Reflectance spectra of meteorites

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A spectrometer at the Geological Survey of Finland was used to obtain 33 high-quality reflectance spectra of 26 individual meteorites. Principal Component Analysis was applied to the spectra to explore grouping strategies for meteorite classification. Initial investigations of surface roughness effects on the reflectance spectra features were made.

INTRODUCTION

Spectral photometry is a powerful tool for establishing links between meteorites and their parent bodies (asteroids, comets, the Moon, Mars). The primary information used to interpret asteroid reflectance spectra comes from absorption bands that are diagnostic of the cosmically significant minerals pyroxene and olivine. Then there are secondary effects that can alter the size of the bands and the slope of the continuum. These effects are primarily due to particle size, surface roughness, and temperature which are poorly characterized in the literature. These effects are important because our knowledge of the physical condition of the surface of bodies such as asteroids and comets is limited. Understanding how light scattering changes the features in the reflectance spectra is then useful for interpreting spectra. A lot of effort has gone into characterizing and modeling the effect of particle size on the reflectance spectra with some success. The reason for this is because most asteroids over 100 m in size are thought to be covered by a layer of impact generated particles. However, there has been little characterization of the meteorite samples in terms of their solid surface roughness.

METHOD

A spectrometer at the Finnish Geological Survey was used to obtain 33 reflectance spectra from 26 meteorites representing undifferentiated (C, H, L, LL and E) to differentiated meteorites. To account for inhomogeneity of the surface composition, reflectance spectra were obtained from ten different locations on the surface and then the average was calculated. To explore light scattering effects, spectra were taken from a matt (sanded) and polished surface for one meteorite (Wellman). From another meteorite (Alfianello) we obtained a spectrum from a natural surface and a spectrum from a sawn surface. To compare solid surfaces to powdered samples, we retrieved 163 reflectance spectra of meteorite samples from NASA’s Planetary Data System [1]. This dataset also includes meteorite groups not represented by our measurements.

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A Principal Component Analysis (PCA) was applied to the combined data sets to explore the distribution of the reflectance spectra structure over the meteorite groups. PCA is a relatively simple mathematical procedure for reorganising a data set so that the information can be described by fewer variables. The technique has been used to explore the distribution of asteroid taxonomic classes [2].

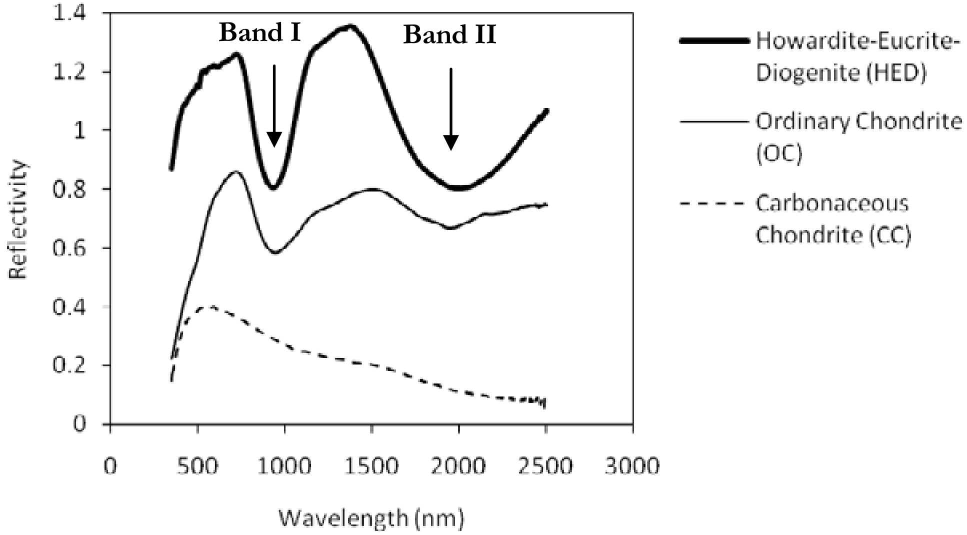

Figure 1. Reflectance spectra obtained by the Geological Survey of Finland. The chart shows examples of spectra for achondrites (HEDs) and chondrites (ordinary and carbonaceous). The spectra have been offset along the y-axis for clarity. Notice how the spectra vary in their structure. This is important for interpreting the PCA results in Fig. 2.

We followed the method of [3] to parameterise the reflectance spectra in principal component space. The slope was removed by this method to account for uncertainties in space weathering and observational uncertainties. Space weathering is not of a concern here but we followed this technique to account for observational uncertainties, such as the phase angle. The spectrum was first normalised and then a slope was least squares fitted and forced to go through unity. The spectrum was then divided by the slope.

RESULTS

The result of a PCA on the meteorite reflectance spectra is shown in Fig. 2. The distribution of the meteorite groups in principal component space can be explained by examining the eigenvectors shown in Fig. 3. Eigenvector 1 has strong loadings close to the locations in wavelength space corresponding to the absorption bands at ~1000 nm and ~2000 nm that are diagnostic of the mineral pyroxene. In Figure 2, the carbonaceous chondrites cluster to the right of the diagram as they have relatively flat spectra. The HEDs then cluster to the left as they have relatively deep absorption bands. Eigenvector 3 has a strong loading close to the location of the bands found at ~1000 nm that are diagnostic of both pyroxene and olivine. The spread along the y-axis for the ordinary chondrites could be explained by the presence of olivine and pyroxene in these meteorites whose relative ratio of abundance varies over the ordinary chondrite group. Eigenvector 2 is shown for completion but does not have loadings at wavelengths of interest for this investigation.

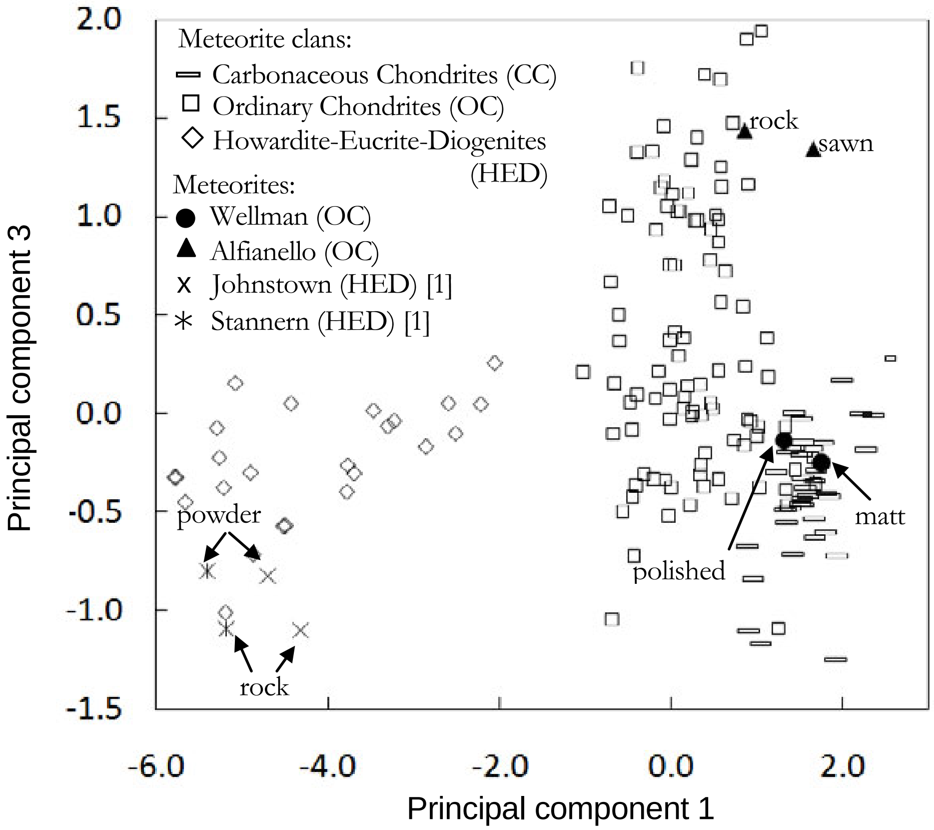

Figure 2. Principal Component Analysis of 196 meteorite reflectance spectra. This includes 33 new measurements from this work plus 163 measurements retrieved from NASA's PDS [1]. The three meteorite clans (groups) are shown. Individual meteorites from these clans are identified with their own symbols and labelled with their surface condition. Wellman and Alfianello are from the spectra obtained from this work.

From measurements by [4], the reflectance spectrum from a rock surface has smaller absorption bands when compared to powdered surfaces. Also an increase in the roughness of the rock surface will increase the band depth. This agrees with measurements made by [1] and shown in Fig. 2. A similar effect occurs with the ordinary chondrites.

In our reflectance spectra, when comparing a matt and a polished surface, the polished surface has deeper absorption bands than found in the reflectance spectrum from the matt surface which suggests that the polished surface is rougher. One explanation suggested in [4] for this contradictory result may be that exposed pore spaces actually increase roughness after polishing. The reflectance spectrum from the rock surface has deeper absorption bands than found in the reflectance spectrum from the sawn surface as would be expected with a rougher surface.

CONCLUSIONS

PCA applied to the reflectance spectra of meteorites successfully separates chondrites and achondrites (HEDs). Meteorites remained inside their specific groups despite changes in the structure of their surface. Future work on understanding surface light scattering effects will help us improve the classification of meteorites using non-destructive methods and help us to further understand the nature of asteroid surfaces.

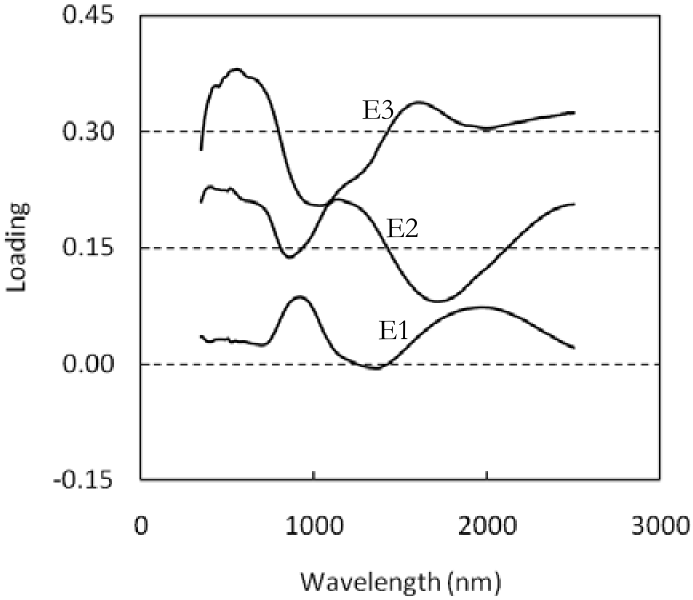

Figure 3. Eigenvectors from PCA of the meteorite reflectance spectra data set. E2 shows that the maximum variation in reflectivity is at around 1000 and 2000 nm while E3 is most strongly correlated to variation in reflectivity around 1200 nm and 1800 nm. E2 and E3 have been offset by 0.15 and 0.3 respectively on the y-axis and the dotted lines are the zero axes.

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