CERES EVOLUTION: WHAT WE HAVE LEARNED FROM DAWN SO FAR. T. B. McCord[1], J-Ph. Combe[1], C. A. Raymond[2], M. C. De Sanctis[3], R. Jaumann[4], J. C. Castillo-Rogez[2], C. T. Russell[5]. [1]Bear Fight Institute, Winthrop, WA 98862 (tmccord@bearfightinstitute.com), [2]Jet Propulsion Laboratory Caltech. Pasadena CA 91109, [3]IAPS-INAF 00133 Rome Italy, [4]DLR IPR, 12489 Berlin Germany, [5]University of California, Los Angeles CA 90095.

Knowledge before Dawn: The global composition of Ceres' surface was determined from ground-based telescopic spectral observations, over 40 years before the Dawn spacecraft orbited Ceres in 2015, to be similar to but not exactly the same as some primitive carbonaceous chondrite meteorites, i.e., phyllosilicates with a darkening agent [1]. As the technology improved, later observations extended this general conclusion and suggested more specific minerals: OH- and maybe H_2O-bearing clays [2], ammoniated clays [3], and brucite [4]. Generally these findings suggest aqueous alteration of primary minerals, but whether internal to Ceres or before the material arrived on Ceres' surface (or both) was a topic of discussion. Modeling of the thermodynamic evolution of Ceres, based on its likely bulk high water content [5], indicated that the ice part of Ceres' original bulk composition melted early, mixed with the original silicates, altered the silicates, and promoted internal differentiation. The degree of evolution and extent of differentiation depends on the time of accretion after CAIs, which determines the amount and timing of energy available, and the details of the mineralization processes and degree of mixing between the deeper and crustal layers. This suggested that hydroxylated and hydrated materials, such as clays and salts, were manufactured internally and likely exist on or near the surface. Telescope measurements of Ceres' shape confirmed that Ceres was at least to some extend differentiated [6], supporting the modeling results. Subtle albedo and color features were reported from two telescope observational campaigns, ground and Earth-orbital, that generally agreed [7], revealing circular features, like craters, suggesting some surface processes. Two intriguing observations of transient activity (OH and H_2O above the surface) suggested periodic water release from Ceres' surface [8]. Subsurface water/ice should affect the ability of the crust to sustain topography, and viscous relaxation should operate preferentially at lower latitudes and higher temperatures, giving some indication of the amount and depth of the ice [9].

What is Dawn: The Dawn Mission [10] is providing the first look at Ceres' surface with spatial resolution sufficient to resolve surface features, thus providing a dramatic new dataset for studying Ceres and making major improvements in our understanding of Ceres' origin and evolution. Dawn's instrument arsenal is providing much new information about the two most important aspects of a planetary body's surface: 1) surface features, that are the topographical expressions of surface and interior processes, and 2) composition - mineral, molecular and elemental - resulting from thermochemical processes and infall.

The Framing Camera (FC) [11] is providing a color view of nearly the entire surface and revealing surface features including impact craters, grooves, ridges, and bright spots. Especially important, the FC also enables detailed mapping of some compositional units using the color imagery. Although the FC spectral sampling does not allow detailed analysis of spectral features, the FC color data set bridges the resolution gap between VIR's detailed spectra and FC's detailed imagery.

The Gamma Ray and Neutron Detector (GRaND) [12] is mapping elemental composition on a regional to global scale. The physics behind the GRaND observations limit its spatial resolution, requires that global coverage be built up over time for all regions simultaneously, and does not allow association of elemental abundances with smaller individual surface features. However, GRaND findings are providing important, unique compositional information on the regional and global scales, and important context for the detailed mineralogical findings.

The Visible and Infrared Mapping Spectrometer (VIR) [13] obtains reflectance spectra of the surface, 0.25-μm to 5-μm, while resolving most of the surface features and the strong spectral absorptions. The spectra are especially informative of mineralogy, as indicated by the earlier telescopic. Further, VIR spectral imaging determines the associations of mineralogy with surface morphology, linking chemistry with geology.

What is Dawn Finding: Two forthcoming sets of publications (*Nature* and *Science*) and presentation at this LPSC47 as well as at recent AGU and DPS conferences introduce some of the first Dawn results. Here we present the highlights that allow us some insight into how Ceres has evolved as a water-containing planet.

Surface Composition: The global surface mineralogy is mostly altered silicates (OH-bearing), best modeled so far using ammoniated phyllosilicates, antigorite, and carbonate added to a dark material (magnetite) [14]. Mixtures with different ammoniated clays can match the Ceres spectrum, but the specific clay mineral cannot be determined. Carbonates are always needed in the fit but all carbonate minerals (dolomite, magnesite and calcite?) produce equivalent fits. The greatest variations in surface color, related to composition, are at lower latitudes (Fig. 1).

Morphology: The surface is heavily cratered with overall relief greater than expected for an icy body: +/-7.5 km and relief/size ratio of 3.6% [15]. However, the largest craters appeared relaxed and distorted toward the equator and their density concentrated toward the poles. There is much evidence of resurfacing, often associated with pits, flow features, cracks and groves [15]. Extrusive-like protrusions (Ahuna Mons) suggest very recent subsurface tectonic/volcanic activity. The entire surface appears "lumpy" on a regional to global scale, as though it had been punched and shoved from below to create bulges and distortions at the surface.

Bright spots: Small but striking deposits of very bright, white material exist, often appearing as if they are the residuum of cryolavas erupted from nearby cracks, but are also mixed into crater walls and ejecta. Occator crater's bright spots appear to be associated with the cratering or post cratering processes. At least one bright spot is associated with the only H_2O detection on the surface so far [16].

Geophysics: The Ceres gravity field is still being analyzed but already suggests some concentration of mass toward the center, i.e., some differentiation has occurred [17]. The diameters are a bit smaller than thought from telescopic measurement, suggesting slightly less bulk water content, but this is partly due to the complex global shape.

Current activity: Two observations might suggest this. The H_2O observation at the surface, if it is free ice as current interpretations prefer, has to be recent as it is unstable on the surface, but it could be present as hydrated minerals. Temporally varying haze is reported over Occator Crater [18] that suggests outgassing in that area of very bright spots. More observations may help confirm and enhance our knowledge.

Conclusions so far: Overall, the results from the initial Dawn observations very generally confirm the early telescopic global observations and interpretations and the thermodynamic modeling studies. However, Dawn is revealing a much more complicated body, set of operating processes, and complex evolution scenario.

In general, the surface composition of Ceres is altered mineralogy with a strong darkening agent and seems to include the predicted ammoniated clays, but the exact mineralogy and distributions are becoming clearer and are providing the basis for working out the interior mineralogical processing that must have occurred. A reducing interior environment during evolution is suspected, perhaps controlled by H_2 from serpentization reactions. The surface is clearly much rougher than sustainable by a predominantly icy crust [19]. The retention of deep craters is not consistent with a simplistic differentiated internal structure consisting of an outer layer composed solely of pure water ice (covered with a rocky lag) overlying a rocky core [20]. More than a factor of 100 increase in viscosity is needed over pure ice [20]. A model that might explain the surface is an outer layer composed of frozen soil/regolith (i.e., more rock than ice by volume) perhaps including salts [20]. However, relaxation and other geophysical processes also are occurring, perhaps over long timescales and preferentially toward the equator. Ceres' interior may be compositionally heterogeneous laterally and radially, and the interior evolution may have been somewhat less complete than for the hotter models, suggesting Ceres formed later with less short-lived radionuclide heating, although this produces less mineral alteration, and/or there was greater mixing of alteration products into the crust. Of great interest is the suggestion of current activity. There are numerous features, extrusions and the bright spots, that appear very fresh and suggest of current activity. Clearly Ceres is or very recently was an active "water world."

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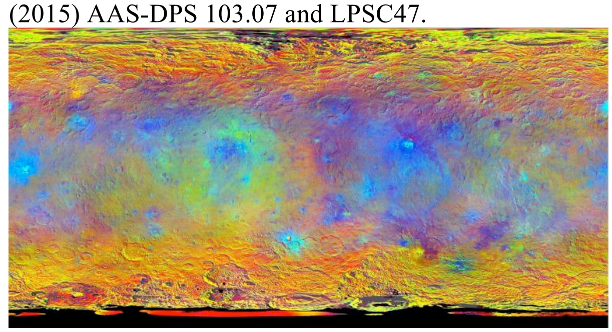

Figure 1. Global enhanced color map of the surface of Ceres, derived from the Dawn Framing Camera data.