

Possible evidence for a source of methane in Enceladus' ocean

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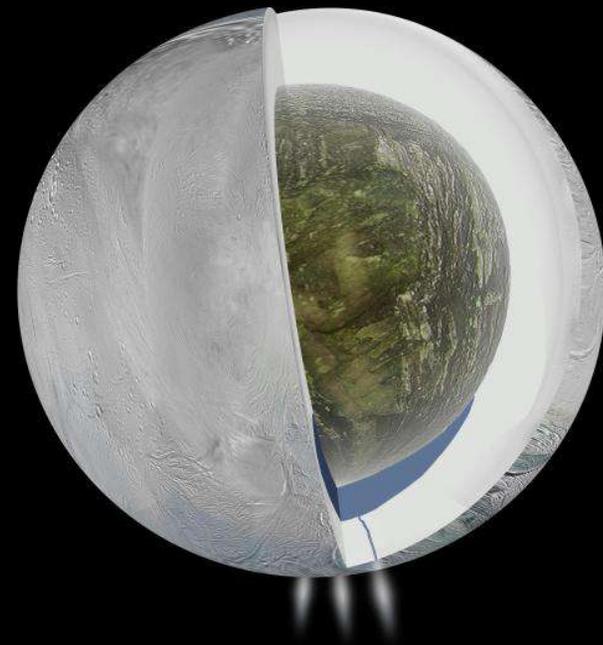
2: Southwest Research Institute, San Antonio, Texas

3: Aix-Marseille Université, Laboratoire d'Astrophysique de Marseille, France

4: Institut UTINAM, Besançon, France

VOLATILES IN THE PLUMES OF ENCELADUS

- Ocean under ~ 35 km of ice
- Water vapor plumes from the ocean
- Not only water! Also:
 - ✓ Carbon dioxide
 - ✓ Methane
 - ✓ Nitrogen/carbon monoxide?
 - ✓ Ammonia
 - ✓ And others...



Credit: NASA/JPL/Caltech

VOLATILES IN THE PLUMES OF ENCELADUS

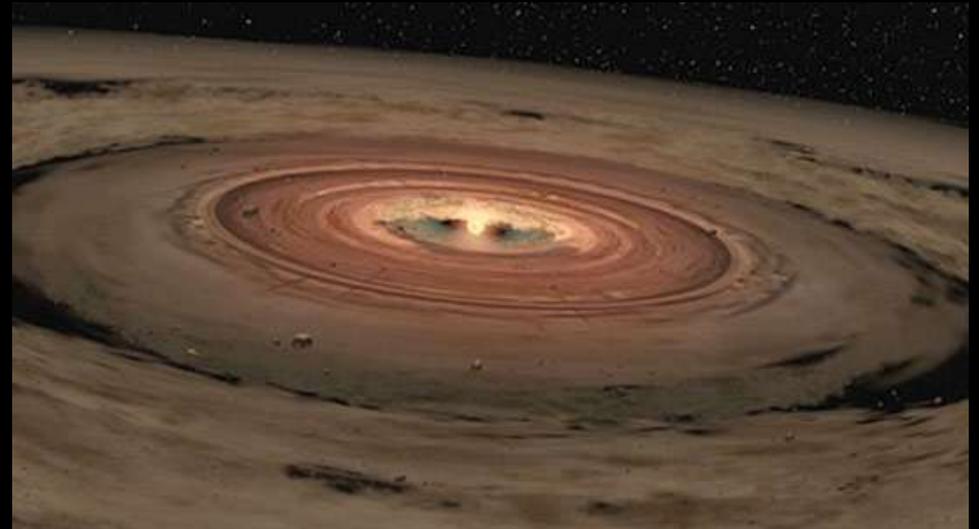
How do we know?

The Ion and
Neutral Mass
Spectrometer
(INMS) on Cassini



VOLATILES IN THE PLUMES OF ENCELADUS

- Volatiles: the conditions of formation of Enceladus



Artist vision of the solar nebula.

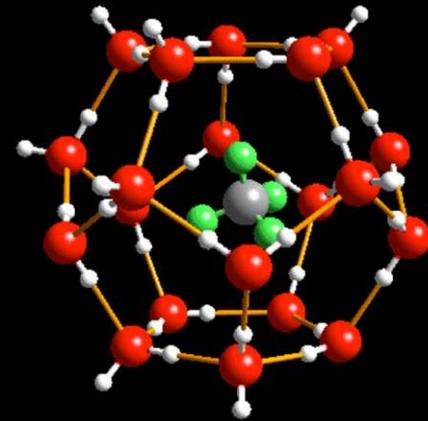
Credit: NASA

How is the mixture we're seeing today representative of the original one?

WHAT CAN CHANGE THE MIXTURE OF VOLATILES?

Trapping in **clathrate hydrates**

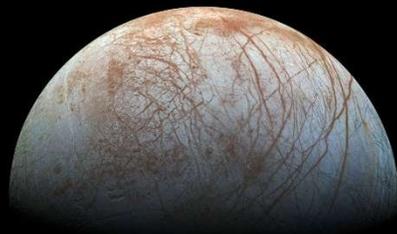
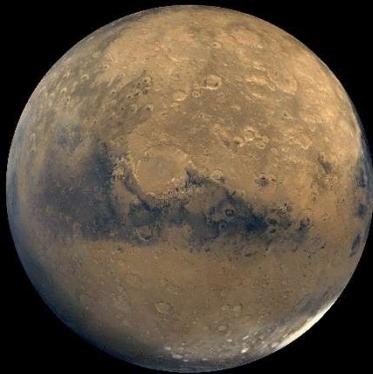
- Clathrates: guest molecules trapped in water cages
- Several types depending on the guests
- Formation: Abundance of water, low temperature, high pressure



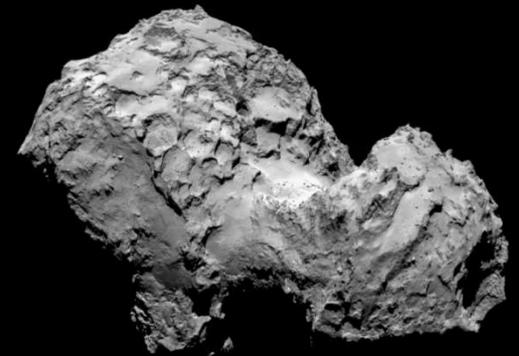
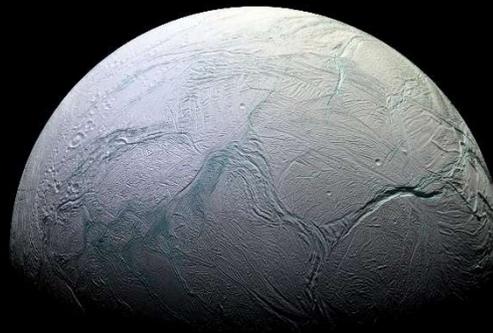
Credit: Caltech

CLATHRATES

Potentially ubiquitous in the solar system



Formation in liquid
water or in solid
ice



Images credit : NASA

CLATHRATES

Present on Earth

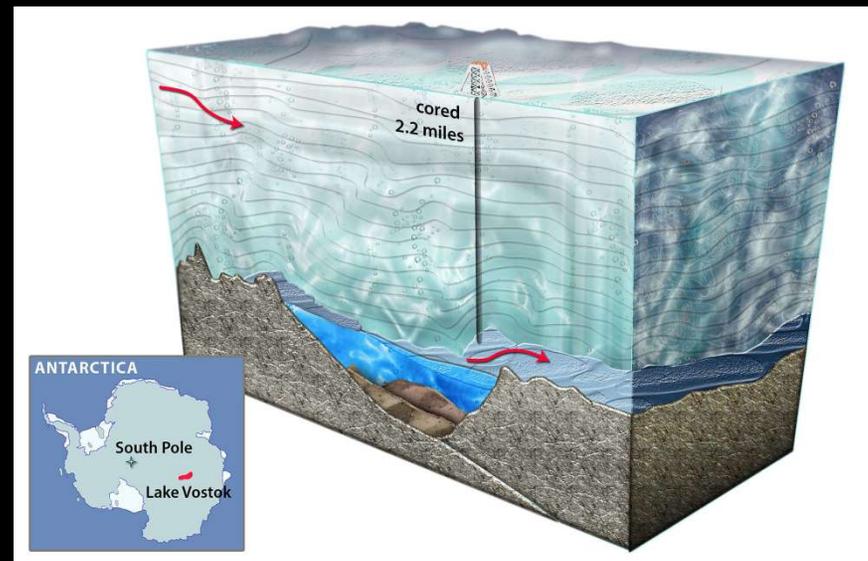
- Methane clathrates in sediments in the oceans
- “Clathrate gun” hypothesis



Credit: NASA

SUBGLACIAL LAKE MODEL OF CLATHRATE FORMATION

- Thermodynamic statistical model describing the guest-clathrate interaction
- Applied to Vostok lake
- Volatiles supplied by melting of ice at the liquid/ice interface

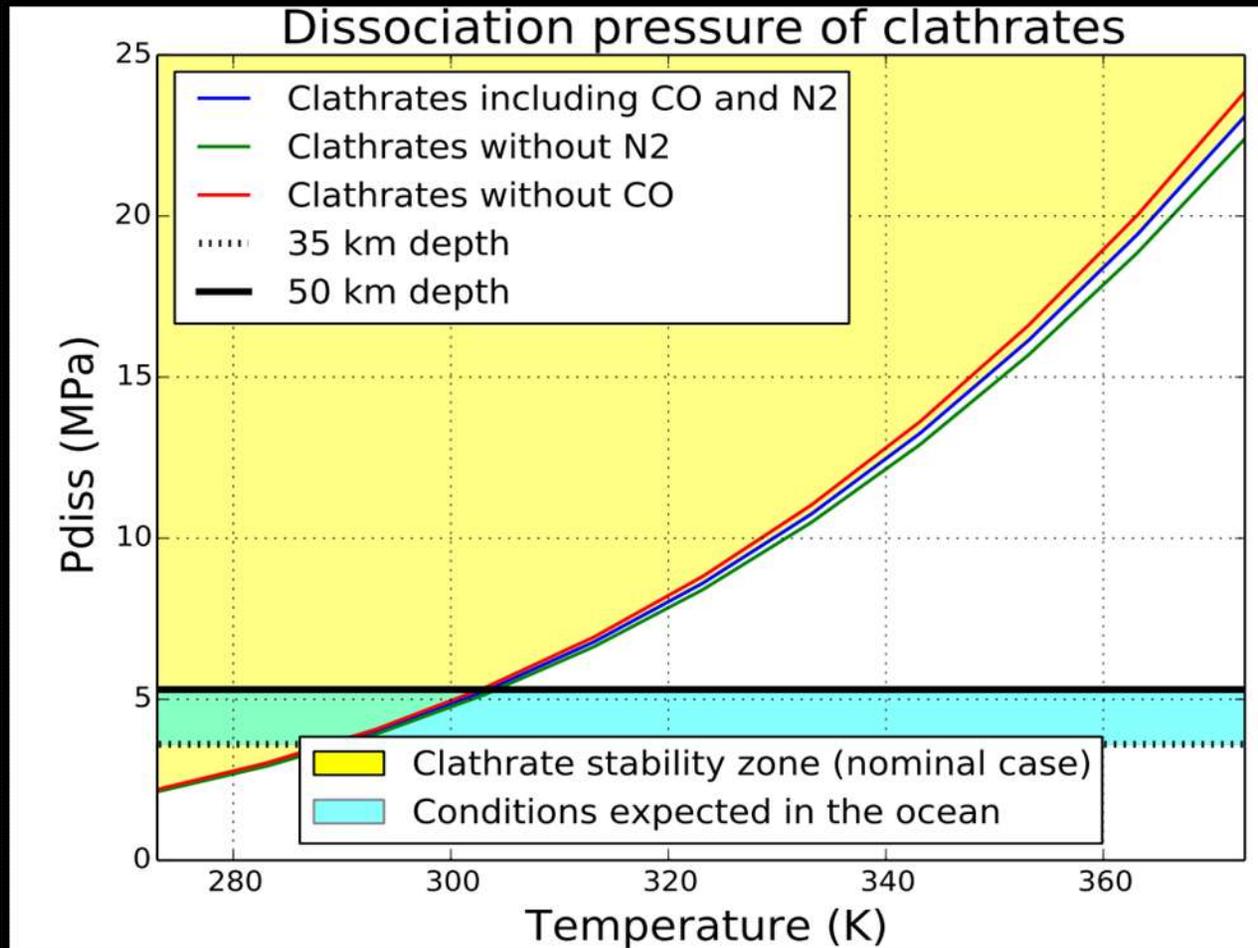


Credit: Nicolle Rager-Fuller / NSF

WHAT SPECIES CAN BE TRAPPED?

- In Enceladus' plumes: Carbon dioxide, Nitrogen, Methane, Carbon Monoxide, Hydrogen Sulfide
- Noble gases: Argon, Krypton, Xenon: tracers of evolution

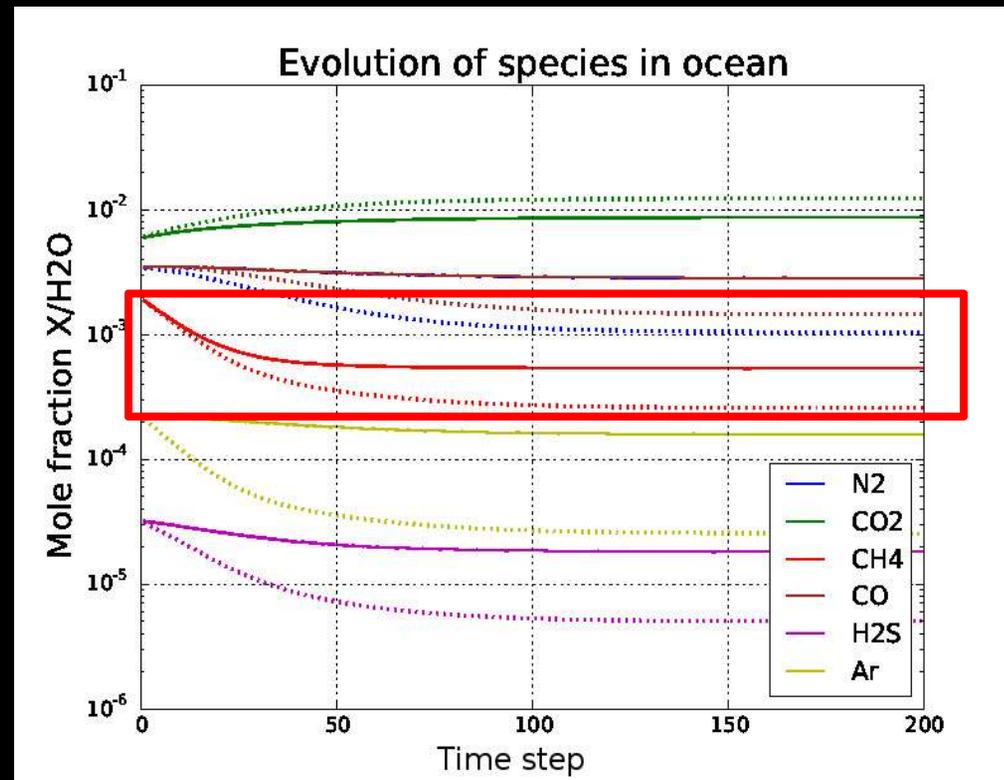
ARE THE CONDITIONS MET?



- Below room temperature (300K) formation and stability is possible

WHAT HAPPENS WHEN WE RUN THE MODEL?

Dotted or solid lines for different clathrate structures

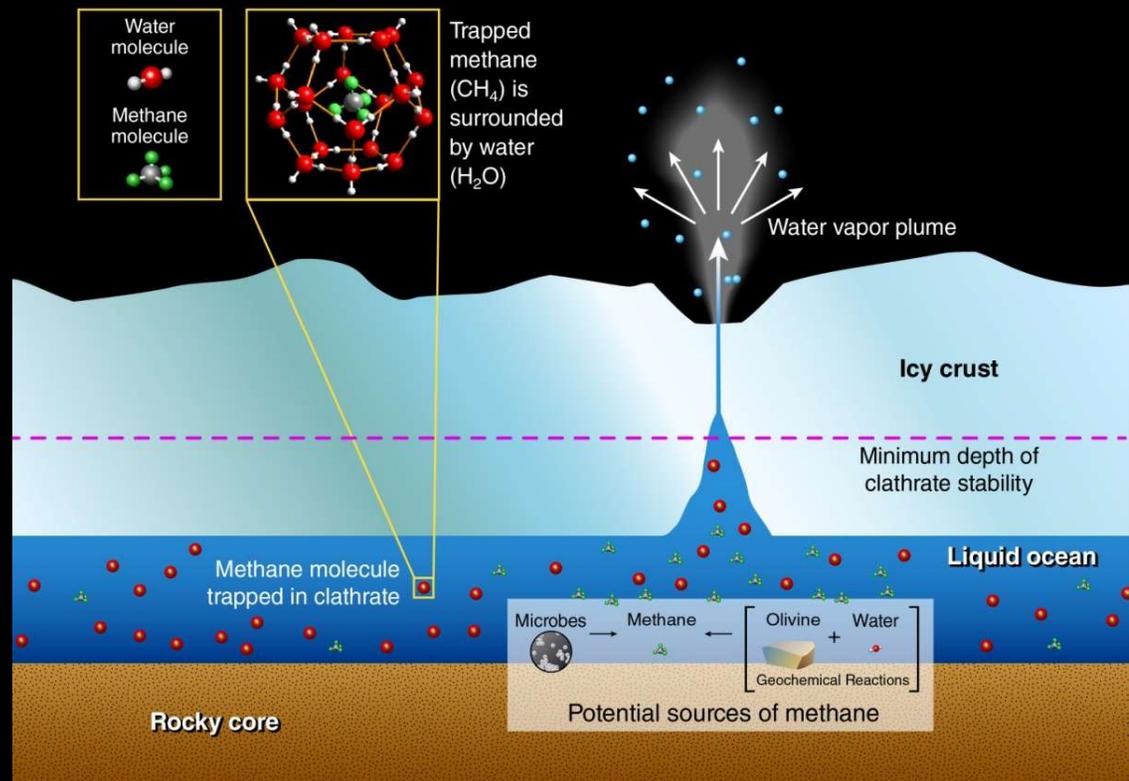


- Depletion of methane in all scenarios

FATE OF THE CLATHRATES

Trapping of Methane in Enceladus' Ocean

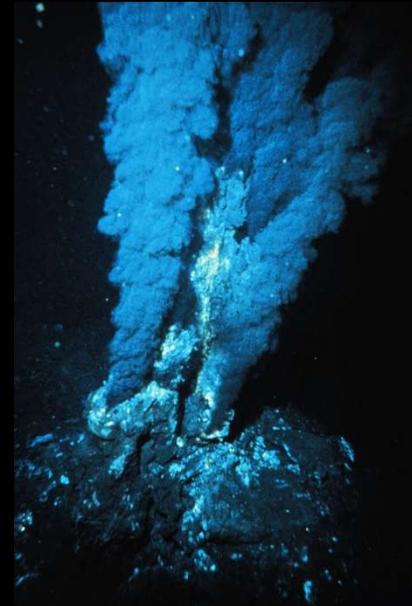
- Calculated density lower than salt water
- Clathrates are not even full!



Credit: SwRI

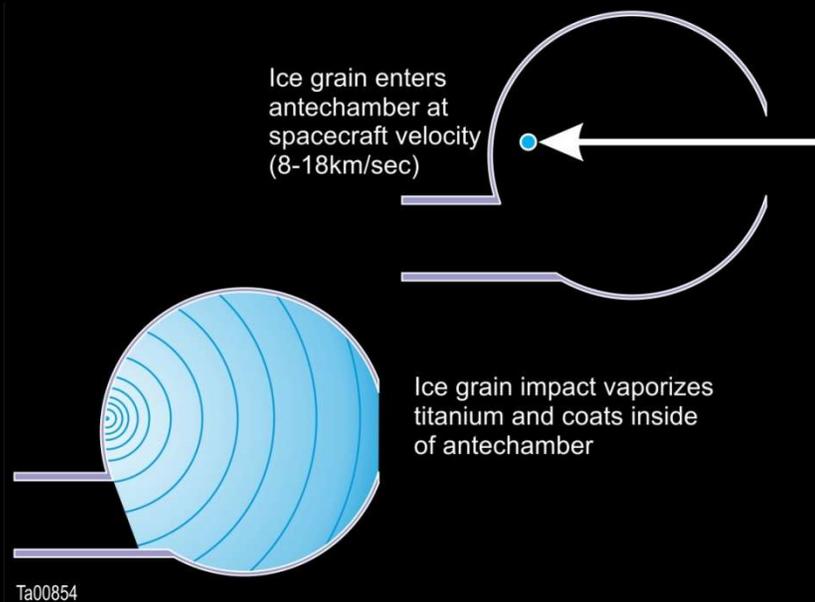
POSSIBLE EXPLANATIONS

- Clathrates are dragged along and ejected in major quantities
 - Hydrothermal activity:
 - Rock/water reactions
 - Ulterior processes involving hydrogen produced by the vents
- Do we see hydrogen?



HYDROGEN, THE “SMOKING GUN”

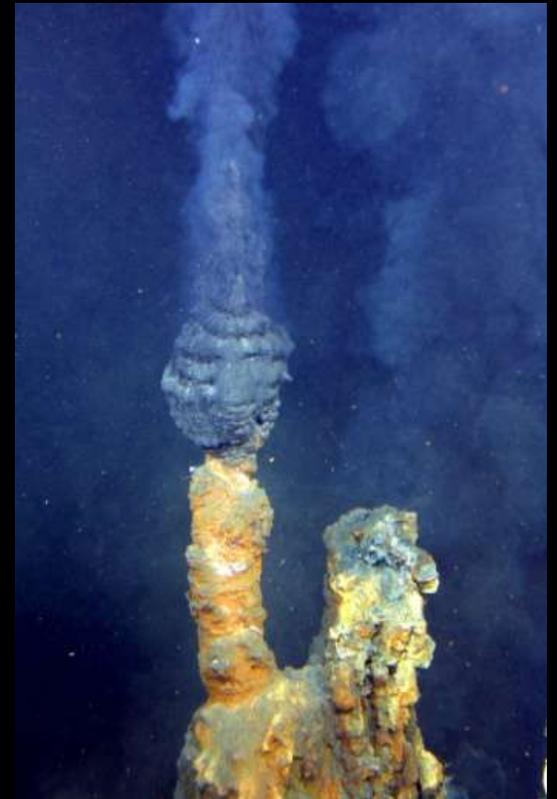
- Do we see hydrogen? **Yes, we do!**
- Not subject to trapping in clathrates
- But... Ice grains impacts



Titanium reacts with water and forms hydrogen!

THE STAKES OF HYDROGEN DETECTION

- “Smoking gun” of hydrothermal activity, direct estimate
- Ratio hydrogen/methane indicative of life? **Very controversial**



TAKE-AWAY

- Abundance of methane in the plume: clathrates participated in the plumes OR hydrothermal activity
- Hydrogen potentially a goldmine for characterizing hydrothermal activity, but quantification is elusive