DARK ASTEROIDS: INSIGHTS INTO SURFACE COMPOSITION FROM COAL SPECTRA. E. A. Cloutis, Department of Geography, 515 Portage Avenue, University of Winnipeg, Winnipeg, Manitoba, Canada R3B 2E9; e.cloutis@uwinnipeg.ca.

Introduction: Dark asteroids, including Centaurs and Kuiper Belt objects display a range of spectral slopes with few, if any, discernible absorption bands [1, 2]. The reflectance spectra of a series of coal samples have been measured in order to provide insights into the possible mechanisms responsible for the variety of slopes, and lack of organic absorption bands, seen in the spectra of these objects.

Experimental Procedure: A total of 21 coal samples, ranging from lignite to anthracite (and 7 graphite samples) have been characterized by reflectance spectroscopy, with additional compositional data available from previous investigations [3,4]. The reflectance spectra were acquired at the RELAB facility at Brown University as follows: 0.3-26 μm relative to halon (5 nm spectral resolution; i=30°, e=0°) and 2.5-26 μm relative to brushed gold (4 cm^{-1} spectral resolution; i=30°, e=30°) [5]. All samples were prepared by gentle hand crushing and dry sieving to produce <45 μm size fractions. All spectra shown are for this size fraction.

Sample Spectra: The reflectance spectra of a subset of the samples are shown in Figure 1. The samples are generally characterized by a range of spectral slopes and variable absorption bands, largely confined to the 3.3 μm region, and associated with the organic phases present in the samples.

It can be seen that as one proceeds from lignite to bituminous coal to anthracite to graphite, the absorption bands in the 3.3 μm region, attributable to C-H stretches become less intense, lower wavelength absorption bands due to water (near 2.9 μm), and clays and organic overtones (near 2.3 μm) become less intense. In addition, the overall spectral slope becomes less red and overall reflectance decreases. However, the graphite spectrum is brighter overall than the anthracite spectrum, probably due to a greater proportion of first surface (specular) scatter.

Spectral-Compositional Relationships: The available compositional data were used to search for

For bodies whose surfaces are optically dominated by organics we expect that the most red-sloped spectra will have the greatest likelihood of exhibiting C-H stretching absorption bands in the 1.7, 2.3, and 3.4 μm regions. This is in fact the case with 5145 Pholus, the most red-sloped

relationships with various spectral features. The most consistent relationship exists between the overall slope of the spectra (as measured by the 2.2/1.0 μm reflectance ratio) and the H/C ratio of the samples. Decreasing H/C ratio, associated with a loss of hydrogen relative to carbon, leads to a decrease in overall slope. The change in H/C ratio could be associated with thermal metamorphism or processing of surficial organics via interstellar irradiation [2]. Decreasing H/C also leads to a decrease in the depth of the 3.41 μm aliphatic organic absorption band.

The 3.28 μm aromatic absorption band shows more complex behavior. It initially increases when proceeding from graphite (which has an H/C ratio of ~0) to a peak around an H/C ratio of ~0.5, and then declines steeply beyond this value (Figure 2). Consequently, organic materials with very high or low H/C values will not exhibit a prominent 3.28 μm absorption band.

Discussion: Centaurs and Kuiper Belt objects exhibit a range of spectral slopes, and few of them show any discernible absorption bands [2]. In the few cases where the spectra do exhibit resolvable absorption bands, these are often associated with water ice, while organic-associated absorption bands are rare [6,7,8].

The coal and graphite spectra suggest that there is a fairly narrow compositional range in which red-sloped spectra are associated with weak or undetectable organic absorption bands. This behavior has previously been noted [9], suggesting that a carbon content of between 90 and 94% is where coal undergoes major structural, compositional and spectral transformations. In the available samples, this transformation occurs somewhere between anthracite (carbon content of 91.4%) and graphite (carbon content of 99.9%).

The spectral changes occurring in this region can be seen in Figure 4 which shows the normalized spectra of anthracite and graphite, including the 3.28 μm aromatic and 3.41 μm aliphatic absorption features (only evident in the anthracite spectrum). As the carbon content in this region increases, the already weak C-H absorption bands disappear and the spectrum becomes increasingly flat.

asteroid for which detailed spectral information is available [8]. With increasing aromatization of the organic fraction, due to thermal metamorphism or interstellar irradiation, overall spectral slopes will decrease and organic absorption bands, both aliphatic and aromatic, will decrease in intensity. The change in overall slope is a result of the absorption edge, attributable to aromatic molecules, moving to longer wavelengths and becoming broader due to the increase in heterogeneity of the aromatic molecules. However, even the graphite samples do not exhibit a flat reflectance spectrum, 2.2/1/0 µm reflectance ratios are not less than 1.2. This suggests that flat-sloped asteroid spectra probably have additional optically-active materials present on their surfaces.

These results suggest that the likeliest candidate bodies to search for organic absorption bands are those which are most red-sloped. However, the lack of organic absorption bands does not necessarily imply a lack of organic molecules, but could indicate a lack of aliphatic molecules, or the presence of other opaque minerals, such as submicron magnetite and troilite in the case of CM chondrites [10], which can heavily modify a reflectance spectrum and subdue absorption bands [11].

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Figure 1 (top). Reflectance spectra of lignite, bituminous coal, anthracite, and graphite.

Figure 2 (middle). Relationship of aromatic 3.28µm band depth and H/C ratio of coals and graphite.

Figure 3 (bottom). Normalized (to 1 at 0.55µm) reflectance spectra of anthracite and graphite.