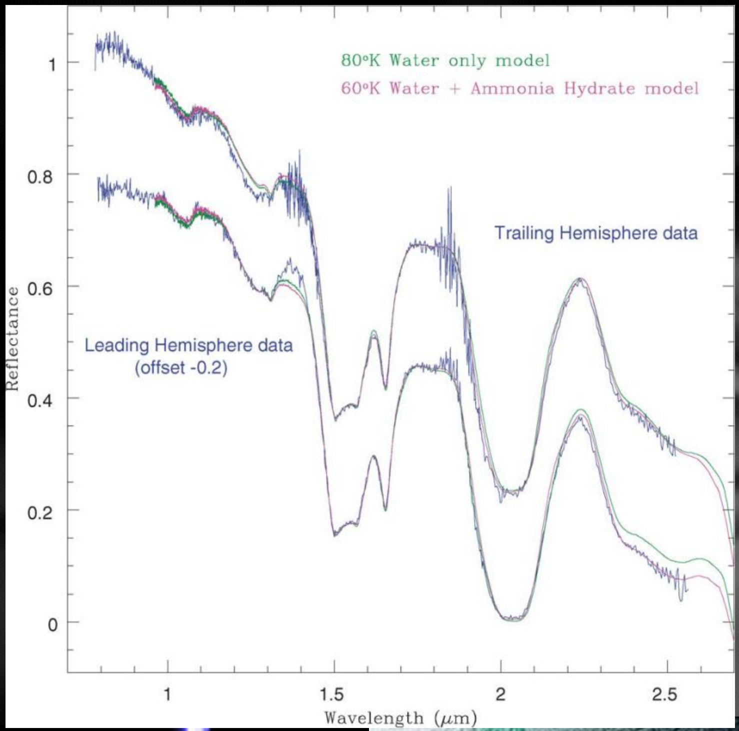
- Tidal heating keeps water ocean from freezing
- Tidal resonance with Io and Ganymede maintains eccentricity in orbit
- Obliquity in orbit may also generate forces in the ocean that contribute substantially to total heat budget
- Salts and ammonia may act as an antifreeze
- Interior and surface may rotate at different rates if decoupled by an intervening liquid layer

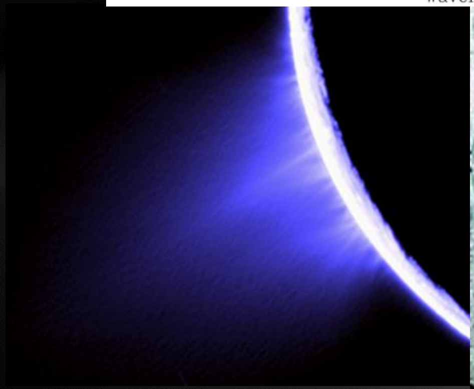


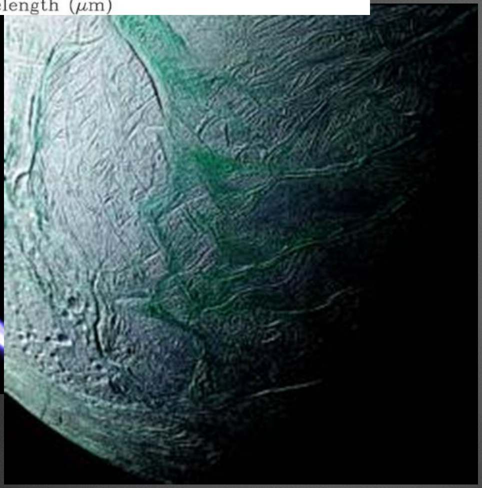


Enceladus

- 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
- Like Europa, the surface is extremely young and relatively crater free
- However, it is thought to be too small to maintain a liquid ocean



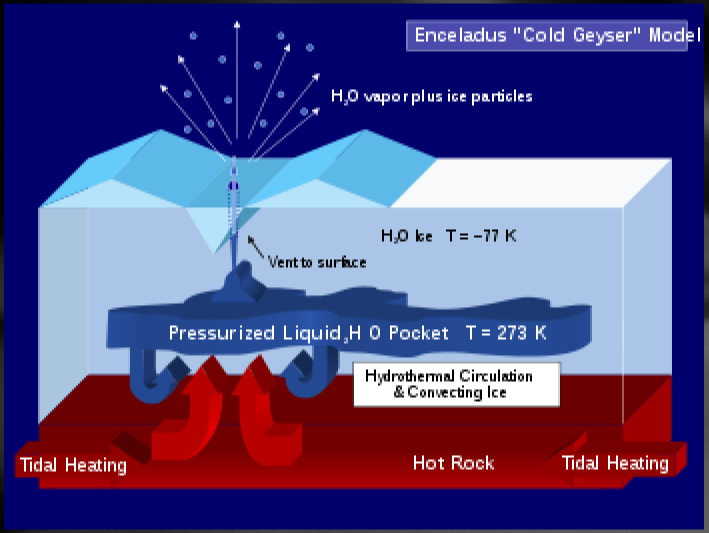


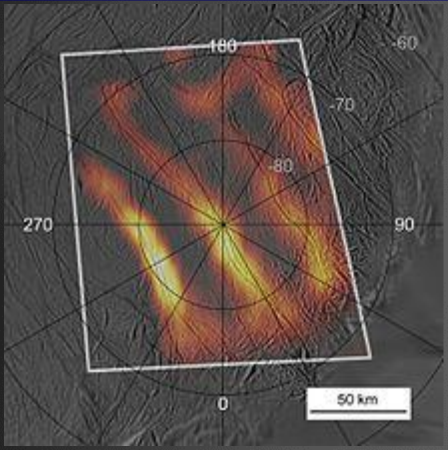


C. J. Hansen, L. W. Esposito, A. I. F. Stewart, B. Meinke, B. Wallis, J. E. Colwell, A. R.

Enceladus

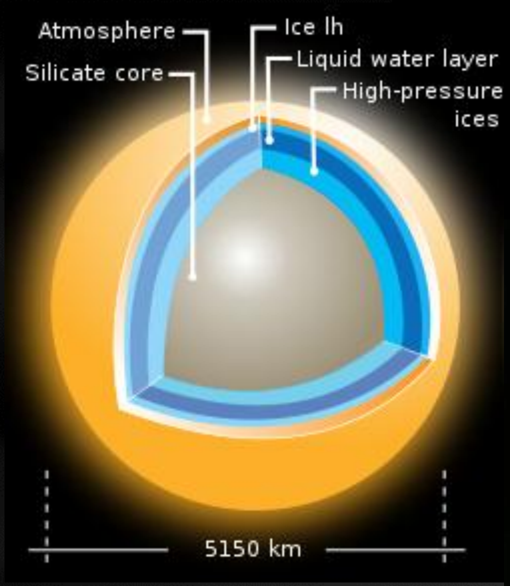
- Structure of the ocean may be substantially different than europan ocean
- There is a distinctive heat anomaly under the southern pole marked by the tiger stripes
- It is thought that the water has formed a diapir and is being forced to the surface by pressure and gravity
- Unlike the europan ocean, this ocean is not believed to be stable in the long term, reducing chances of life

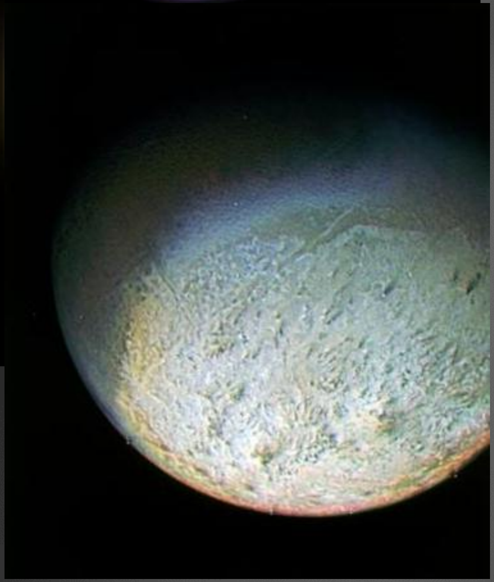




Titan & Triton

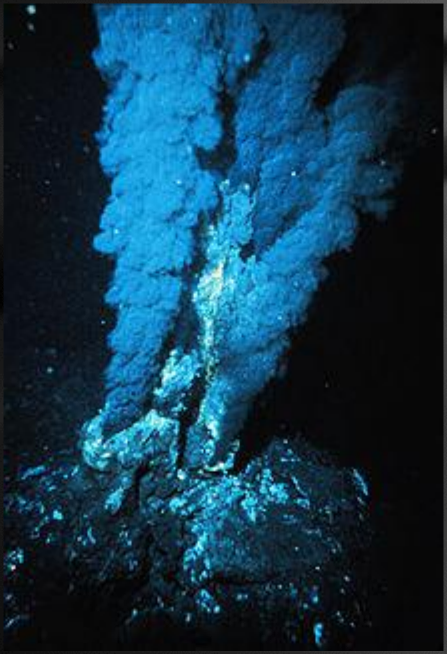
- Titan and Triton are probably quite similar in their water oceans
- The ocean is thought to be sandwiched between low pressure ices on top, and high pressure ices just above the rocky core
- Ammonia acting as an antifreeze can allow for a deeper ocean
- Evidence of cryvolcanism on surface
- Evidence that Titan’s core is decoupled from surface and rotates at a slightly different rate.
- Electrical field detection interpreted as evidence for liquid ocean





Conclusion

- 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.



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