EXOGENIC OH ON VESTA: IMPLICATIONS FROM AND FOR OTHER ASTEROIDS. A S. Rivkin, [1]JHU/APL (andy.rivkin@jhuapl.edu).

Introduction: The HED (howardite, eucrite, diogenite) meteorites, generally thought to be from Vesta, are by and large free of hydrated phases. This gave rise to an expectation that Vesta itself would currently be free of hydrated minerals (regardless of what may have occurred earlier in its history).

Initial observations of Vesta in the 3-μm spectral region, where diagnostic absorptions due to OH and H_2O are found, were consistent with an anhydrous surface [1], but later observations at higher spectral resolution showed a shallow absorption that was interpreted as due to infall of carbonaceous material [2]. While confirmation of the 3-μm band was stymied by a lack of suitable laboratory spectra for comparison, the infall idea was supported by the albedo distribution on Vesta's surface [3].

Dawn's arrival at Vesta firmly established the presence of hydrated minerals on Vesta via observations of a band at 2.8 μm that is obscured by Earth's atmosphere as well as hydrogen measurements by the GRaND neutron spectrometer [4,5]. This hydrogen/OH is associated with low albedo areas, and the interpretation that surviving remnants of carbonaceous impactors are responsible is still the leading theory [6].

C chondrites and C asteroids: Laboratory spectra of the CM, CI, and CR subgroups of carbonaceous chondrites (CC) show absorptions due to phyllosilicates, with band minima in the 2.7-2.8 μm range depending on mineralogy [7-8]. The C-complex asteroids are seen to have a variety of spectra in the 3-μm region, including a group that looks like the hydrated CC at the wavelengths where the Earth's atmosphere allows good data to be collected [9,10].

While data in the 3-μm region has only been obtained for roughly 100 C-complex asteroids, visible and near-IR (0.5-2.5 μm) data is available for many more, and the WISE mission has obtained high-quality albedos for thousands of asteroids. All told, evidence suggests that the C complex objects dominate the asteroid belt, accounting for half of the objects even in the inner belt where they are least common [11,12]. Statistical arguments based on a shallow absorption near 0.7 μm suggests that the CM group may constitute upward of 30% of the C-complex population [13].

All told, hydrated carbonaceous material would be very common impactors, and their low-albedo, neutral spectra would be very effective in providing a 3-μm absorption while leaving shorter wavelengths more or less unaffected.

What this might help explain: There is no obvious reason to think that Vesta alone would feel the effects of carbonaceous impactors. Surfaces throughout the asteroid belt will potentially accumulate the kind of carbonaceous material that is thought to be present on Vesta. Accordingly, the prospect of impactor contamination causing a 3-μm band on asteroids is prompting a reevaluation of our interpretations of other asteroid spectra.

Some M-class asteroids, once generally considered to be parent bodies for iron meteorites, were reinterpreted due to the presence of a 3-μm band. Given the association of OH and water with aqueous alteration, and the incompatibility of iron meteorites with aqueous alteration, it was thought that the presence of a 3-μm band precluded an object from being analogous to iron meteorites [14,15].

In-depth studies of M asteroids have established that many have radar albedos consistent with rocky or partially-rocky rather than metallic natures. However, an accumulation of carbonaceous chondrite debris could plausibly explain those objects for which 3-μm bands and high radar albedos coexist [16].

In addition to the M asteroids, carbonaceous impactors may be responsible, or partially responsible, for the spectra of two large S-class near-Earth objects (NEOs), 433 Eros and 1036 Ganymed. These were not expected to have hydrated minerals, but have 3-μm bands a few percent in depth [17]. In addition, Eros was observed by NEAR Shoemaker to have accumulations of darker material on its surface, though it was interpreted as vapor-deposited nanophase iron coatings on native material, created through micrometeorite impacts [18].

The Eros/Ganymed observations also present an additional challenge. While GRaND measurements at Vesta can be used to argue that Vesta's hydrogen isn't delivered by the solar wind, similar measurements are absent for typical asteroids. Therefore, additional care must be taken to correctly interpret 3-μm absorptions as primarily solar wind-created (like those on the Moon are thought to be) or impactor-related (like those on Vesta are thought to be).

What this doesn't explain and makes more complicated: In addition to Vesta, one other asteroid has been recently visited by a spacecraft with spectral capability in the 3-μm region: 21 Lutetia by Rosetta. Unlike the objects discussed above, the data returned from Lutetia is difficult to reconcile with the idea that asteroids are commonly accreting carbonaceous debris.

Contrary to the Dawn findings at Vesta, the Rosetta spectra of Lutetia are reported to have no absorption in the 3-μm region within 2% [19], and thus no OH or water is interpreted as present.

Given that Lutetia orbits in the same part of the belt as Vesta, we would expect its impactor population to be largely the same as Vesta's. Furthermore, the retention of impactor material would seem to be more a function of impact speed and whether it survives the impact than a matter of escape speed and keeping ejecta. Making sense of both Lutetia and Vesta is still work to be done.

It also seems likely that impactor contamination could be a factor at Ceres. Ceres resides in a more C-asteroid rich part of the asteroid belt, and would presumably have as much material survive as does Vesta.

However, unlike Vesta, which has a native composition and spectral properties that provided a strong contrast with carbonaceous impactor material, it is less obvious how best to account for this material at Ceres. Ceres has a distinct reflectance spectrum in the 3-μm region compared to what is seen in the CC meteorites, and while on large scales it is unlikely that an impactor-delivered component will cause much confusion, on small scales and in particular regions ambiguity is possible between a native, unusual area and impactor contamination. Calibration from Vesta may be necessary to allow accurate estimates of any exogenic contribution to Ceres' surface.

It is likely, at least, that Bennu is too young to have incorporated much endogenic material, and so the OSIRIS-REx sample return results seem unlikely to be spoofed by foreign material. Still, a more thorough study of S-class NEOs like Eros and Ganymed, and perhaps even a sample return with a significant mass returned may be necessary before this issue is fully understood.

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