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**Introduction:** The surface of dwarf planet Ceres contains water ice and aqueous alteration products, evidence that liquid water was once present within Ceres' interior. Minerals bearing ammonium and hydroxyl are widespread within Ceres' global regolith [1]. A few craters contain bright carbonate deposits, possibly the result of impact-induced hydrothermal activity [2]. Local deposits of surficial ice have been detected [3], and analyses of data acquired by Dawn's Gamma Ray and Neutron Detector (GRaND) show that ice is near the surface within broad, high-latitude regions, consistent with a receding ice table [4].

While no meteorites are yet connected with Ceres, the aqueously altered CI and CM carbonaceous chondrites are potential analogs [5]. Apart from the most volatile elements, abundances for the CI chondrites are very similar to that of the solar photosphere, thought to be representative of the solar nebula [6]. Despite their primitive composition, these meteorites are highly altered. They consist primarily of phyllosilicates, magnetite, sulfides, carbonates and organic matter and typically lack anhydrous silicates and chondrules. This "primitive-yet-altered" paradox can be explained if liquid processing occurred in a closed system, perhaps on a small parent body where the low permeability limited the transport of fluids [7].

In contrast, Ceres is large enough that materials should have been redistributed within the interior via convection [7, 8]. Gravity measurements allow for partial differentiation [9]. If Ceres underwent ice-rock fractionation, the elemental composition of the surface should deviate from that of the accreted nebular material [4]. Measurements by GRaND provide constraints on regolith ice content and the composition of the non-icy regolith needed to test hypotheses for Ceres evolution.

**GRaND data:** Data acquired during Dawn's primary mission at Ceres (March of 2015 through June of 2016) were archived in the Planetary Data System [10]. Elemental measurements were made while in close proximity to Ceres in a circular polar, low altitude mapping orbit (LAMO), with an altitude of about 0.8 body radii, similar to LAMO at Vesta. In the primary mission, about 5 months of LAMO data were acquired with instrument gain settings selected to enable comparison of Vesta and Ceres. In Dawn's extended mission, the gain of the bismuth germanate (BGO) gamma ray spectrometer was reduced for about a month to search for high energy Ni capture gamma rays, after which Dawn ascended to higher altitudes where GRaND is acquiring additional background data needed to improve the precision and accuracy of elemental analyses.

**Primary mission results:** The analysis and interpretation of data acquired in the primary mission was reported by [4] and is summarized here. Maps of counting data show a strong decrease from the equator to the poles, consistent with the presence of water ice near the surface at high latitudes. Low energy neutrons are sensitive to regolith hydrogen content. Analyses of neutron counting data indicate that the regolith contains around 10 wt.% water ice with total hydrogen content of roughly 30 wt.% water equivalent hydrogen, consistent with Ceres' bulk density.

Equatorial measurements are sensitive only to the composition of non-icy soil. The equatorial average Fe concentration was determined to be 16 ± 1 wt.% from measurements of the 7.6 MeV gamma ray produced by neutron capture with $^{56}$Fe. The hydrogen concentration in water equivalent units was 17 ± 2 wt.%. Hydrogen concentrations are uniform with longitude, which implies that the processes that resulted in the presence of this material at the surface acted on a global scale. Analysis of fast neutrons and gamma rays produced by inelastic scattering with C and O shows that Ceres' regolith contains C, possibly in greater amounts than found in carbonaceous chondrites. Analysis of gamma rays produced by the decay of $^{40}$K shows K at levels similar to CM and CI chondrite meteorites.

The elemental data indicate that the materials that formed Ceres were extensively altered by liquid water; however, the concentrations of Fe and H within Ceres non-icy regolith are lower and higher, respectively, than for the CI chondrites. The difference can be explained by the addition to the CI composition of about 13 wt.% of an as yet unknown material, possibly organic matter. This is consistent with Ceres having undergone moderate ice-rock fractionation, resulting in differences between the composition of the surface and interior.

**Extended mission results:** A preliminary estimate of the Fe/Ni mass ratio was determined from gamma ray spectra acquired with reduced gain in LAMO. Gamma rays produced by neutron capture with $^{58}$Ni at 8.5- and 9-MeV contribute to a broad peak above the $^{56}$Fe 7.6-MeV capture gamma ray (Fig. 1a). The peak also contains contributions from Fe, which were removed by the peak fitting procedure. Our analysis assumed that Fe and Ni are in constant proportions over the entire surface within depths sensed by GRaND (about a meter). Further analysis will be carried out to validate the observation.

Our initial estimate for Ni/Fe is compared with selected solar system materials, including achondrites, carbonaceous chondrites, and "other" (enstatite and ordinary) chondrites in Fig. 1b. Three compositional groups can be distinguished. The chondrites, which represent primitive solar system materials, have whole rock compositions with similar Fe and Fe/Ni ratios. Meteorites with igneous parent bodies cluster into two complementary groups: i) silicates from the crust and mantle (achondrites, with low Fe) for which Fe and Ni have been removed and fractionated during core formation, reaching very high Fe/Ni ratios, and ii) irons and stony irons with high Fe content but subchondritic Fe/Ni. Ceres has a low Fe/Ni ratio and does not overlap any meteorite category; however, relatively low Fe/Ni values were found by [11] for some matrix materials (Fig. 1b). This is likely the result of selection bias, where large particles, of magnetite, sulfides, and/or metal, were not analyzed in order to isolate the fine grained matrix. By analogy, perhaps the accumulation of relatively heavy, Fe-Ni bearing particles at depth [cf. 12], accompanied by partitioning of Fe and Ni between sulfides, magnetite, and silicates during aqueous alteration contributed to the low Fe/Ni ratio of Ceres' surface. Understanding the conditions that lead to fractionation of Ni and Fe will bring new insights into Ceres' hydrothermal evolution.

**Conclusions:** Analyses of GRaND data show that Ceres' regolith is rich in hydrogen, which is partitioned between water ice, products of aqueous alteration, and perhaps bound water and organics. Differences between Ceres' composition and that of the CI chondrites indicate that ice-rock fractionation occurred. The neutron and gamma ray data acquired in Dawn's primary and extended missions will enable us to accurately quantify and map H, C, O, Si, K, Fe, and Ni and to characterize H layering.

**References:** [1] Ammannito E. *et al.* (2016), *Science, 353*, 6303, aaf4279. [2] De Sanctis M. C. *et al.* (2016), *Nature, 536*, 7614, 54-7. [3] Combe J. P. *et al.* (2016), *Science, 353*, 6303, aaf3010. [4] Prettyman T. H. *et al.* (2017), *Science, 355*, 6320, 55-59. [5] Rivkin A. S. *et al.* (2010), *Space Science Reviews, 163*, 1-4, 95-116. [6] Anders E., and Grevesse N. (1989), *Geochimica Et Cosmochimica Acta, 53*, 1, 197-214. [7] Bland P. A. *et al.* (2009), *Earth and Planetary Science Letters, 287*, 3-4, 559-568. [8] Castillo-Rogez J. C., and McCord T. B. (2010), *Icarus, 205*, 2, 443-459. [9] Park R. S. *et al.* (2016), *Nature, 537*, 7621, 515-517. [10] http://sbn.psi.edu/pds/resource/dwncgrd.html. [11] McSween H. Y., Jr., and Richardson S. M. (1977), *Geochimica Et Cosmochimica Acta, 41*, 1145-1161. [12] Neveu M., and Desch S. J. (2015), *Geophysical Research Letters, 42*, 23, 10,197-10,206. [13] Nittler L. R. *et al.* (2004), *Antarct. Meteorite Res., 17*, 231-251.

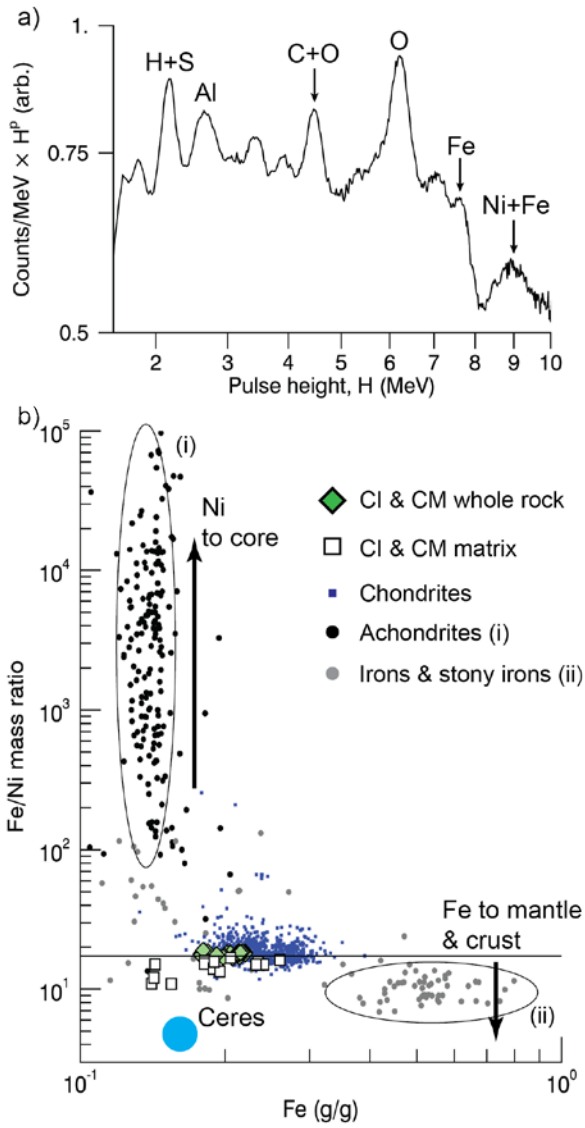


**Figure 1.** a) Gamma ray spectrum accumulated during the extended mission, with selected peaks marked with primary elemental contributions. For visualization, the spectrum was arbitrarily scaled by a power law ($p \approx 2$). b) The Fe/Ni mass ratio for selected meteorites and Ceres as a function of Fe concentration. Whole rock meteorite analyses compiled by D. Mittlefehldt (priv. comm.) and [13].