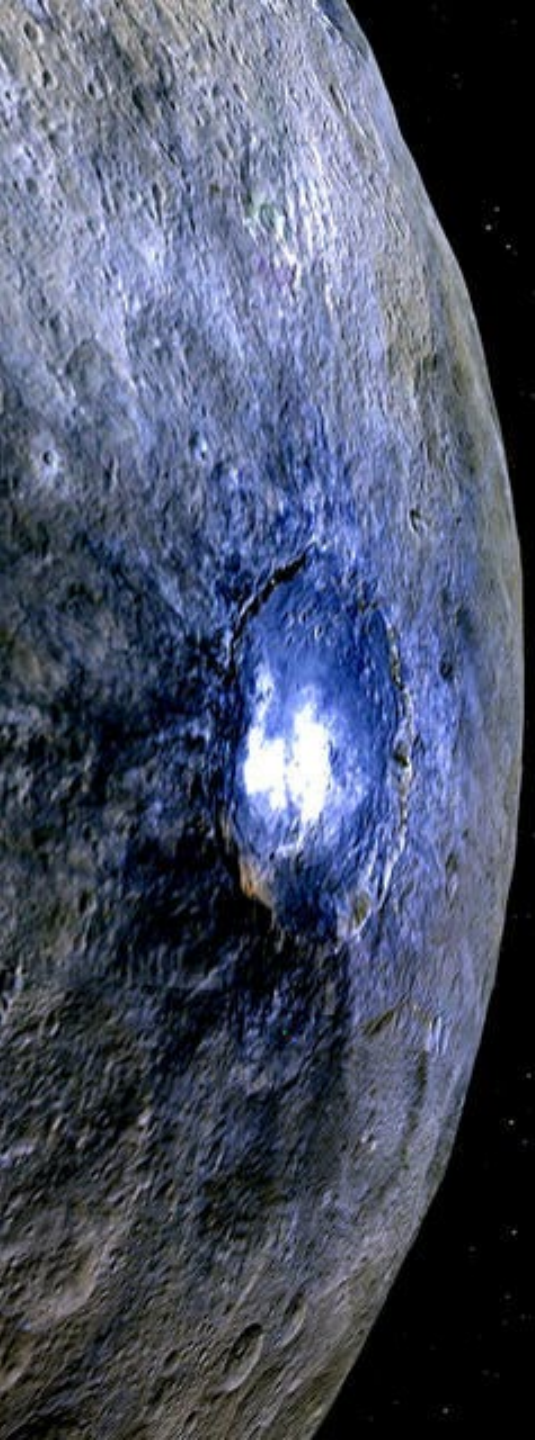

Jet Propulsion Laboratory
California Institute of Technology

Planetary Protection for Missions to Ceres

State of Understanding after the Dawn Mission

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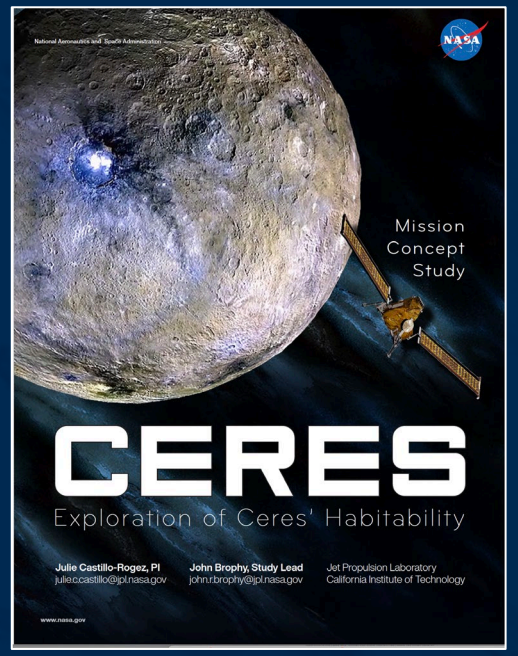
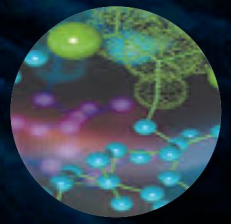
Presentation to Committee on Planetary Protection – March 22, 2023

Context for Independent Mission Categorization



- Study developed for the *Ceres Habitability Planetary Mission Concept Study* for the OWL Decadal Survey in 2020.
  - 5 other mission concepts about Ceres since 2019.
- Intended to address a gap in policy.
- Based on site analysis (geology and composition), but acknowledging that there are limitations to our knowledge.
- Built on end of Dawn mission PP assessment (2019) that led to 50-yr stable orbit requirement.
- Assessment submitted to *Astrobiology,* two rounds of peer-review.

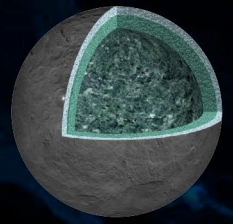
CHNOPS



WATER

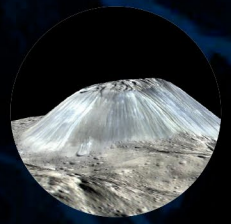
ENERGY

Dawn has revealed the astrobiological potential of dwarf planet Ceres, a candidate ocean world



possible ocean world

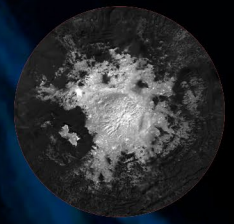
geology



recent volcanism

surface salts

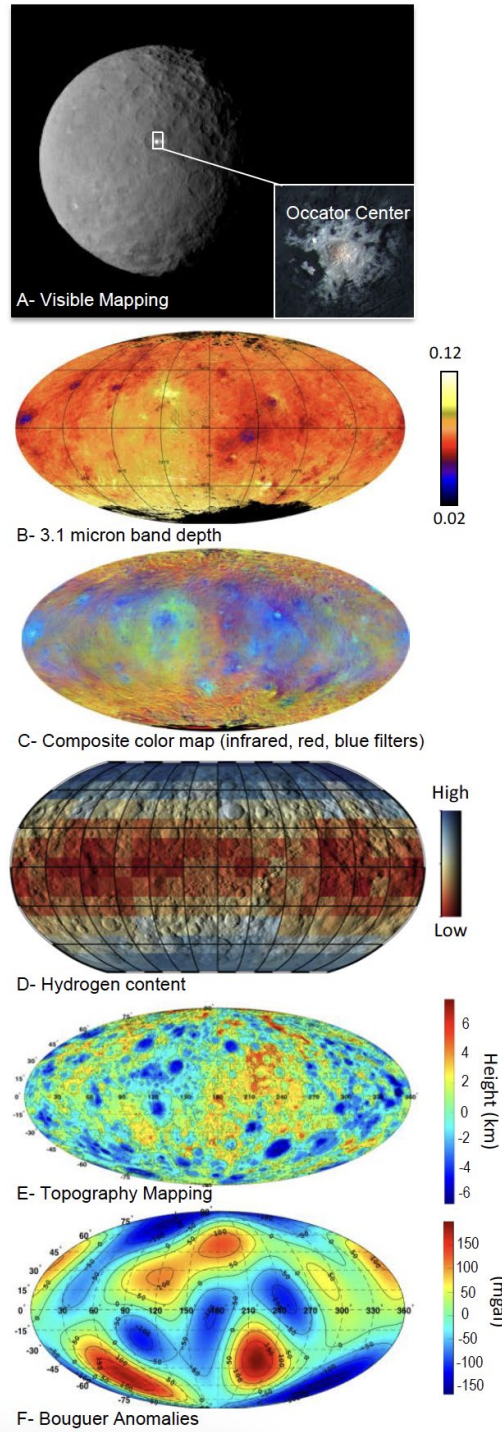
organic matter



recent brine

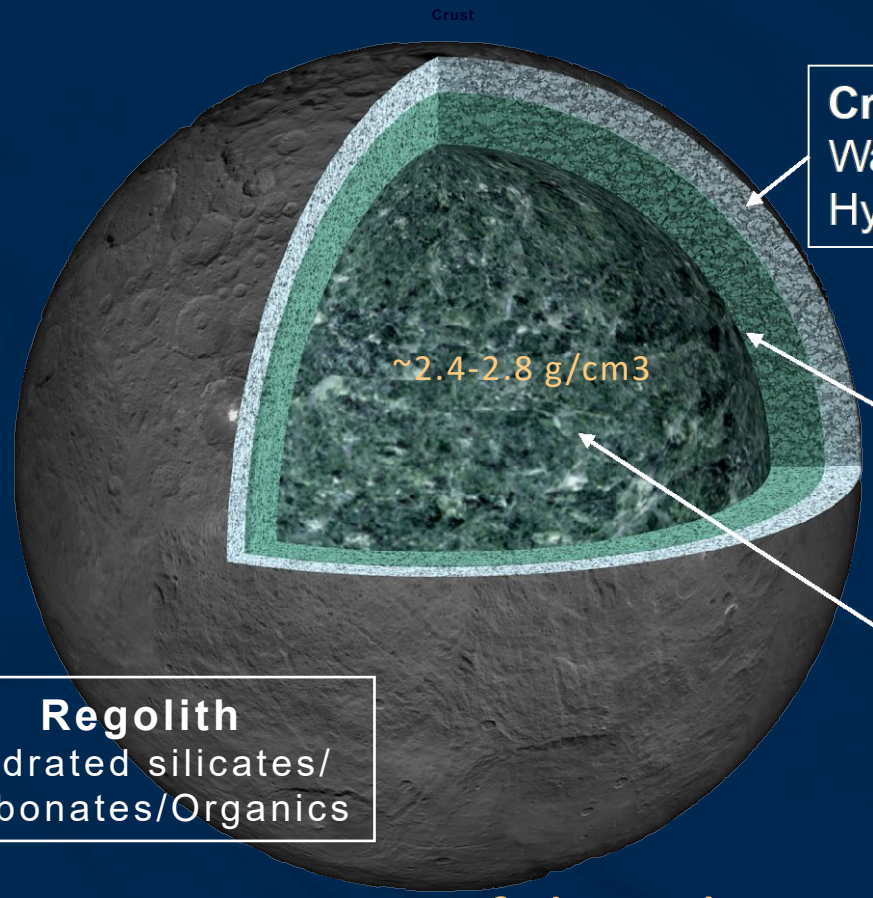
Scientific Analysis of the Dawn Results

- The Dawn mission acquired data from March 2015 to October 2018
  - Several generations of results: before and after gravity results (08/2016)
  - Evolution of the understanding of Ceres' interior structure over the course of the mission
- Ceres is the most extensively studied ice-rich body by Earth-bound telescopes and by spacecraft
  - Global imaging at 35 m/px and locally at 5 m/px
  - Gravity harmonics up to degree 18 at global scale and 50 locally
  - Topography model at 100 m resolution on global scale
  - Mineralogy maps 150-180 m resolution on global scale
  - Elemental composition on regional scale (100s km)



Ceres' Interior

Global



Crust ~1.25 g/cm3
Water/Salts/
Hydrates/Organics

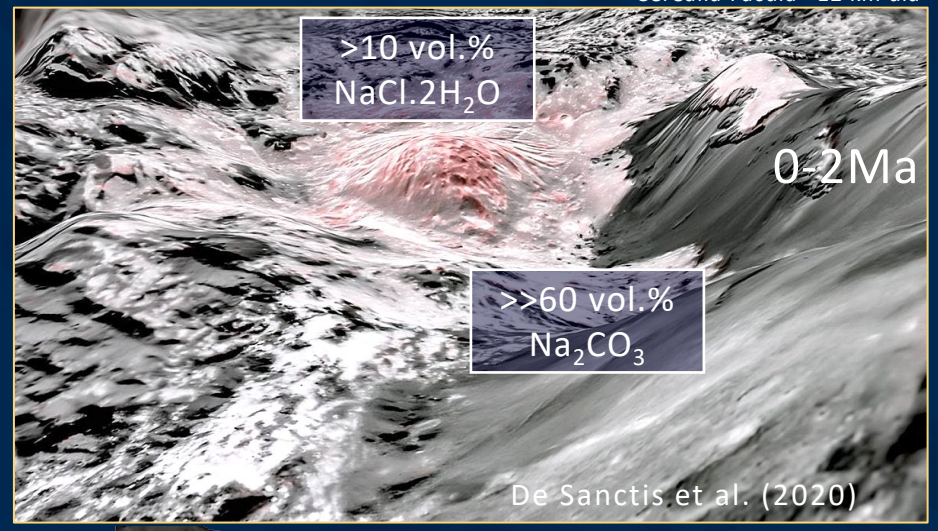
Upper Mantle
Rock/Brine (mud)

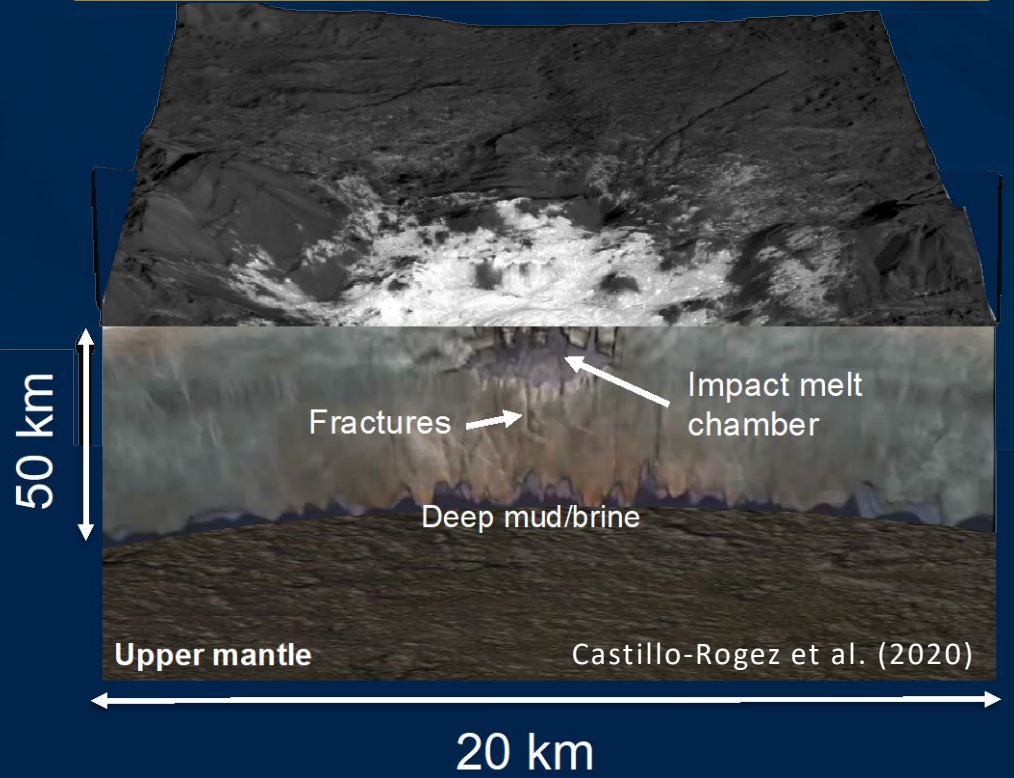
Lower Mantle
Porous rock,
Brine?

Regolith
Hydrated silicates/
carbonates/Organics

Temperature of deep brines ~250±5 K
inferred from salt composition

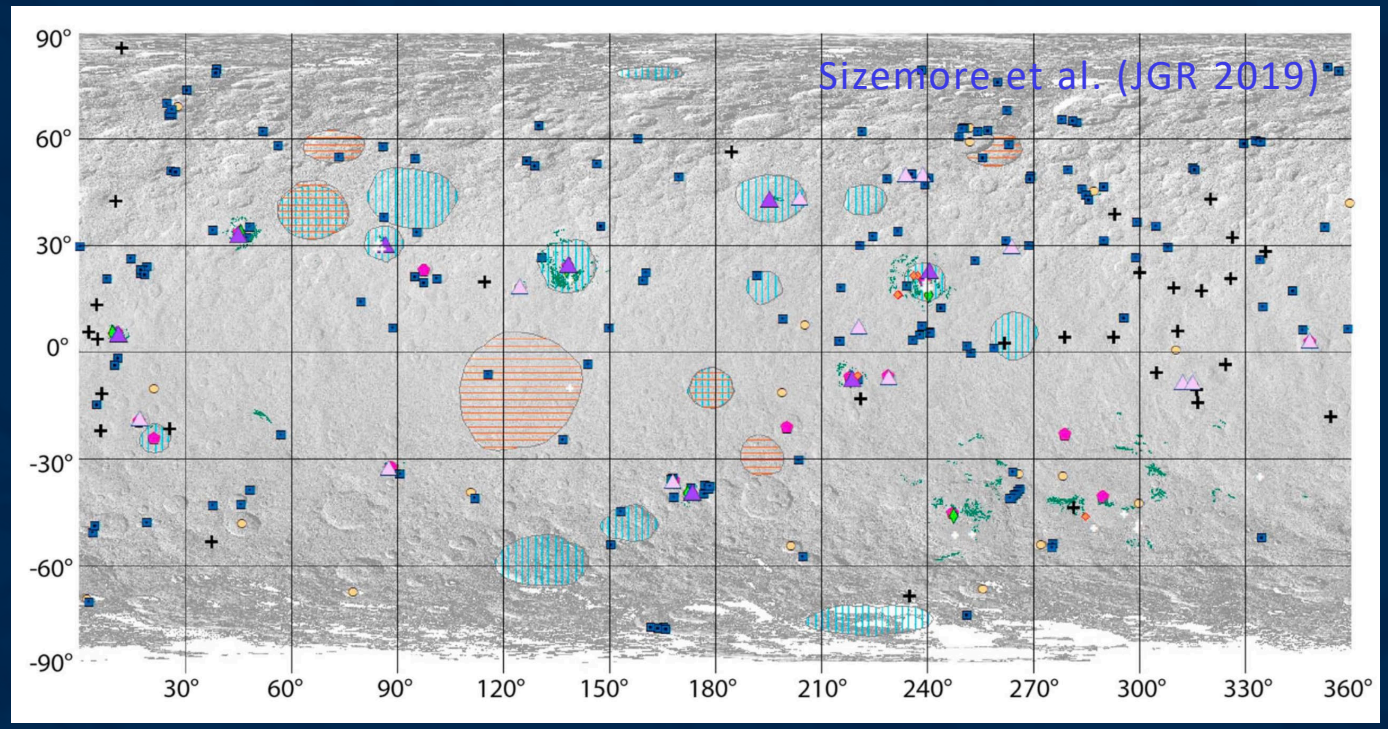
Local

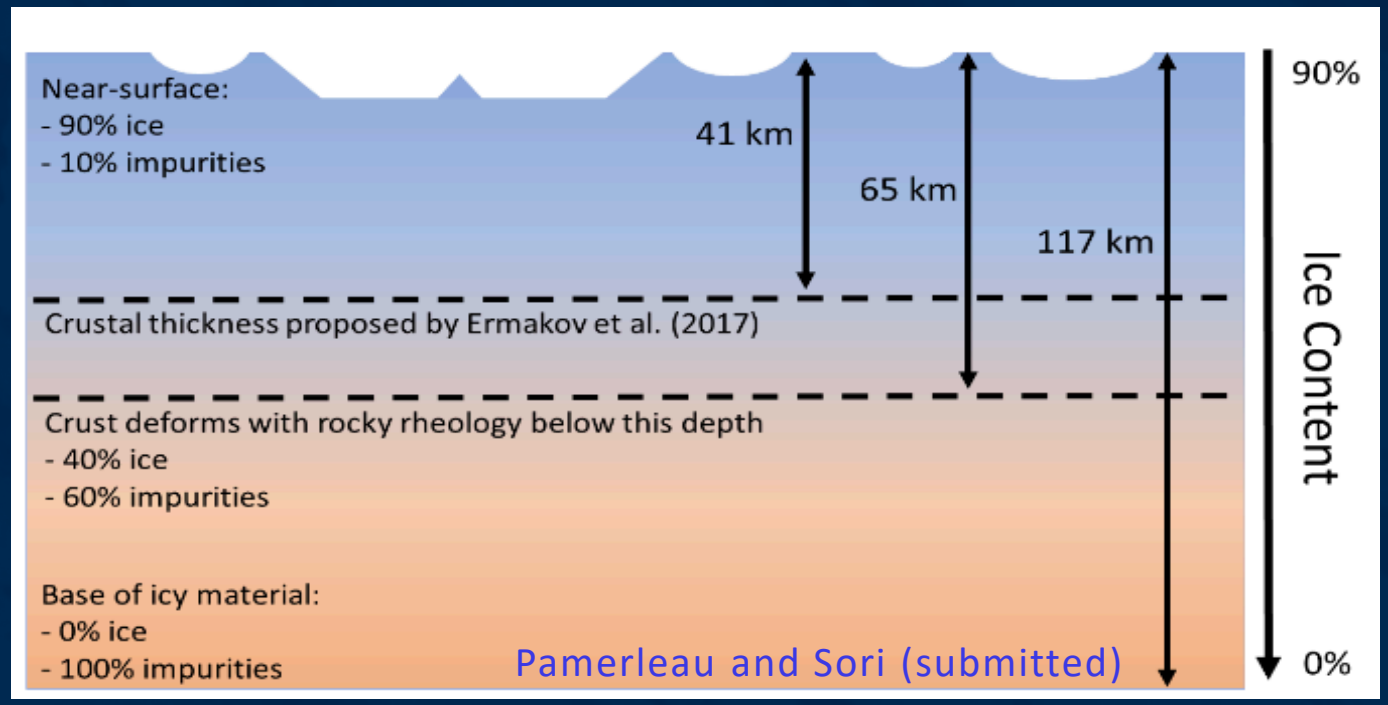




Ice on Ceres

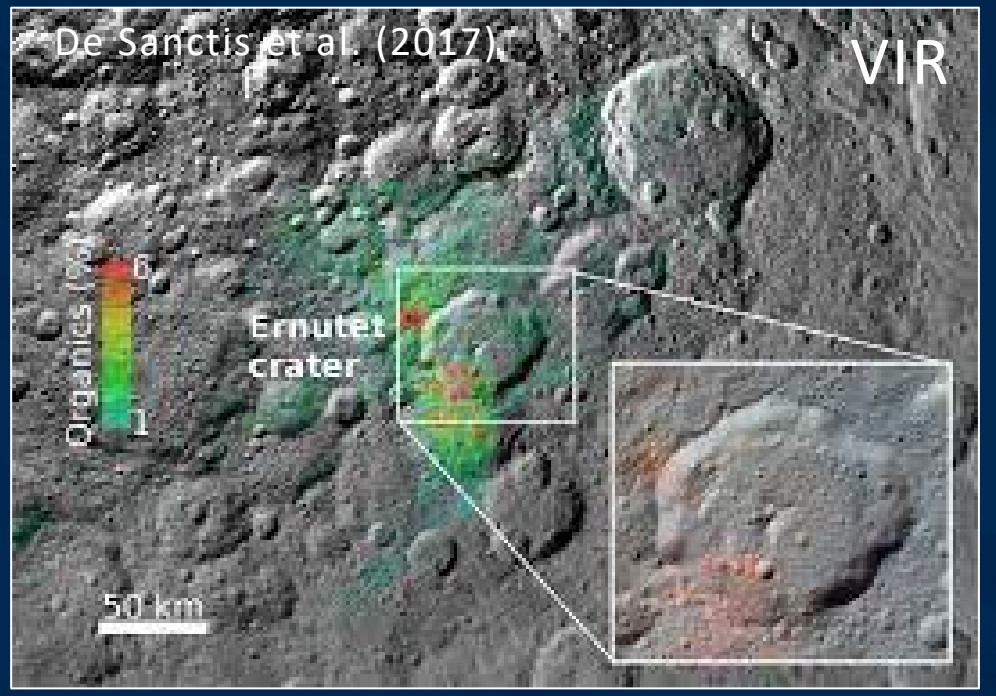
- Low-density crust inferred from gravity data
- Ice is not stable on Ceres' warm surface, found in a dozen cryptic sites
- Ice present <1 m depth at latitudes >40 deg.
- Pervasive evidence of ice in geomorphology
- Water vapor detected by Herschel Space Observatory

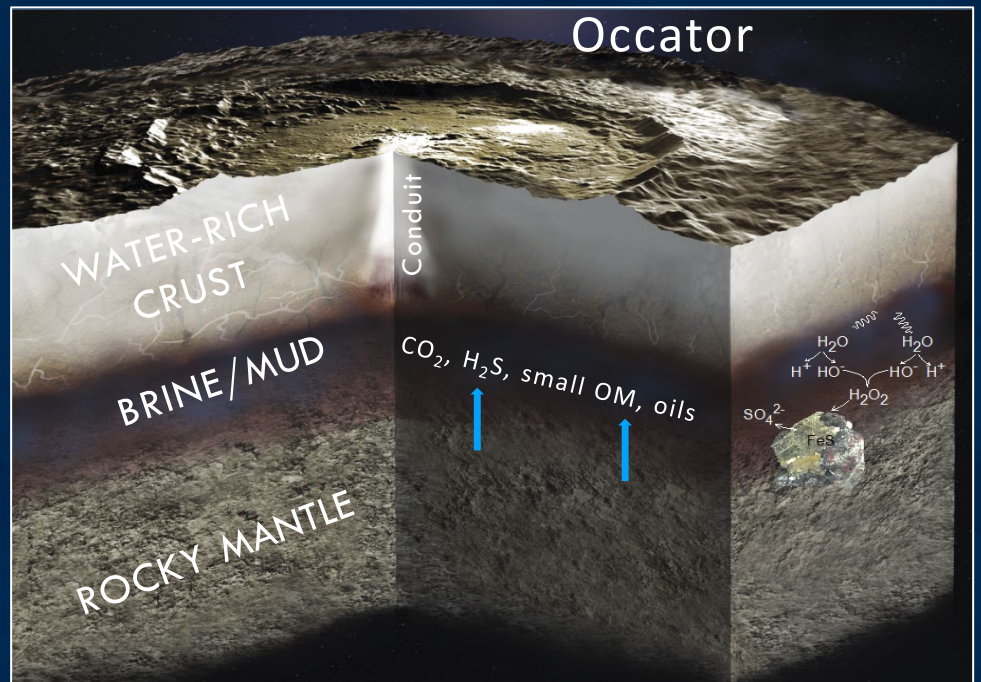




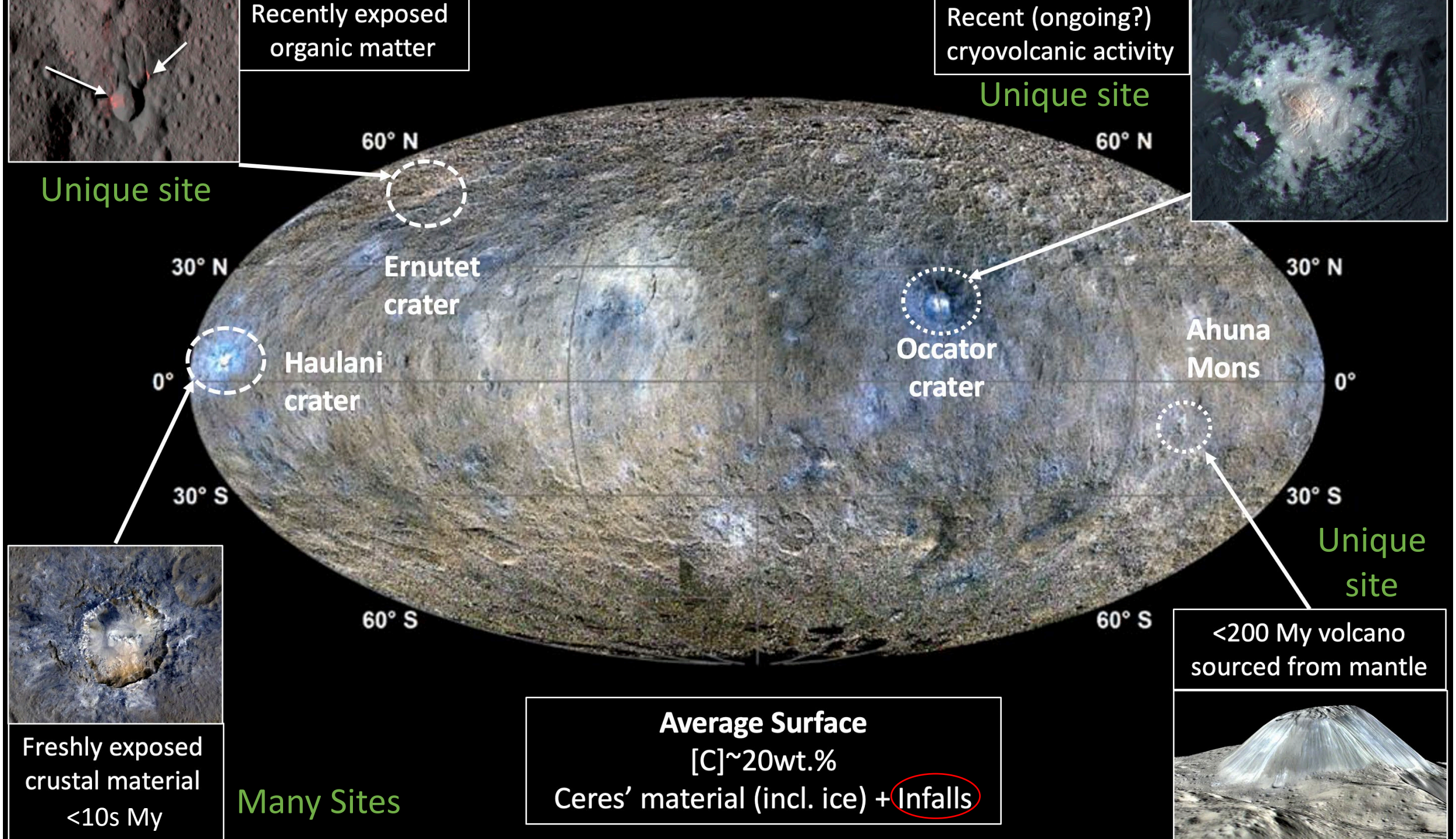
Organic Matter on Ceres

- Globally up to 20wt.% C in Ceres' regolith, interpreted as amorphous carbon
- Very local enrichment in "fresh" aliphatic organic compounds
- No distinct organic spectral signatures observed at sites of recent eruption (Cerealia, Vinalia), but the presence of OM cannot be excluded





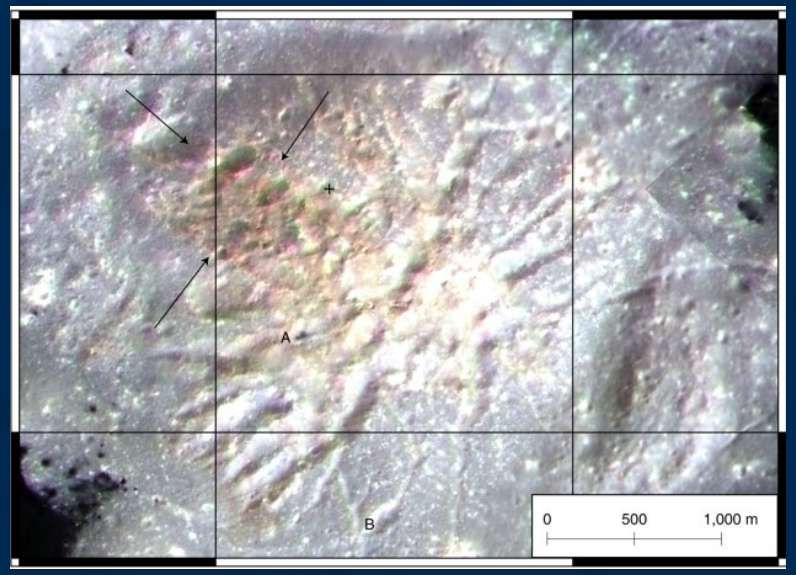
Young 92-km crater (<20 Ma) with fresh (0-2 Ma) salt exposure


Recently exposed organic matter
Unique site
Recent (ongoing?) cryovolcanic activity
Unique site
60° N
60° N
30° N
30° N
Ernutet crater
Haulani crater
Occator crater
Ahuna Mons
0°
0°
30° S
30° S
60° S
60° S
Unique site
<200 My volcano sourced from mantle
Freshly exposed crustal material <10s My
Many Sites
Average Surface
[C]~20wt.%
Ceres' material (incl. ice) + Infalls

Ceres has been the Focus of Several Mission Concepts

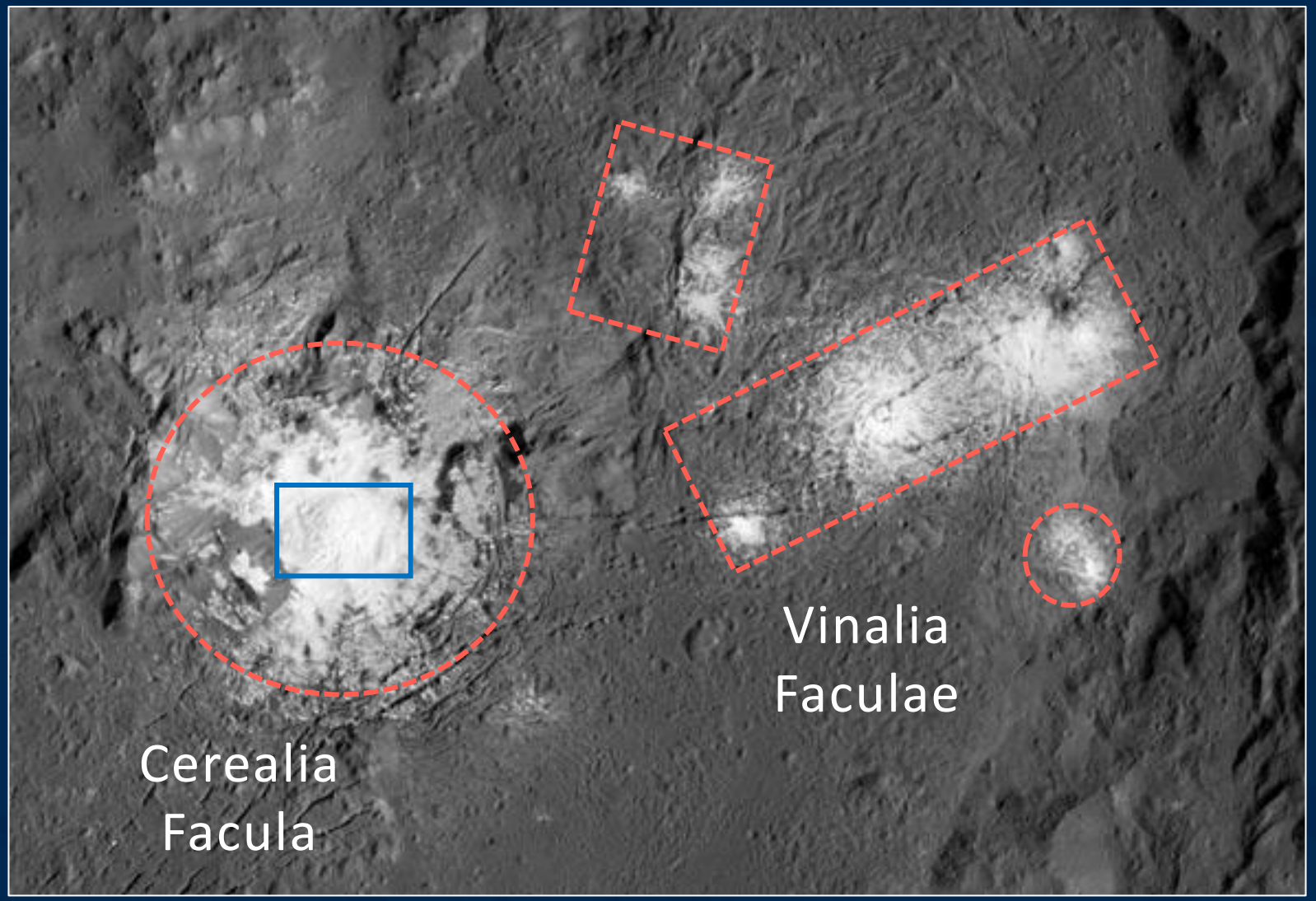
Name	Program	Science	Architecture	Site
CALICO	M-Class Proposal (ESA)	Origins Prebiotic Chemistry Habitability potential	Lander	Occator crater
”Ceres Sample Return”	Decadal Survey New Frontiers (NASA)		Orbiter-Lander-Sample Return	Occator crater
Calathus	Summer School (ESA)		Orbiter-Lander-Sample Return	Multiple (Occator, icy region)
GAUSS	M-Class (concept) (ESA)		Lander	Occator crater
??	Discovery (NASA)		Lander	Occator crater?
tbd	CNSA		Sample return	tbd

Occator Crater – Main Sites



Cerealia Tholus

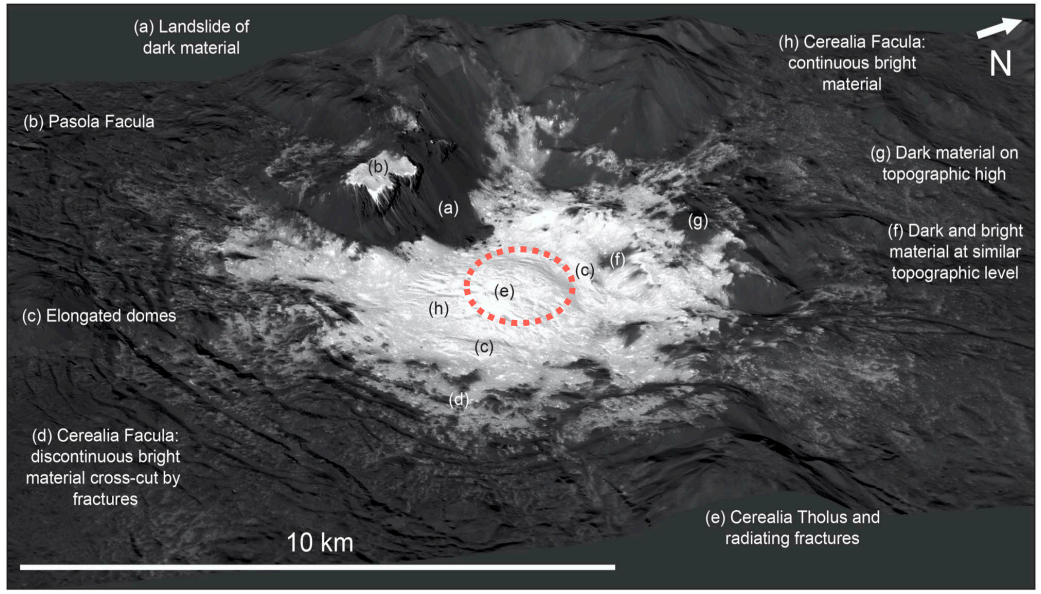
Evidence of hydrates
-> recent exposure

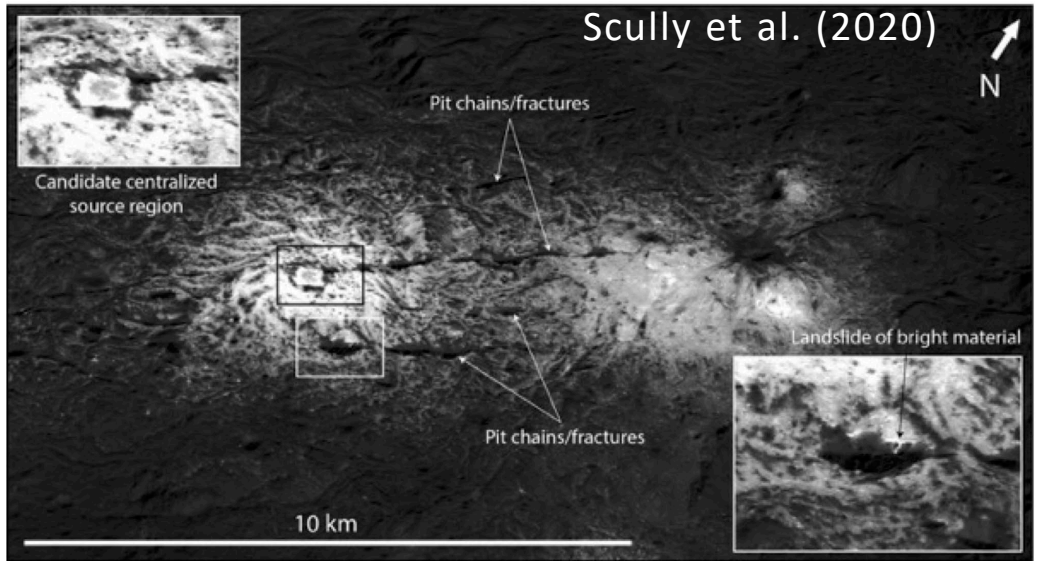


Summary of Site Analysis

Region of Interest to Future Mission	Age	Sterilization Level	Risk of Forward Contamination
Average Ceres Surface	>>200 My	>8 Mrad down to at least 1 m depth	Null (sterilization level; diurnal average T <163 K, T below skin depth <155 K)
Organics in Ernutet Crater	<<10 My (the region itself is >400 My)	Unknown – assume unsterilized	Null (surface T <180 K, T below skin depth <130 K)
Icy Sites	~10^3 y	<<2.5 Mrad, assume unsterilized	Null (surface T <190 K, T below skin depth <130 K)
Occator Crater, floor material outside of evaporite region	<20 My	~8 Mrad down to at least 1 m depth	Null (surface T <210 K, T below skin depth <150 K)
Occator Crater, Vinalia Faculae Evaporites	Ongoing – ~10^5 y	<2.5 Mrad, assume unsterilized for future mission concepts	Potential depending on access to large fractures Outside fractures, T <210 K on surface, T below skin depth <150 K
Cerealia Facula	<10^4 yr (top)	Unknown – assume unsterilized	High

Potential Brine Access at Occator Crater





Exposure of new material at the top of Cerealia Tholus

Deep fractures in Vinalia Faculae

- Large fractures represent between 1% to 6% the total area of the Vinalia Faculae. (Scully et al. 2020)
- Widest fracture mapped in VF is 300 m.
- Total length of mapped fractures in VF is 44 km
- *Astrobiology* review: raised concern that fractures could provide access to deep brine.
- Categorization of lander mission depends on the likelihood that a future flight system, or debris thereof, could access large fractures in off-nominal scenarios.

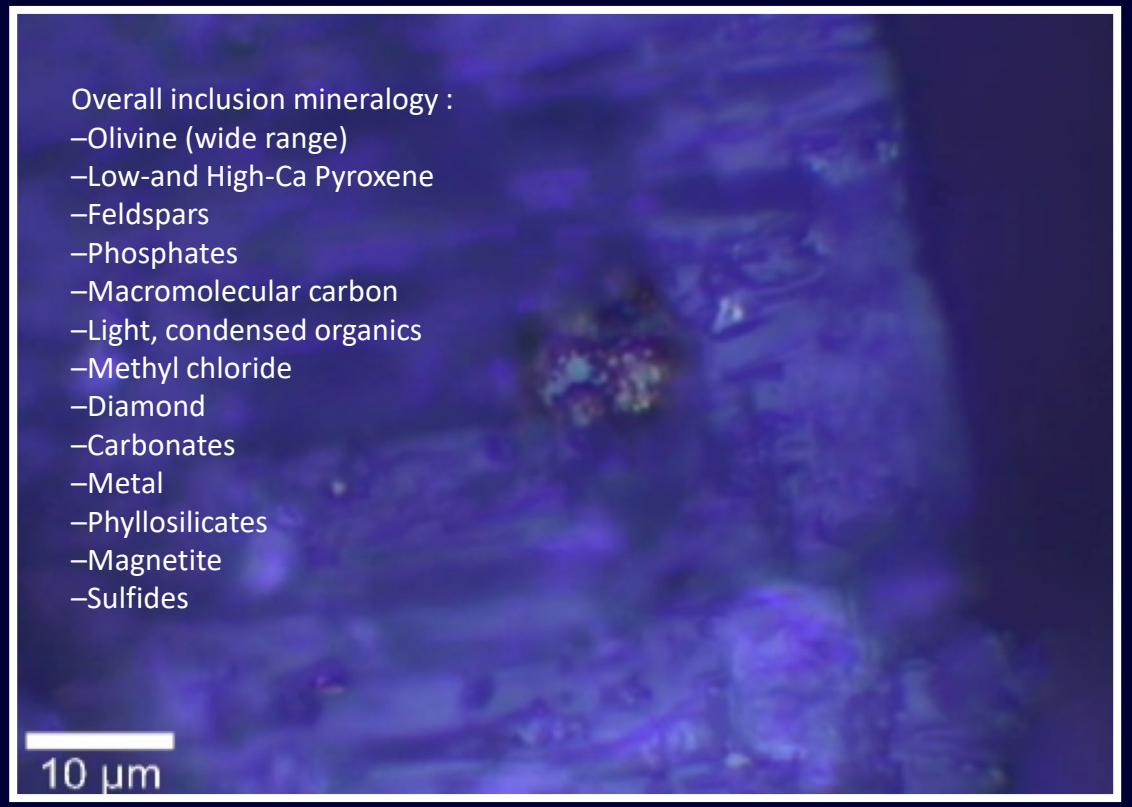
Current Thinking about the Existence of Life In Ceres

- The emergence and maintenance of life on Ceres is thermodynamically unfavored but cannot be excluded
- Several peer-reviewed papers assume that life existed and may still exist in Ceres at present, but based on scant evidence

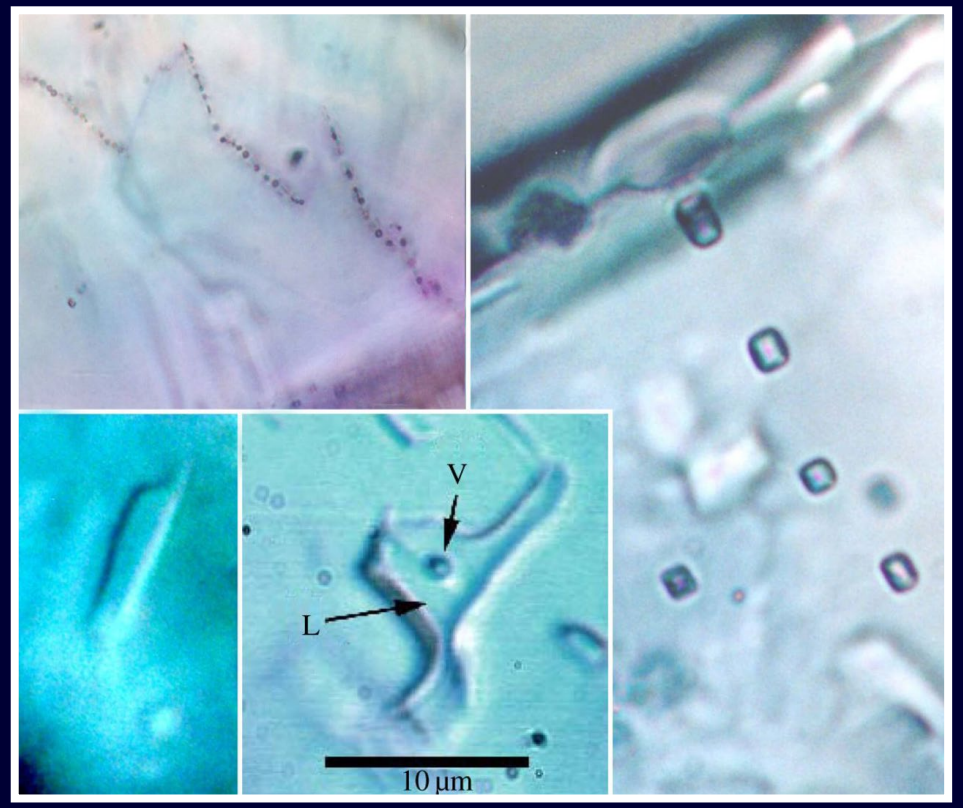
Dwarf Planet Ceres' Contribution to Seeding Life Across Our Solar System (AAS243)

- Prospect that organic matter could spend significant time in aqueous environment creates concern that organic compounds could have evolved into active biomolecules hazardous to Earth.

Facula Material: Salts Evolved from Deep Brines, Trapped Organics and Fluids



Organic Matter inclusion – Monahans halite



Fluid inclusion - Zag halite

Source: M. Zolensky, NASA/JSC

Finding from Astrobiology Review Process

Considering the interest of the community for Ceres as a target of astrobiological value, a sample return mission should be considered Category V restricted for the majority of Ceres' surface, *unless it can be demonstrated that evaporites sourced from Ceres' deep brine region and recently exposed in Occator crater have not been scattered to the rest of Ceres' surface,* and therefore reducing the probability of an unsterilized particle to an acceptably low value to be determined by a future study.

Astrobiology Journal Anonymous Reviewer

Rationale for Cat V Restricted Sample Return Mission Categorization

- *Astrobiology* study demonstrates that the bulk of the surface has been sterilized by radiation (analysis by Nordheim et al., *Astrobiology*, 2022).
- Cannot exclude that material from Occator crater has scattered across Ceres' surface
- Recommendation from *Astrobiology* review is to err on the side of caution and categorize sample return missions *from any Ceres site* as Category V restricted.
- Consistent with the NRC 1998 framework *Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies: Framework for Decision Making*
- If science is not compromised, possibility to sterilize samples following return, prior to distribution - impact on science return would be mission specific.

Questions	State of knowledge / Gaps
1 - Does the preponderance of scientific evidence indicate that **there was never liquid water** in or on the target body?	NO – Ceres has likely had liquid water throughout its history
2 - Does the preponderance of scientific evidence indicate that **metabolically useful energy sources were never present?**	NO – Ammonium, carbonate, and (likely) organic compounds are found throughout the surface, and there is organic material concentrated locally
3 - Does the preponderance of scientific evidence indicate that **there was never sufficient organic matter** (or CO_2 or carbonates and an appropriate source of reducing equivalents) in or on the target body to support life?	NO – There is pervasive evidence for carbonates, high carbon abundance in the regolith, and mineralogy formed under high partial pressure of hydrogen
4 - Does the preponderance of scientific evidence indicate that **subsequent to the disappearance of liquid water**, the target body has been subjected to extreme temperatures (i.e., >160ºC)?	NO – There is no such evidence, and Ceres still contains liquid water (below ~40 km thick icy crust), at least locally
5 - Does the preponderance of scientific evidence indicate that **there is or was sufficient radiation for biological sterilization of terrestrial life forms?**	YES – 99% of the surface has been exposed to sterilizing levels of radiation for >> 100 My over >1 m depth NO for ~1% of the surface that is younger than 100 My
6 - Does the preponderance of scientific evidence indicate that there has been a natural influx to Earth, e.g., via meteorites, of material equivalent to a sample returned from the target body?	UNKNOWN – No confirmed meteorite from Ceres has been found, which may be due to its icy surface (Rivkin et al. 2014). Dust influx cannot be ruled out.

Seeking Consensus on Planetary Protection Policies for Future Ceres Missions

- Assessment based on input from literature (100+ papers) and diverse team: Ceres and icy moon experts; geophysicists, geologists, geochemists, space physicists; JPL PP Office representatives; CoPP co-chair
- Received feedback from several peer-reviewers and NASA HQ PP Officers
- Assessment is consistent with 2017 COSPAR categorization: Cat II for future orbiter mission; Cat II for in situ missions for 99% of the surface, but highlights Occator's faculae and fractures as regions of possible access to a deep brine reservoir
- Lack of consensus on the categorization of a sample return mission

Way Forward

- Will resubmit study for peer-review soon
- Welcome suggestions for developing scientific consensus process