

THE NATURE AND EVOLUTION OF THE ORGANIC MATTER IN CERES

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Introduction: Observed by the Dawn spacecraft since March 2015, Ceres is a fascinating world [1]. Its surface, covered by phyllosilicates, carbonates, ammoniated-bearing hydrated minerals, water ice, salts and opaque materials indicates a complex chemical environment [1,2,3]. VIR, the Visible and InfraRed mapping spectrometer onboard the Dawn mission, has revealed the presence of aliphatic carbons with new bands around 3.4 μm , near the Ernutet crater [4]. With the VIR resolution, the 3.3 to 3.6 μm spectral range has been identified to contain hydrogenated sp³ carbon from the antisymmetric and symmetric stretching modes of methyl (CH₃) and methylene (CH₂) functional groups [4] (hereafter named $\nu_{\text{as}}(\text{CH}_3/2)$ or $\nu_{\text{s}}(\text{CH}_3/2)$ respectively). The origin of this organic matter (OM) is likely related to an endogenous source and we investigated its nature and its formation/evolution inside Ceres. We have measured some organic standards and compared them along with bitumen spectra to the Ceres organic-rich (OR) spectra [4] to constrain the nature of the OM. We propose scenarios to explain the formation and evolution of the OM inside Ceres, based on Ceres global evolution, and meteorites studies.

Experimental Work and Organic Standards: We used the SPectral IMaging (SPIM) facility at the IAPS-INAF laboratory to analyze organic materials in reflectance mode, in the range 0.2-5.1 μm . In order to obtain more information about the $\nu_{\text{s}}(\text{CH}_3/2)$ and $\nu_{\text{as}}(\text{CH}_3/2)$ band variations with the chemical structure, we measured various polymers with different distributions of methyl and methylene groups, and with or without oxygen functions and one polycyclic aromatic compound (PAH) (Fig. 1). We also compared Ceres spectra with bitumens spectra (complex carbon- macromolecule) found in the literature. Additionally, we used the relative quantities of the antisymmetric stretching mode of methylene $\nu_{\text{as}}(\text{CH}_2)$ and methyl $\nu_{\text{as}}(\text{CH}_3)$ to derive the crosslinking level of the OM observed on Ceres.

Table 1 : Estimation of $\nu_{\text{as}}(\text{CH}_2)/\nu_{\text{as}}(\text{CH}_3)$ ratios of the four Ceres spectra (namely OR-1 to OR-4).

Spectra name	Band positions (μm)		CH_2/CH_3 ratio
	$\nu_{\text{as}}(\text{CH}_2)$	$\nu_{\text{as}}(\text{CH}_3)$	
OR-1	3.431	3.382	1.08 ± 0.05
OR-2	3.422	3.377	1.65 ± 0.08
OR-3	3.421	3.373	1.34 ± 0.06
OR-4	3.426	3.373	1.30 ± 0.06

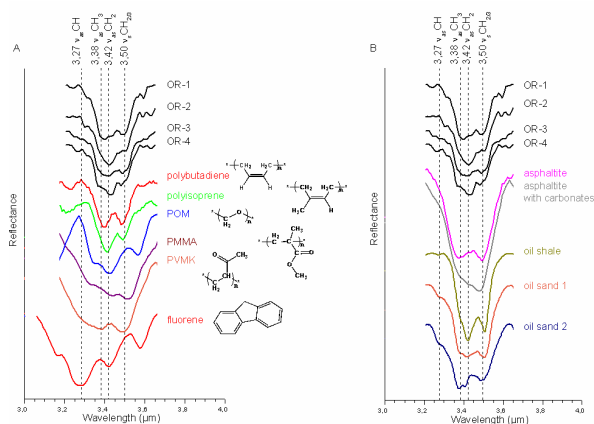


Figure 1 : Infrared spectra of the four organic-rich area of Ceres described by [4] (from organic-rich pixels, 450 m/pixel, called OR-1 to OR-4) compared to infrared spectra of A) polymers and organic compounds, and B) asphaltite, oil shale and oil sand.

Nature of the Organic Matter in Ceres: Multiple organic compounds are possible in the 3.2-3.6 μm spectral range and we derived only some constrains from our measurement and spectral deconvolution to assess the nature of the OM in Ceres:

- Absence or low abundance of OH, COOH groups : no broad band between 2,7 and 3,2 μm (as POM)
- Oxygen molecules with ketone, aldehyde, ester or ether might be present, but less than 30 wt% (based on meteorite and bitumens OM, [5])
- Aromatic carbons are possible, as well as nitrogen compounds (amines, imines, nitriles)
- Low CH_2/CH_3 ratio : carbon structure highly crosslinked (high abundance of CH_3) in aliphatic chains or aromatic rings.

Overall, the carbon structure of the OM in Ceres should be a cross-linked aliphatic, likely with aromatic carbons and with a rather low abundance in oxygen atoms.

Hypothesis About Organic formation and Evolution in Ceres: We focus on an endogenous origin of the OM around the Ernutet crater, proposing some pro-

cesses for the formation and evolution of OM inside Ceres, based on Ceres' internal evolution [6].

Internal processes. The pervasive hydrothermal alteration of Ceres might have created an environment in the interior conducive to producing organic compounds [7] (Fig. 2). Hydrothermal environments are recognized to drive serpentinization and Fischer-Tropsch-type processes [8] (FTT), that are known to produce hydrocarbons. Serpentinization processes are likely to have proceeded inside Ceres, producing serpentine and other hydrated minerals observed at the surface [2,9]. Ceres is massive enough to retain H_2 from the serpentinisation process, an important reactant for FTT reactions. Hydrocarbons production might have been very efficient at Ceres scale through FTT processes.

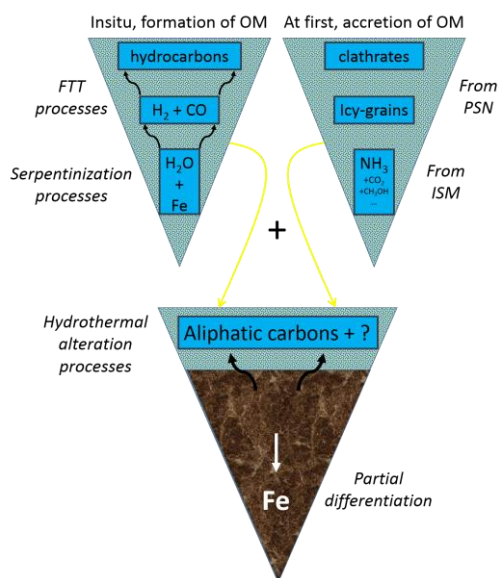


Figure 2: Illustration of the organic matter formation inside Ceres with the accretion of key materials at first and their co-evolution inside Ceres

Interstellar medium and protosolar nebula sources: The nature of the OM formed from serpentinization and FTT processes cannot explain the high abundance of ammonia on Ceres. Due to its correlation with phyllosilicates, it seems that the ammonia was initially present in Ceres body and so another source of organic matter is required. Organics are everywhere in the interstellar medium (ISM) [10], and were likely abundant components of the protosolar nebula (PSN) before Ceres accretion, as suggested by the diversity of organic matter observed in meteorites and comets. Simple interstellar OM were modified during protosolar nebula formation, and a large diversity of organic compounds might have composed the PSN [11].

Impact of hydrothermal alteration and partial differentiation in Ceres. The degree of hydrothermal alteration in Ceres was much more severe than in the most altered carbonaceous chondrites [12], and must have affected the initial OM. The high abundance of carbonates in Ceres, for example, might be correlated with the decomposition of molecules and the release of CO_2 during hydrothermal alteration, especially as a correlation has been observed between carbonate and OM abundances around Ernutet [13]. Based on meteorite studies, some chemical evolution for the OM are suspected in Ceres, such as polymerization and alkylation reactions.

The partial differentiation might have driven most of the volatiles species close to the surface, and allowed more chemical reactions, specially between inorganic and organic materials, to form, for example, the ammonium-phyllosilicates [9].

Implication for Ceres OM:

- OM in Ceres might be a mix of FTT product compounds and ISM + PSN organic compounds, altered by the pervasive hydrothermal alteration.
- Its spectral signature in the $3 \mu m$ range implies a low temperature formation (low CH_2/CH_3 ratio; $T < 150 \text{ }^\circ C$) [5]
- A close relationship between inorganic and organic phases is observed at the surface [9,13]: is the OM chemically bond to the inorganic phases and protected from surface alteration?
- A unique evolution of the OM in Ceres due to the differentiation, a high water/rock ratio, an alkaline environment.
- Can we have a fresh material, with abundant organic materials beneath the surface?

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