Feierberg et al. 1981: Spectroscopic evidence for aqueous alteration products on the surfaces of low-albedo asteroids

Discussion Leader: Brendan Anzures

Summary: Authors present IR spectra (0.9-2.5μm) and narrowband photometry (3.0-3.5μm) for low-albedo asteroids 1 Ceres, 2 Pallas and 324 Bamberga in comparison with primary carbonaceous chondrite matrix material (CCMM) and secondary alteration products. They conclude that spectral differences between C-type asteroids and carbonaceous chondrites are due to differing degrees of aqueous alteration of CCMM (and that the asteroids are compositionally distinct), and that Ceres is especially interesting due its inferred composition of clay minerals with hydrated salts.

Important methods, figures, and findings:

| Table 1. Spectroscopic evidence for aqueous alteration products on the surfaces of low-albedo asteroids |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Primary Components          | Spectral Reflectance Properties | 1 Ceres | 2 Pallas | 324 Bamberga |
| Fe-rich clay minerals       | strong absorption features in uv due to iron catalysts and at 3 μm due to water molecules | - | - | - |
| Carbon                      | low-albedo opaque suppresses absorption features of other components | - | - | - |
| Fe-poor olivine, pyroxene   | low optical density, spectrally featureless | - | - | - |
| Alteration Products         | Changes in Spectral Reflectance | - | - | - |
| Fe-poor clay minerals       | absorption feature in uv due to iron catalysts much weaker | - | - | - |
| Magnetite                   | low-albedo opaque, can be distinguished from carbon by its 1-3 μm spectrum | - | - | - |
| Hydrated salts              | high albedo, low optical density, strong absorption feature at 3 μm due to water molecules | - | - | - |

Table 1 summarizes much of the spectroscopic and mineralogical conclusions found by comparing the spectra of the low-albedo asteroids with hydrated minerals (varying temperature), CCMM, and low-albedo opaque minerals (varying amounts of carbon or magnetite). 1 Ceres is found to be composed mostly of clay minerals with some hydrated salts. 2 Pallas is found to be low in low-iron clay minerals, rather iron-free olivines and pyroxenes like CM chondrules. 324 Bamberga is found to have some clay minerals and an abundance of magnetite (an alteration product of iron-rich clays).

Figure 5 is important in showing comparisons and trends of the main spectral features at 2.2μm (albedo) and 3.0μm (sensitive to water of hydration). The dashed line follows the trend of chlorite with increasing amounts of carbon (and is similar to mixture trend lines for other low-albedo opaque minerals with increasing alteration products). Strong 3μm features on this plot provide evidence for hydrated salts, which is concluded for 1 Ceres but not the other asteroids.

Outstanding Question:

1. How well did mineralogical predictions from this study almost 40 years ago match recent measurements of Ceres from the Dawn mission?

References for Further Reading:

The Geomorphology of Ceres (Buczkowski et al., 2016)

Discussion Leader: Rachel Sheppard

Summary: The authors present a new DTM and geologic map derived from Dawn data, as well as high-resolution images of several sites with interesting geomorphology. They conclude that the surface is rock-dominated, possibly with small amounts of ice or salts, but that crater morphology suggests a strong crust. They argue that there is abundant ice in the subsurface based on morphological evidence of cryovolcanism/cryomagmatism (FFCs, Occator dome, Ahuna Mons).

Important methods, figures, and findings: They focus on the distributions and origins of domes, craters, and flows (Fig. 1). They argue that there are two classes of domes/mounds based on size: smaller mounds are probably impact ejecta while larger ones (especially Ahuna Mons) may be associated with cryovolcanism.

Figure 1: New geologic map of Ceres.

They describe several craters that are similar to lunar fracture-floored craters (FFCs). Like their lunar counterparts, the FFC-like craters are anomalously shallow compared to their depth to diameter (d/D) ratios (Fig. 2). Craters can provide information on interiors, and the authors argue that these craters may be shallow due to intruding low-density material uplifting the floors. This is their first example of possible cryomagmatism.

There are a range of linear features on Ceres, including impact features (e.g. secondary crater chains), potential subsurface faults with no relationship to craters, and fractures on domes due to potential salt diapirism.

Three classes of lobate flow morphology are observed near impact craters (Fig. 3). The three distinct morphologies have latitudinal trends, which suggests multiple emplacement mechanisms. They classify the flow morphologies based on three different formation processes: ice flows, landslides, and fluidized ejecta blankets associated with impact into an ice-rich surface. Type I flows (blue crosses) are seen in high-latitude craters and may be ice-cemented flows. Type 2 flows (green triangles) are thinner, fan-shaped, and originate at a crater wall, mostly at high latitudes. They seem consistent with landslides found on icy satellites. Type 3 flows (yellow dots) are wide sheets of smooth material with interspersed hummocky regions and end in layered lobes. They are consistent with fluidized ejecta blankets of rampart craters which implies impact into ice-rich ground and are found in mid-latitudes.

We can better understand the crust and interior by looking at morphological features. The craters seem relatively unrelaxed, implying a rock-dominated crust that may have some ice or salts mixed in. Water ice has been observed at one location but does not dominate the crust. Several types of features consistent with cryomagmatism suggest an ice-rich interior.

Figure 2: Depth to diameter ratios of the FFC-like craters.

Figure 3: Locations of three types of lobate flows. Blue crosses represent Type 1 flows, green triangles are Type 2 flows, and yellow dots are Type 3 flows.
Cratering on Ceres: Implications for its crust and evolution
(Hiesinger et al., 2016)

Discussion Leader: Alyssa Pascuzzo

Main Point/Findings: The authors present a synthesis of the various unique crater morphologies/geometry, distribution and ages of craters and terrain on Ceres from Dawn data. They note the surface is both visually and compositionally heterogeneous. The unique distribution of craters with size show large craters are absent, have relaxed substantially, or been overprinted and that the d/D of smaller craters suggest a weaker ice-rich-rock mixture for the crust.

Summary: The morphologies of craters with diameters less than 30 to 40 km resemble those on moons such as Dione and Tethys. These morphologies include flow like deposits on the sides of crater walls and smooth crater floor fill, which are interpreted as typically features of ice material seen on mid-sized icy moons. Unique to Ceres are the occurrences of central pits and floor fractured craters present in smaller craters which are only seen in crater greater than 75 km on other icy moons.

Crater degradation is consistent with a surface crust composed as a mixture of ice and rock. The apparent relaxation of large craters like Kerwan crater (284 km), lack of relaxation of smaller craters, and unexpectedly large depth to diameter ratios for smaller craters are consistent with this notion. They also found that the transition from bowl-shaped craters to modified simple craters and simple-to-complex occurs at 7.5 - 12 km and 10.3 km, respectively. If Ceres was a rocky body simple-to-complex transition would occur at 50 km, thus supporting a weak, ice-rock mixture crust.

The distribution of craters is heterogeneous with a concentration in crater density located in the northern hemisphere and low crater densities at the equator and southern hemisphere (Figure 1). The authors propose the low crater density terrain to be related to large impact-driven resurfacing (viscous relaxation, ejecta burial, and seismic shaking are less likely).

The authors’ approached dating Ceres’ surface with two methods: 1) lunar-derived model (LDM) and 2) asteroid-derived model (ADM) (Figure 2). Both methods have pros and cons. The major cons include the assumption that the impactor flux for Ceres was equal to that of the Moon and the apparent incompleteness in asteroid observations of smaller bodies in the asteroid belt, for LDM and ADM respectively. They used both dating methods to estimate the formation age of two large depressed regions (one slightly smaller than the other), which resulted in formation ages of 3.5 Gya (smaller region) and 3.7 Gya (larger region) using the LMD. The AMA yielded a much younger age, 2.8 Gya, for the smaller feature and an age older than 4.0 Gya for the larger feature. These methods were used to date the Kerwan Smooth Deposits which resulted in fairly young formation ages (550 [ADM] or 720 Ma [LDM]) suggesting these deposits were the result of recent geologic activity.

Outstanding Question: Could we constrain a origin depth for the material that is thought to have been resurfaced by large impacts? What sized crater would you need to resurface material at x-depth? What depth would the material or layer need to be for a crater of x-diameter to resurface it?

Could large impactors produce enough energy and heat to melt and form a localized subsurface ocean?