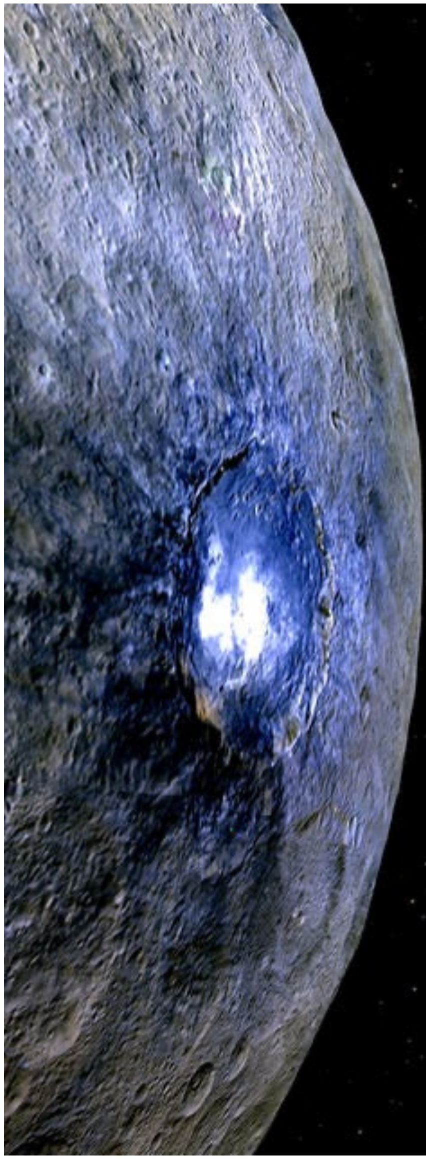

Planetary Protection Requirements for Future Exploration of Ceres

State of Understanding after the Dawn Mission

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Presentation to COSPAR Planetary Protection Panel – December 6, 2023

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Context for Independent Mission Categorization Analysis

- Study developed for the *Ceres Habitability Planetary Mission Concept Study* for the Planetary Science and Astrobiology Decadal Survey in 2020.
- Built on end of Dawn mission PP assessment that led to 50-yr stable orbit requirement, including assessment of impact at Occator.
- Based on site analysis (geology and composition) by Dawn team (see refs), but there are limitations to our knowledge.
- Used 2012 NRC study *Assessment of Planetary Protection Requirements for Spacecraft Missions to Icy Solar System Bodies* as framework.
- Co-authors include: JPL PP Office representative and NAS Committee on Planetary Protection co-chair
- Assessment submitted to *Astrobiology,* two rounds of peer-review.

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CHNOPS WATER ENERGY

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

possible ocean world | geology | recent volcanism | surface salts | organic matter | recent brine

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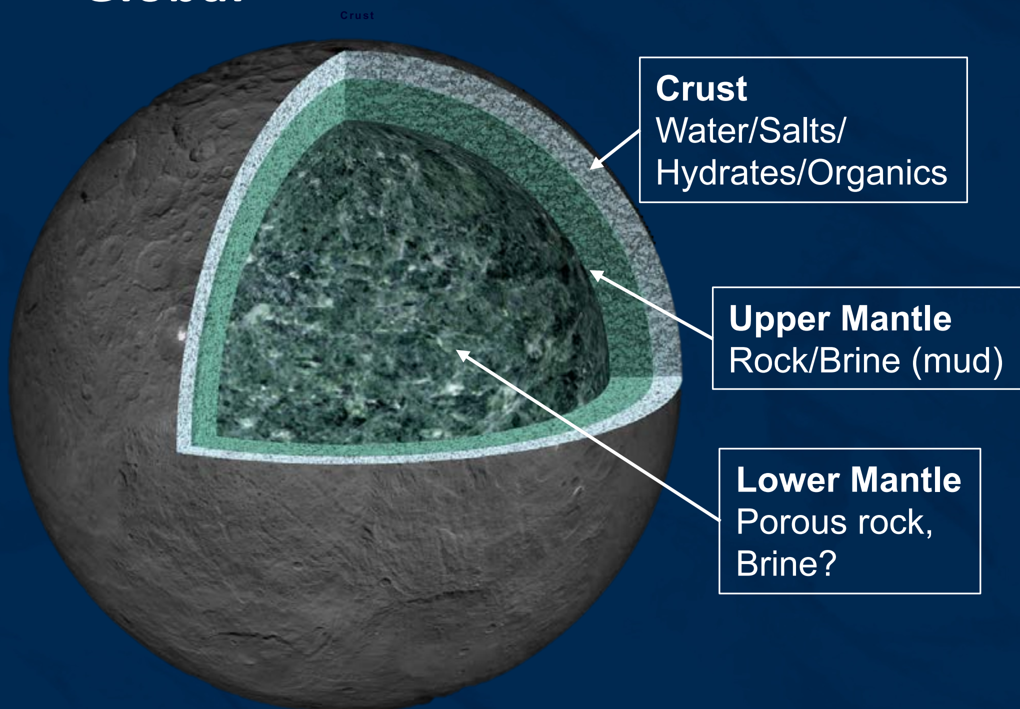
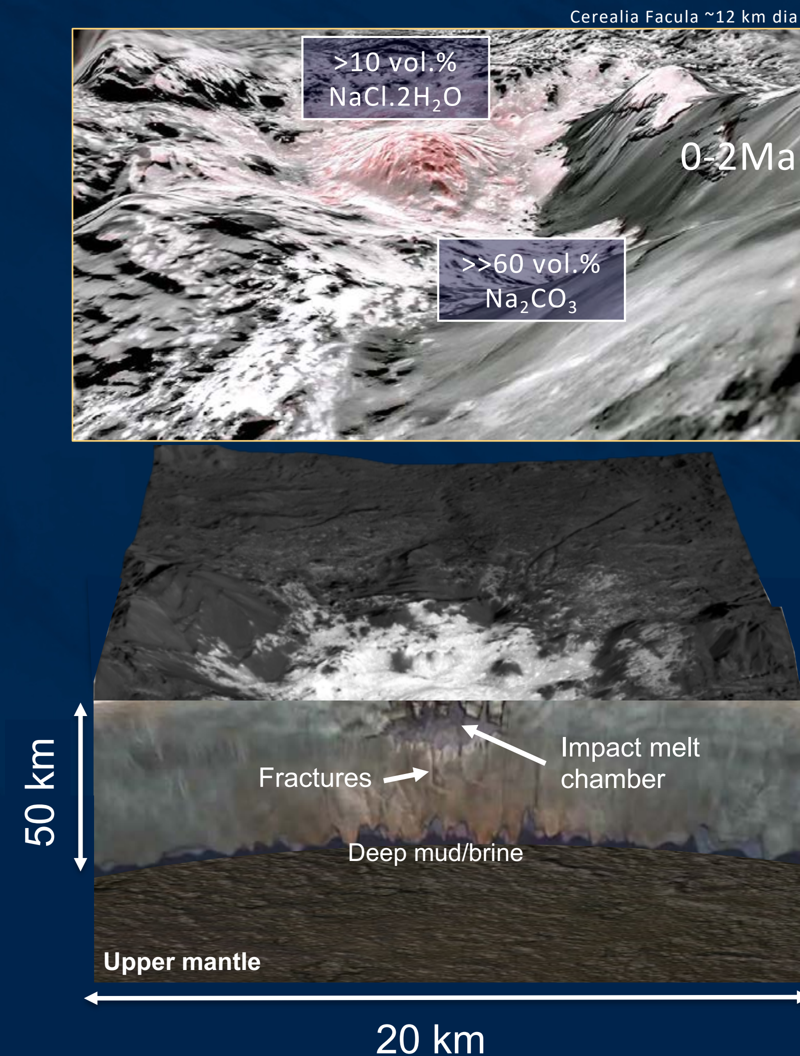
Ceres’ Interior

Global



Local



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

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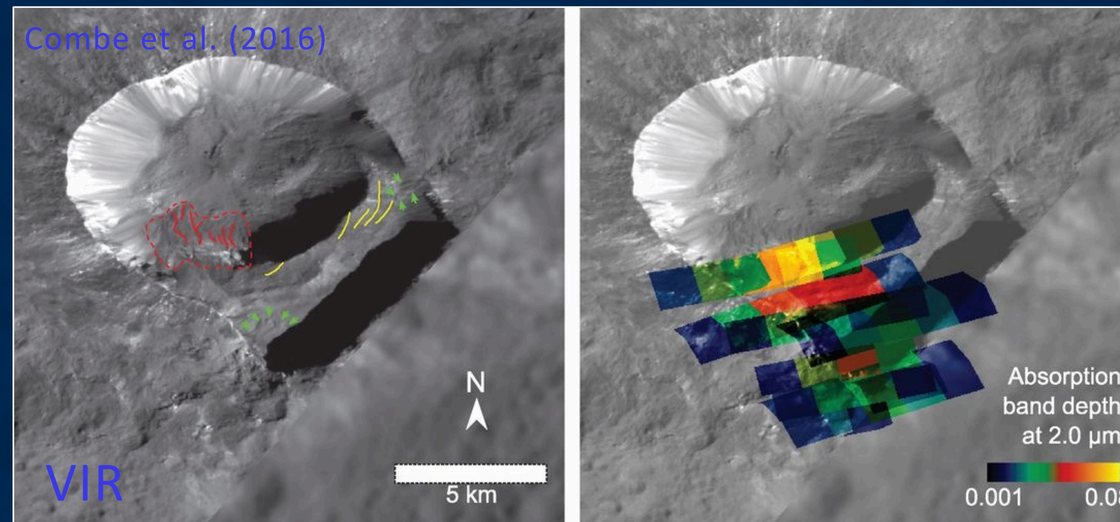
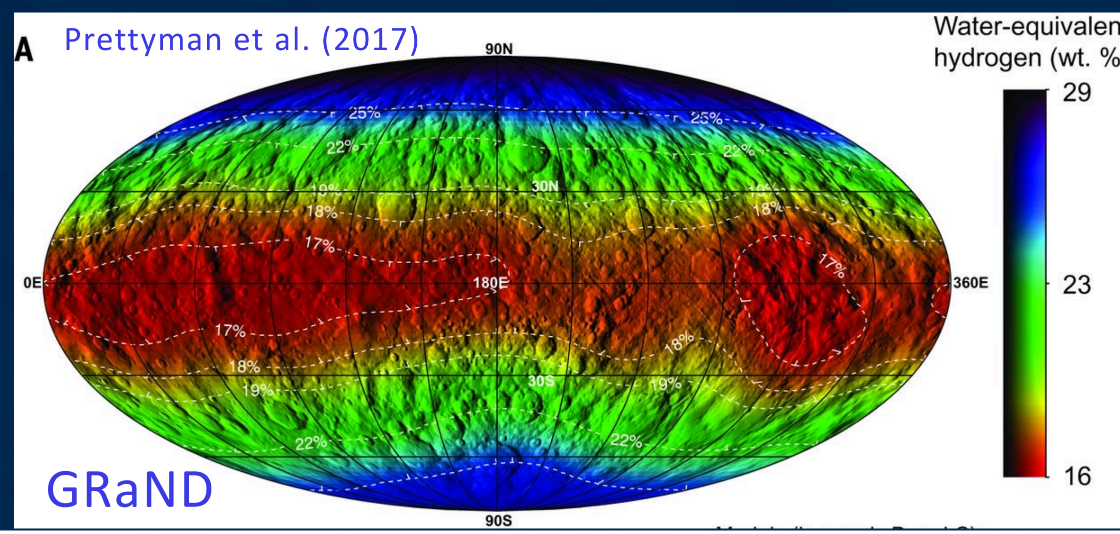
Ice on Ceres

- 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
- Potential water vapor detected by Herschel Obs.





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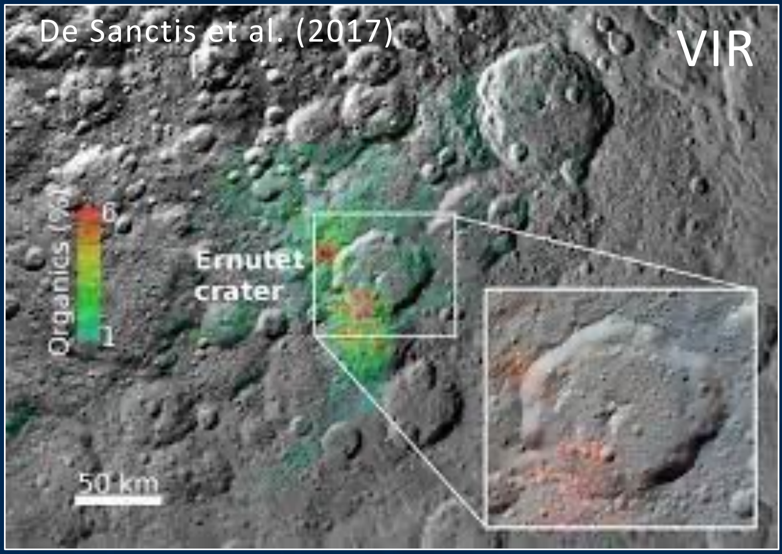
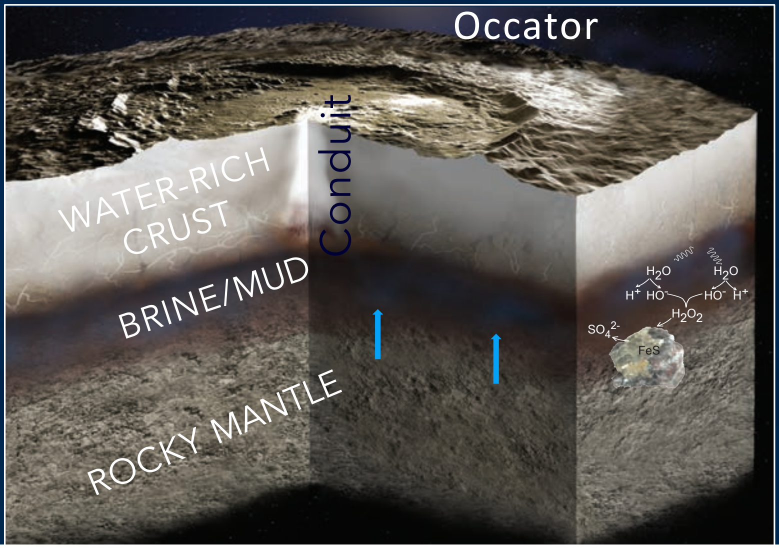
Organics on Ceres

- Globally >5-15% C in Ceres' regolith, interpreted as amorphous carbon
- Very local enrichment in "fresh" organic compounds
- No distinct organic spectral signatures observed at sites of recent eruption (Cerealia, Vinalia), but the presence of organics cannot be excluded





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

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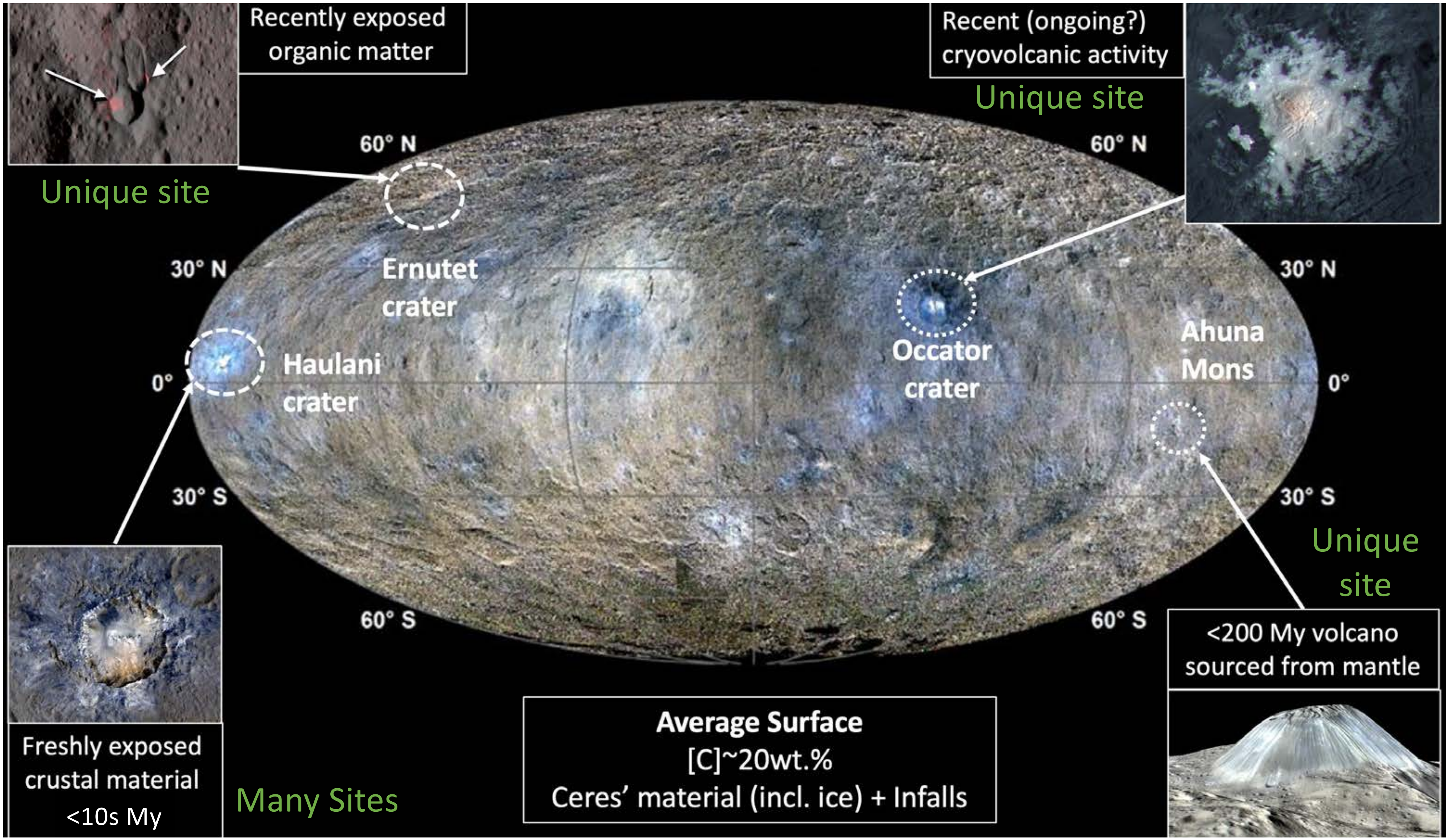
Recently exposed organic matter
Unique site
Recent (ongoing?) cryovolcanic activity
Unique site
60° N
60° N
30° N
30° N
Ernutet crater
Haulani crater
Occator crater
Ahuna Mons
0°
0°
30° S
30° S
60° S
60° S
Unique site
<200 My volcano sourced from mantle
Freshly exposed crustal material <10s My
Many Sites
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

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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.

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

Summary of Site Analysis

Orbiter Missions: Category II, or III if Mars flyby (Dawn)

In Situ Missions: Category II for 99% of the surface; *tbd* for Occator crater

Sample Return: Recommendation from reviewer is Category V restricted Earth return, *from any site*

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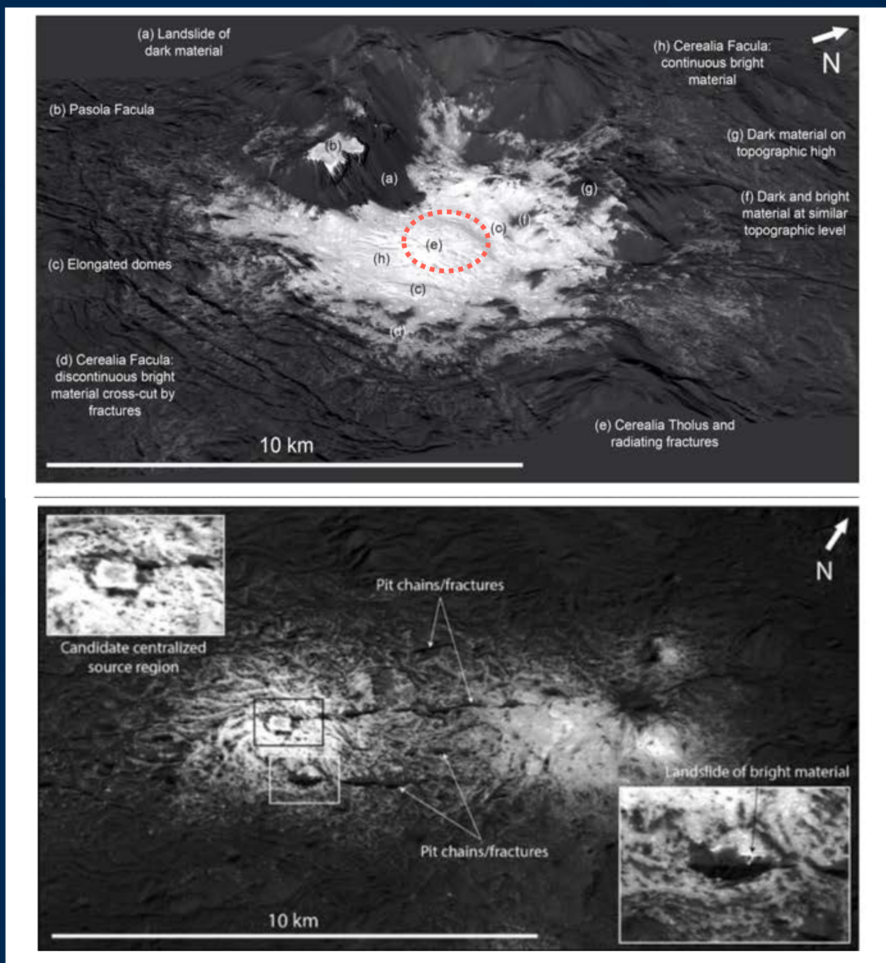
Potential Brine Access at Occator Crater



Scully et al. (2020)

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.

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Rationale for Cat V Restricted Sample Return Mission Categorization

- Prospect that Ceres that organic matter could spend significant time in aqueous environment creates concern that prebiotic chemistry could have produced organic compounds that present hazard to Humanity.
- The presence of life on Ceres (independent origin or brought from Earth) is thermodynamically unfavored but cannot be excluded.
- *Astrobiology* study could demonstrate that the bulk of the surface has been sterilized by radiation (analysis by Dr. Tom Nordheim).
- Could not demonstrate that there is no material from Occator crater scattered across Ceres’ surface (analysis by Dr. Nico Schmedemann).

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Rationale for Cat V Restricted Sample Return Mission Categorization

- Recommendation from *Astrobiology* review is to err on the side of caution and categorize sample return missions as Cat V restricted.

- If science is not compromised, possibility to sterilize samples following return, prior to distribution - impact on science return would be mission specific.

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BACKUP SLIDES

Findings from Dedicated Study

(a) Outside of the region of Occator crater, Ceres shows no geological evidence for conduits from the surface to the interior;

(b) 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.

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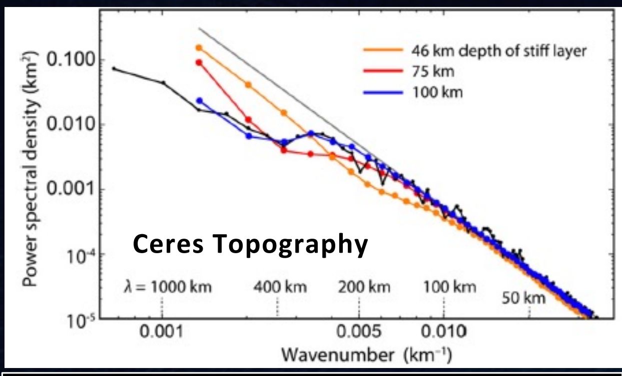
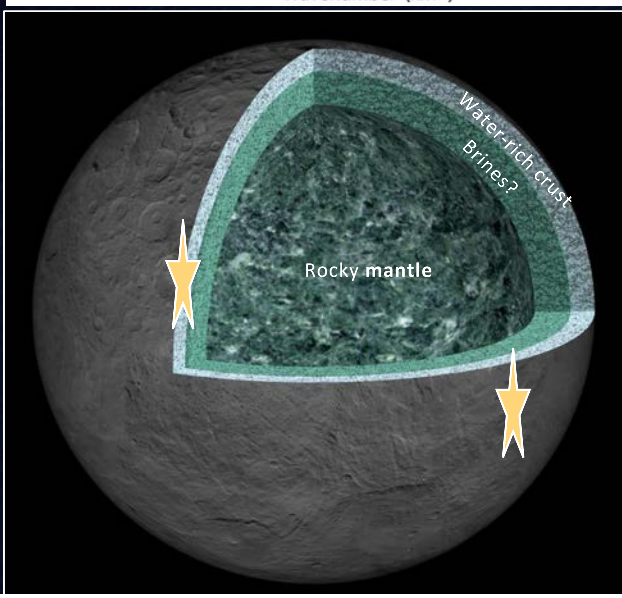
Relevant References

- Nordheim et al.
- see special issue of Icarus on *The Geologic Mapping of Ceres*

Evidence for and Extent of Brines Inside Ceres





~40 km thick ice-rich crust

1.25 g/cm^3 - <20vol% silicates

Viscosity >10^{26} Pa s

Low-Density Rocky Mantle

2.4-2.9 g/cm^3 – 10-30% porosity

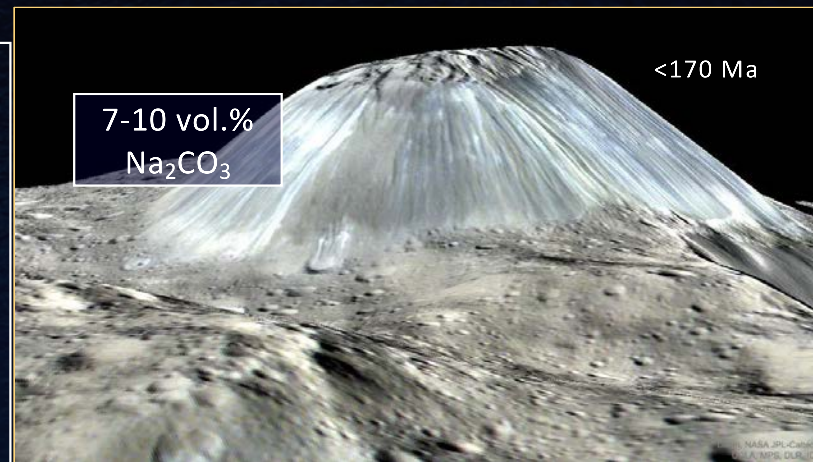
Viscosity <10^{21} Pa s

at > 100 km depth

Material extruded from upper mantle at two recent landforms

Reservoirs 100s km extent

Advanced freezing likely but thin residual layer cannot be excluded



Ahuna Mons 4km x 17 km

Cerealia Facula ~12 km dia