
Introduction: Ceres is the largest and most massive asteroid in the solar system and is rightfully termed a dwarf planet exhibiting a complex evolution. The Dawn team has spent over a year evaluating the character of its dark surface [1] and has documented the pervasive presence of Mg-serpentinite, ammoniated clays, and opaques [2, 3] with notable unusual deposits of bright carbonates within Occator crater [4]. Recently, using data from Dawn’s visible near-infrared imaging spectrometer (VIR) the unmistakable signature at 3.4 µm of organic materials was identified at a few localized areas in the northern hemisphere [5]. As illustrated in Figures 1 and 2, these correspond directly to areas previously found to exhibit a very unusual red-sloped continuum across visible wavelengths as analyzed independently by global multispectral images from the Dawn framing camera (FC) [6]. Here we discuss the geologic context and possible origin of these Red, Organic-Rich materials (designated ROR) as discerned from Dawn’s high and low altitude mapping orbits (HAMO and LAMO).

![Figure 1. Example ROR spectrum in the Ernutet region and background Ceres. Left: Scaled FC 7-color visible spectra illustrating the red-sloped continuum of ROR. Right: VIR near-infrared spectrum for the same ROR area illustrating the 3.4 µm organic feature (OR). A relative reflectance spectrum of the ROR area relative to the background reference area is shown above to illustrate the character of the 3.4 µm absorption. High resolution LAMO FC images of this ROR example area are shown in Fig. 3.](image1)

Ceres ROR materials are found across the northern latitudes generally above 45°N and between 20° and 90°E longitude. The highest concentration is associated within and along the SW rim of Ernutet crater and a comparable highly degraded crater to the SW. Ernutet crater is a 52 km diameter impact structure at the center of the Coniraya quadrangle (52.9°N/45.5°E) [7]. It is partially degraded and has no identifiable ejecta blanket but exhibits a central peak and intact crater walls. The crater floor is slightly terraced and contains several large slumps of wall material, but most of the floor is relatively smooth. Either optical property, the presence of 3.4 µm absorption or the notable red visible continuum, can be used to map the spatial extent of these unusual ROR materials and compared to background Ceres materials (Fig. 2). Since the FC instrument acquires higher spatial resolution data than VIR during Dawn’s lower orbits, the most detailed information for geologic evaluation can be derived from FC multi-spectral images.

![Figure 2. HAMO data of ROR for the Ernutet region illustrating independent estimates of spatial distribution. TOP: Brightness images from (A) VIR at 1200 nm and (B) FC at 965 nm. BOTTOM: Spectral parameters stretched for spatial comparison. (C) VIR intensity of 3.4 µm organic absorption strength. (D) FC 965/438 nm color ratio identifying areas of “red” continuum slope at visible wavelengths. Initial impressions suggest the three floor craters and part of Ernutet SW wall expose ROR materials.](image2)

Average Ceres exhibits a dark, generally featureless spectrum across visible wavelengths at the resolution obtained from Dawn’s higher orbits, but subtle variations of a few percent are spatially coherent and mapped globally [6]. However, there are notable exceptions,
each with distinct geologic properties, namely large fresh craters (which are relatively blue) and special features exist within and across both Occator and Ernutet craters [6, 8].

Figure 3. LAMO FC images of Ernutet SW rim. Two of the three floor craters are outlined. The white arrow indicates the location of ROR spectra in Fig. 1. Top: 965 nm brightness image. Bottom: 965/438 nm ratio image identifying ROR areas with a notable ‘red’ visible continuum. All are associated with small fresh craters at or below the 35 m resolution. [Lower left has residual registration errors. Shadows are masked.]

Based on superposition and relative sharpness of features in FC HAMO and LAMO images, the sequence of pertinent events in the Ernutet region is the following: (a) as part of the evolving crust of Ceres the old now heavily eroded ~50 km crater SW of Ernutet was formed, (b) Ernutet crater formed with a central peak, (c) several sections of wall material slumped onto the floor of Ernutet, (d) a group of 3 craters (largest ~4 km) SW of the central peak formed on Ernutet floor materials (not likely simultaneous), (e) a 6.5 km fresh crater ~70 km to the west formed on the rim of Hakumyi (termed area C not shown here but described in [5]), with a near simultaneous lobate flows of material from area C [7], (f) a family of small impact craters (a few 100 m or less) exposed or deposited ROR material across Ernutet, area C, and at several other small localized areas. Given the uniform youth and uniqueness of ROR areas, we hypothesize these small craters (f) to have formed together within a short period of time. The 6.5 km crater of area C and lobate flows have been dated at ~40–50 My [7] so the small craters exposing ROR occurred later. No regional thermal anomalies are observed across the Ernutet region with VIR data to 5 μm.

The high resolution data identifying the location and distribution of the red organic-rich material on Ceres is important for identifying the origin of the organic material. A clear association of ROR with very small fresh craters strongly suggests a near-surface location. Two possibilities are being discussed for the origin of ROR, each with wide-ranging implications for understanding organic material in the solar system:

Endogenic organic material formed on Ceres. In addition to hydrated silicates, Dawn has documented the presence of ammonium phyllosilicates and carbonates on Ceres [2,3,4]. The production of the latter two appears to be a result of early global scale aqueous alteration [3,9]. Since the relative abundance of organic material observed at Ernutet is greater than the abundance found in primitive meteorites, a similar endogenic origin is viable. However, the localized surficial character of ROR and lack of any large crater exhibiting similar properties challenges the internal source hypothesis.

Exogenic organic material delivered to Ceres recently. The distinct red continuum of these small ROR craters is opposite that documented for large fresh craters on Ceres [6,8] [9] [10]. The pattern of these small fresh red craters and similar diffuse markings (below 35 m resolution) found across a limited region in the north suggests deposition by highly unconsolidated material. This would require a mechanism for retaining the organic material during emplacement on Ceres, such as suggested by [10]. A viable external source (currently unknown) for the concentrated organics needs to be found or hypothesized to cross Ceres location at ~2.8 AU in the solar system.

In addition to pursuing the fundamental origin of the organic materials on Ceres, there are several basic lessons learned from Ernutet. The first is that inferences made using only low resolution data may be found to be inadequate (or wrong) when high resolution data becomes available. Second, a lesson we continue to relearn, our current knowledge of solar system materials based largely on meteorites is enormously incomplete.