MINERALOGY OF CERES: COMPARISON WITH CM CARBONACEOUS CHONDRITES.

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Introduction: The Dawn spacecraft is analyzing the dwarf planet Ceres from orbit. Initial visible/near-infrared spectroscopy confirms spectral features previously observed by telescopes but also includes a prominent 2.7 μm OH absorption band obscured by Earth's atmospheric water vapor. The Ceres spectrum is clearly distinct from those of CM/CI carbonaceous chondrites, but the inferred mineralogies are similar. "Carbonaceous chondrites are likely the closest analogs for Ceres in existing meteorite collections, although their specific alteration pathways may differ" [1] appears to be a prescient prediction.

CM Alteration Trends: Mineral identities and proportions in CMs have been quantified by x-ray diffraction [2]. The chondrites also contain organics not identified by XRD, mostly aromatic macromolecules but some aliphatic compounds as well [3]. Progressive alteration trends in CMs are: transformation of olivine and pyroxene to cronstedtite (Fe-serpentine) and, if sulfur is present, tochilinite; conversion to Mg-serpentine, magnetite, and sulfides; formation of saponite, ferrihydrite, magnetite, and sulfates [2]. These progressive trends, which reflect the addition of water and oxidation, can be discerned in matrix chemistry [4].

Ceres and CM Spectra: For comparison with VIR spectra of Ceres, the meteorite spectra must be measured under anhydrous conditions [4]. The best spectral match for Ceres, prior to Dawn, is: brucite (MgO) + Mg-carbonate + magnetite + cronstedtite [5]. All of these phases except brucite occur in moderately altered CM chondrites. However, tochilinite (interlayered brucite + Fe-sulfide) has a spectrum [6] very similar to brucite, suggesting the possibility that this phase might occur instead of brucite on Ceres. In that case, the mineralogy of Ceres surface would resemble CMs, although spectral distinctions may signal variations in mineral proportions that reflect differences in alteration pathways and conditions. There are other spectral differences as well: the ~4.0 μm carbonate feature is stronger in Ceres spectra than in CM spectra, and the ~3.4 μm organics feature is strong in CMs than in Ceres spectra. Most CMs and Ceres do not show detectable olivine/pyroxene features, although 10-30% relict olivine and pyroxene occur in CMs.

It is not yet clear to what degree the surface of Ceres consists of altered materials derived from thermal processing in the interior versus exogenic materials. However, color variations seen in Dawn's Framing Camera maps indicate that the surface cannot be uniformly covered with accreted materials. Comparison with CM chondrites reveals minerals to look for that have not yet been detected. We might also expect disequilibrium assemblages reflecting different degrees of alteration, as observed in brecciated CM chondrites.

References: [1] Rivkin A.S. et al. 2011 *Space Science Reviews* 163:95-116. [2] Howard K.T. et al. 2011 *Geochimica et Cosmochimica Acta* 75:2735-2751. [3] Alexander C.M.O'D. et al. 2013 *Geochimica et Cosmochimica Acta* 123:244-260. [4] Takir D. et al. 2013 *Meteoritics & Planetary Science* 48:1618-1637. [5] Millikin R.E. and Rivkin A.S. 2009 *Nature Geoscience* 2:258-261. [6] Moroz L.V. et al. 1997 28th Lunar and Planetary Science Conference, abstr. #1288.