Subsurface Oceans in the Outer Solar System

Version #1

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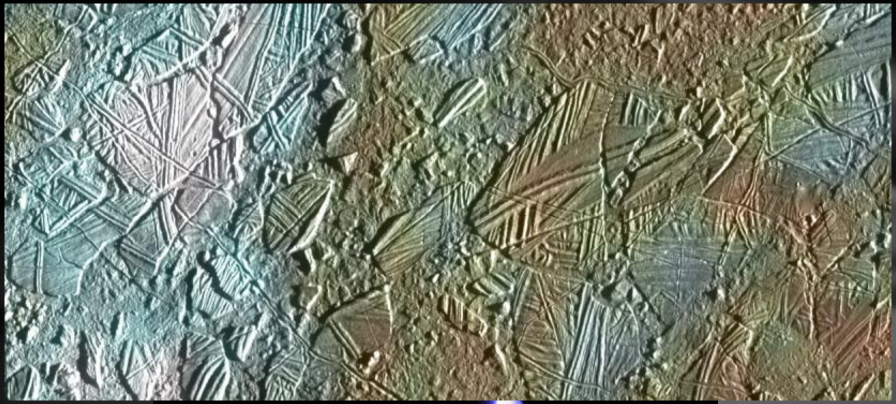
Introduction

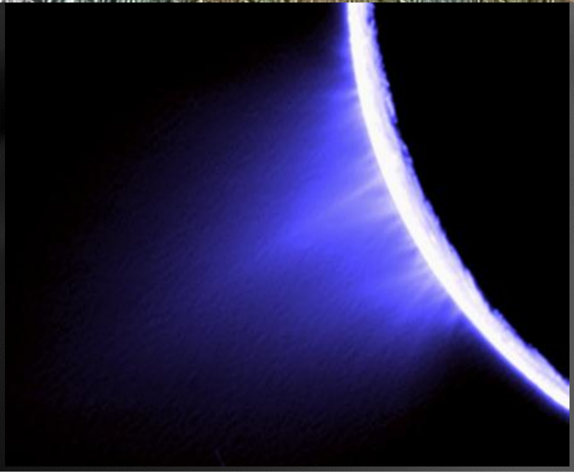
- *The search for life beyond Earth depends on search for liquid water.*
- *Images of Europa from Voyager I & II gave us first glimpse that it could be possible.*
- *Maybe a dozen worlds in the outer Solar System could be candidates for liquid water oceans in their interiors.*

Enceladus

Europa & Enceladus

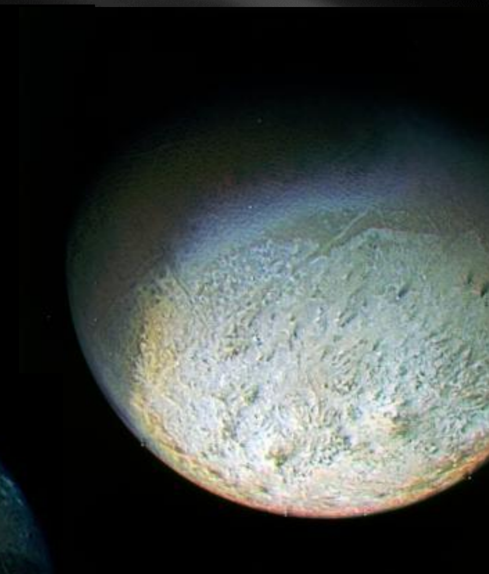
- *Young surfaces resembling ice fields on Earth*
- *Tidal heating*
- *Water ice plumes above surface*
- *Measurements of tidal Love numbers*
- *Plans for future spacecraft visits*





Titan, Ganymede & Triton

- *Differentiated interiors*
- *Oceans deep under icy surface*
- *Ganymede:*
  - Tidal heating
- *Titan & Triton:*
  - Radioactive decay
  - Young surfaces of methane
- *Largest moons in the Solar System*



Are there more?

- *While only Triton could have a pure water ocean, the introduction of ammonia could allow oceans to remain liquid on many moons and dwarf planets including smaller objects like Sedna, Rhea and Oberon.*
- *Oceans could be nearly 200 km deep on objects the size of Triton, Pluto and Eris.*
- *Greatly expands the possible environments for life to form.*

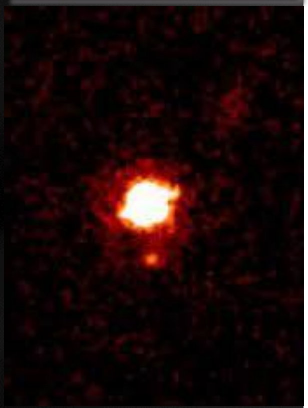


Table 6
Results from the 3-layer model (ice thickness D, ocean thickness D_{oc}, core radius, relative core radius, rock-to-ice mass ratio, dimensionless axial moment of inertia, ammonia content within the ocean X, assumed initial ammonia content X_0)

	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).

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

Conclusion

- *Far more objects in the solar system have large bodies of water on them than ever previously suspected.*
- *Could increase the chance for life in the solar system (besides us) dramatically*
- *Open questions remain, like number, temperature, stability, and whether life can survive in ammonia-water environments.*

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