CERES EVOLUTION: THE PICTURE BEFORE AND AFTER DAWN. T. B. McCord[1], J. C. Castillo-Rogez[2], C. T. Russell[3] and C. A. Raymond[2]. and the Dawn Team, [1]Bear Fight Institute, Winthrop, WA 98862 (tmccord@bearfightinstitute.com), [2]Jet Propulsion Laboratory Caltech. Pasadena CA 91109, [3]University of California, Los Angeles CA 90095.

Pre-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, carbonates and other salts, with a darkening agent [1]. 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 minerals are markers of 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 [Figure 1], 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 might operate preferentially at lower latitudes and higher temperatures, giving some indication of the amount and depth of the ice [9].

Dawn: The Dawn Mission [10] has provided 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. For the past two years Dawn's instrument arsenal (camera, optical/IR/neutron/gamma spectrometers, gravity survey [11]) has been providing extensive datasets about the interior mass distribution, surface features, that are the topographical expressions of surface and interior processes, and composition, mineral, molecular and elemental resulting from thermochemical processes.

Post-Dawn: As the Dawn mission approaches a successful conclusion at Ceres, it seems time to assess how its findings have sharpened the picture of Ceres' evolution. Several collections of papers (*Science* and *Nature*) and two forthcoming sets of publications (*MAPS* and *Icarus*) and presentations at recent conferences (GSA, DPS, AGU) introduce some of the Dawn observations and interpretation. Here we synthesize these to assess where our knowledge of how Ceres has evolved as a water-rich planet.

Dawn's results confirm the early findings and extend them dramatically to reveal a very evolved and active small planet, probably even today. A nearly uniform global distribution of surface mineralogy, which includes Mg-serpentines, ammoniated clays, and salts including carbonates, suggests extensive, endogenous, planet-wide aqueous alteration [12]. Local deposits of carbonates and other salts appear to be primarily associated with craters [13]. Some local exposures of H_2O deposits are seen [14], especially in higher latitudes and in low-illumination regions, that must be very young, as water ice is unstable under Ceres' surface temperatures. Ice is also likely in abundance at higher latitudes in the upper few meters of the surface, as suggested by near surface H-rich north polar deposits [15] and observations of permanently shadowed regions [16]. Gravity field measurements indicate a concentration of mass toward the center and near isostatic equilibrium, consistent with at least some differentiation and water-related evolution [Figure 2]. Abundant small and mid-sized craters but relaxed or missing large craters suggest a stiff and probably lower water content upper crust [9, 18]. Surface features, such as flows, extrusions, and domes, some geologically very recent, are evidence of subsurface active processes. Ahuna mons, a tall mountain to be of cryovolcanic origin, even suggests that Ceres is probably active today [19]. Questions arise, such as why Ceres seems so aqueously altered but only partially differentiated? Where is the free water that should have been left over after an early phase of aqueous alteration and that should have enhanced differentiation? Are there subsurface bodies of liquid water/brines today? How much water/ice has been lost from the surface over geologic time and is the stiff upper crust today a planet-wide lag deposit or remnant of an early crust? What is the source of

Ceres' occasional weak atmosphere? We will address these open questions and their implications for the field of dwarf planet evolution at large.

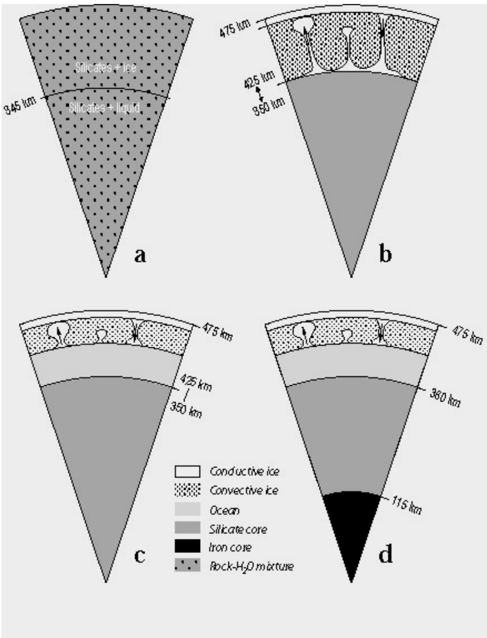

Figure 1. Different internal structures based on different thermodynamic modeling scenarios [5]: homogeneous asteroid made of a mixture of H_2O and high-density silicates (a), differentiated Ceres with high-density silicate core equivalent to Vesta (core radius of 350 km) or low-density serpentine (core radius of 425 km) and outer ice layer (b), same as b but the presence of anti-freezing material (ammonia) maintains a liquid layer (c), and fully differentiated model of Ceres with an inner iron core (d).

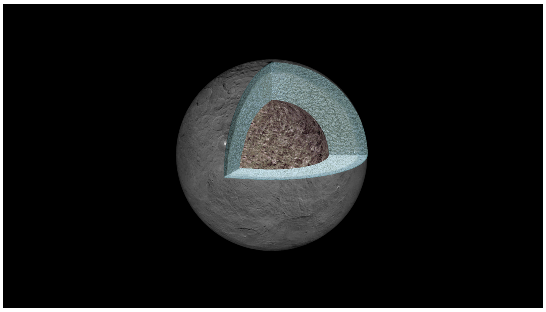

Figure 2. Dawn findings suggest that Ceres has a weak interior, and that water and other light materials partially separated from rock during a heating phase early in its history. Ceres appears to be in or near hydrostatic equilibrium and has differentiated physically and chemically [17].

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