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INFRARED DIFFUSE REFLECTANCE SPECTRA OF WEATHERED AND UNWEATHERED CR2 CHONDRITES: COMPARISON WITH ASTEROIDS

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Abstract: The presence and intensity of absorption band near 3 μm in the reflectance spectra are due to the presence and abundance of hydrates and/or hydroxyl ions. Previously, we have shown that Renazzo (CR2 chondrite) is an excellent spectral match to 2 Pallas (B-type asteroid) in the wavelength region near 3 μm. In this paper, we have measured infrared diffuse reflectance spectra of eight Antarctic CR2 chondrites and have compared reflectance spectra of CR2 chondrites with those of eight asteroids which belong to the C, G, B and F taxonomic classes. The spectral absorption near 3 μm of Antarctic CR2 chondrites are deepened and rounded compared to that of Renazzo (fell 1824). This difference implies the presence of corrosion products probably due to terrestrial weathering of the Antarctic CR2 chondrites. This is the reason why no asteroids has been found that has an Antarctic CR2 meteorite counterpart. In addition to the close similarity between Pallas and Renazzo, the overall spectral profile of 511 Davida also exhibit similarity to the Renazzo spectrum.

1. Introduction

Absorption bands near 3 μm in diffuse reflectance spectra of the silicates are due to the presence of hydrates and/or hydroxyl ions and the intensity of the 3 μm band is related to the amount of hydrous minerals in a silicate sample (*e.g.*, MIYAMOTO, 1991). Molecular water in minerals shows broad absorption bands near 3400 cm^{-1} (2.94 μm) and hydroxyls typically show sharp absorption bands near 3650 cm^{-1} (2.74 μm) (*e.g.*, RYSKIN, 1974; SALISBURY *et al.*, 1988).

Therefore, the absorption bands near 3 μm are the spectral signatures of hydrated silicates included in meteorites and surface materials of solar system objects.

Aqueous alteration processes on asteroids would have been possible if liquid water, derived from the originally accreted water ice, were available (ZOLENSKY and MCSWEEN, 1988). Liquid water could have been produced by any or all of the heating processes of asteroids, such as decay of radionuclides, accretional bombardment and induction heating (SCOTT *et al.*, 1989). Thus, the 3 μm absorption bands of asteroids are thought to be results of the aqueous alteration processes.

We have previously compared the reflectance spectra near 3 μm of asteroid 1 Ceres and 2 Pallas (commonly classified into G and B type, respectively) with those of various carbonaceous chondrites, including thermally metamorphosed ones. We have shown that Renazzo (CR2 chondrite) is an excellent spectral match to Pallas (SATO *et al.*, 1997). In this paper, we measured infrared diffuse reflectance spectra of eight CR2 chondrites

from Antarctica and examined the spectral profiles of the absorption bands near 3 μm. The spectral features of the 3 μm absorption bands are compared with those of asteroids which are members of the C, G, B and F taxonomic classes. The C, G, B and F type asteroids have been thought to be compositionally similar to carbonaceous chondrites because of their low albedos and neutral colors in the visible-near infrared wavelength region.

2. Samples and Experimental Techniques

CR2 chondrites studied in this paper are summarized in Table 1. Samples of these CR2 chondrites weighing approximately 50 mg were ground in a corundum mortar and passed through a 100 μm sieve to obtain powder samples for spectral measurements. Each powder sample was dried in a desiccator at room temperature for at least 48 hours in order to remove any adsorbed water from the grain surface. A specimen weighing approximately 20 mg was taken from each powder sample and used for the spectral measurements. Diffuse reflectance spectra were measured in dry-air surroundings by the use of a Fourier transform infrared spectrometer (JASCO, FT/IR-300E) equipped with a diffuse reflectance attachment at Mineralogical Institute, University of Tokyo. Each powder sample was placed in the hollow space of a sample holder 1.5 mm in depth. After setting the sample in the spectrophotometer, the sample was left in dry-air surroundings for at least 1 hour before measuring diffuse reflectance spectra. Dry air was passed into the spectrophotometer throughout the reflectance measurement. Spectra were taken over the range from 7900 cm^{-1} (1.27 μm) to 400 cm^{-1} (25 μm) at a resolution of 4 cm^{-1}. An aluminum-coated mirror was used as standard. Scans were integrated 1000 times to enhance the signal-to-noise ratio. The ratio of meteorite reflectance to standard spectrum displays only mineralogical features. Diffuse reflectance spectrum of Renazzo was measured under similar conditions and was taken over the range from 3950 cm^{-1} (2.53 μm) to 400 cm^{-1} (25 μm) at a resolution of 4 cm^{-1}.

Table 1. Summary of CR2 chondrites studied and the integrated intensity of absorption band near 3 μm.

Meteorites	Integrated intensity#	Weathering	Remarks
Renazzo	124	—	Fell 1824
Y-790112	197	B	Antarctic
Y-793495	254		Antarctic
Y-8449	266		Antarctic
A-881595	192		Antarctic
EET 87747	257	B/C	Antarctic
EET 87770	185	B	Antarctic
EET 92042	244	B	Antarctic
EET 92052	276	B/C	Antarctic

The unit is normalized reflectance×cm^{-1}.

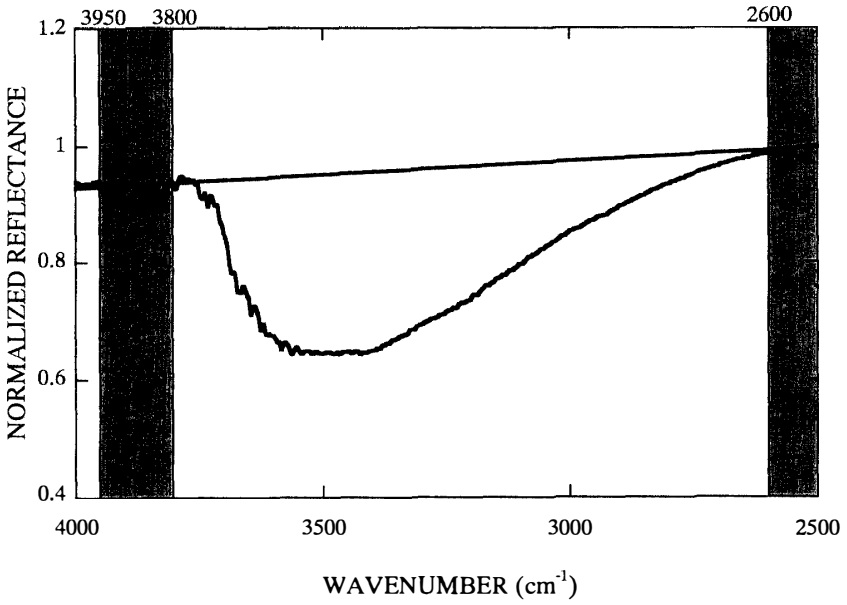

Fig. 1. Infrared diffuse reflectance spectrum near 3 μm of CR2 chondrite, Asuka-881595, with a background line obtained by least squares fitting. The reflectance spectrum is scaled to 1 at 2500 cm^{-1}.

We calculated the integrated intensity of absorption bands near 3 μm in order to study the integrated intensity of carbonaceous chondrites. The integrated intensity of absorption bands near 3 μm was calculated as follows: Fig. 1 shows an example of the normalized reflectance spectrum of Asuka-881595 with the background line obtained by the least squares fitting. A continuum is approximated using a straight line fit to the spectrum using reflectances from 3950 to 3800 cm^{-1} and from 2600 to 2500 cm^{-1}. After normalizing reflectance data at 2500 cm^{-1}, the integrated intensity was calculated by numerically integrating the spectra from 3800 to 2600 cm^{-1}. The unit of the integrated intensity is normalized reflectance×cm^{-1}.

3. Results and Discussion

3.1. Reflectance spectra of CR2 chondrites

Infrared diffuse reflectance spectra of nine CR2 chondrites are shown in Fig. 2. They exhibit various intensities of absorption bands near 3 μm which are caused by hydrous minerals. The values of the integrated intensity of the absorption bands are summarized in Table 1. Antarctic CR2 chondrites show more intensive hydration bands than Renazzo, and their values of the integrated intensity are 1.4–2.2 times larger than that of Renazzo. The shape of their 3 μm bands is more round than that of Renazzo which exhibits a triangular shape. As was mentioned above, the 3 μm hydrated silicate bands are composed of a sharp 3650 cm^{-1} feature dominantly due to hydroxyl ions and a much broader 3400 cm^{-1} absorption dominantly due to interlayer molecular water. The 3 μm absorption feature in the reflectance spectrum of Renazzo is due to the presence of hydroxyl ions in the intergrown phyllosilicates contained in the matrix (Nelen *et al.*,

1975; ZOLENSKY *et al.*, 1993; WEISBERG *et al.*, 1995). Goethite, reported as a major corrosion product of Fe-Ni alloys in Antarctic meteorites by BUCHWALD and CLARKE (1989), shows broad absorption bands near 3 μm. The position of reflectance minima of goethite is about 3150 cm^{-1} (3.17 μm). For severely weathered Antarctic meteorites, the absorption bands near 3150 cm^{-1} becomes noticeable because of the presence of corrosion products (MIYAMOTO, 1991). The round shape of the 3 μm bands of Antarctic CR2 chondrites may be due to some corrosion products. Among 8 Antarctic CR2 chondrites, 4 meteorites which belong to EET series are paired with each other (GROSSMAN, 1994; GROSSMAN and SCORE, 1996). Spectral profiles of EET 87747, EET 92042, and EET 92052 are almost the same and this result is consistent with the consideration that they are paired with each other. Spectral profile of EET 87770 is similar to those of other 3 EET meteorites but shows weaker absorption bands near 3 μm. This probably indicates that EET 87770 is terrestrially less weathered than other meteorites of EET series, although we cannot exclude the possibility of sample heterogeneity.

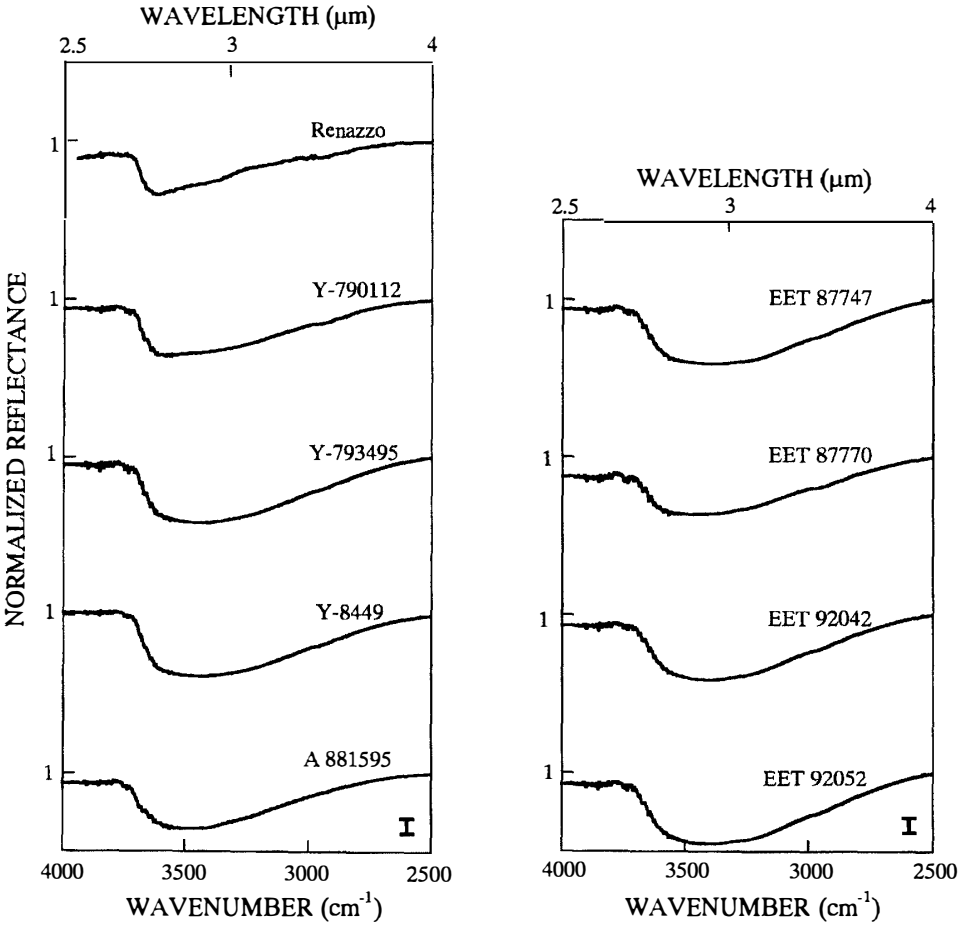

Fig. 2. Infrared diffuse reflectance spectra of CR2 chondrites. All spectra are scaled to 1 at 2500 cm^{-1} and offset for clarity. The scale bar for 10% is displayed on the lower right side of figures.

3.2. Reflectance spectra of asteroids

A majority of dark asteroids which have relatively flat visible and near infrared reflectance spectra are classified as the C, G, B and F asteroids. The C, G, B, and F asteroids have been considered to be related to carbonaceous chondrites, on the basis of their low albedos and featureless reflectance spectra in the visible-NIR wavelength region. Telescopic reflectance spectra of low-albedo asteroids near 3 μm were reported by JONES *et al.* (1990) and we utilized their spectral data. Eight asteroids selected based on

Table 2. Summary of selected eight asteroids compared with CR2 chondrites.

Asteroids	Class	Date of observation
1 Ceres	G	04/25/1987
2 Pallas	B	04/24/1987
10 Hygiea	C	02/01/1988
13 Egeria	G	10/03/1987
130 Elektra	G	02/02/1988
148 Gallia	GU	02/01/1988
409 Aspasia	CX	02/03/1988
511 Davida	C	04/21/1987

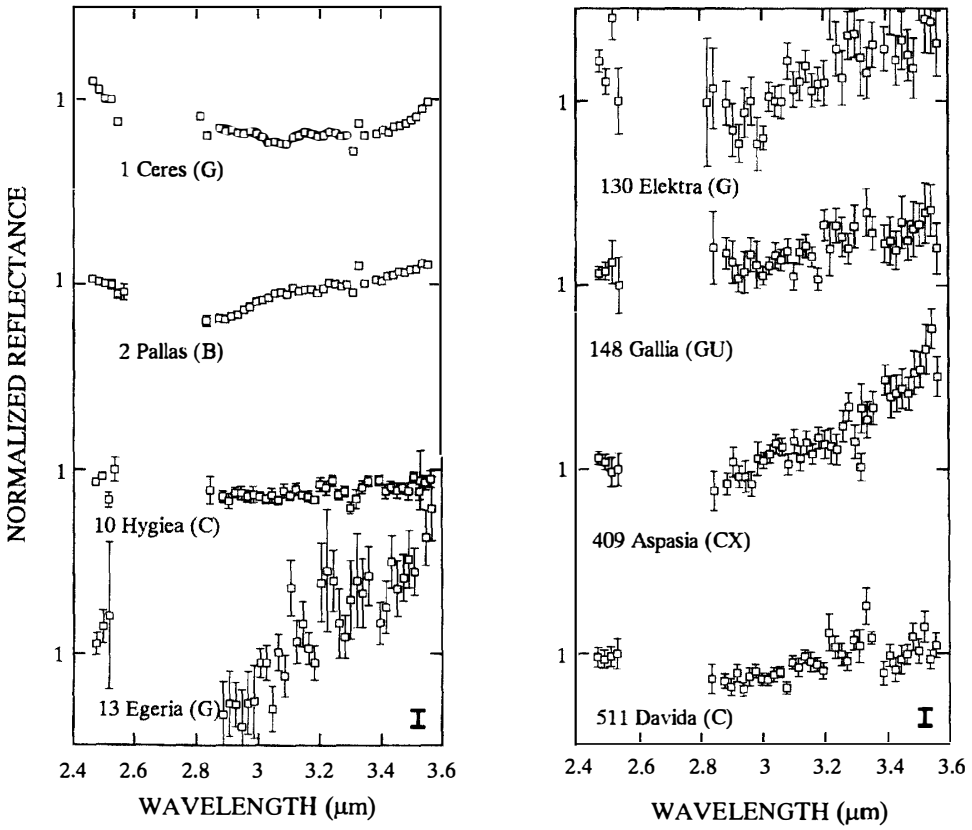

Fig. 3. Telescopic reflectance spectra of selected eight asteroids. All spectra are scaled to 1 at 2.53 μm and offset for clarity. The scale bar for 10% is displayed on the lower right side of figures.

higher quality of their spectral data are summarized in Table 2. Telescopic reflectance spectra of these asteroids are shown in Fig. 3 and their reflectance spectra were compared with those of CR2 chondrites. The taxonomic classifications of asteroids are based on THOLEN and BARUCCI (1989). Because of obscuration by the telluric atmosphere, the telescopic reflectance observations do not include the region around 2.7 μm. This is the important region where minerals containing structural or adsorbed water can be distinguished.

3.3. Comparison between CR2 chondrites and asteroids

We have compared reflectance spectra of newly studied CR2 chondrites with those of 8 selected asteroids. Shown in Fig. 4 are the closest spectral matches. As was reported by SATO *et al.* (1997), spectral shapes of asteroid 2 Pallas and Renazzo are in excellent agreement in the wavelength region near 3 μm. In addition, although the quality of telescopic spectral data for 511 Davida is lower than that of Pallas, the overall spectral profile of 511 Davida also exhibits similarity to the Renazzo spectrum.

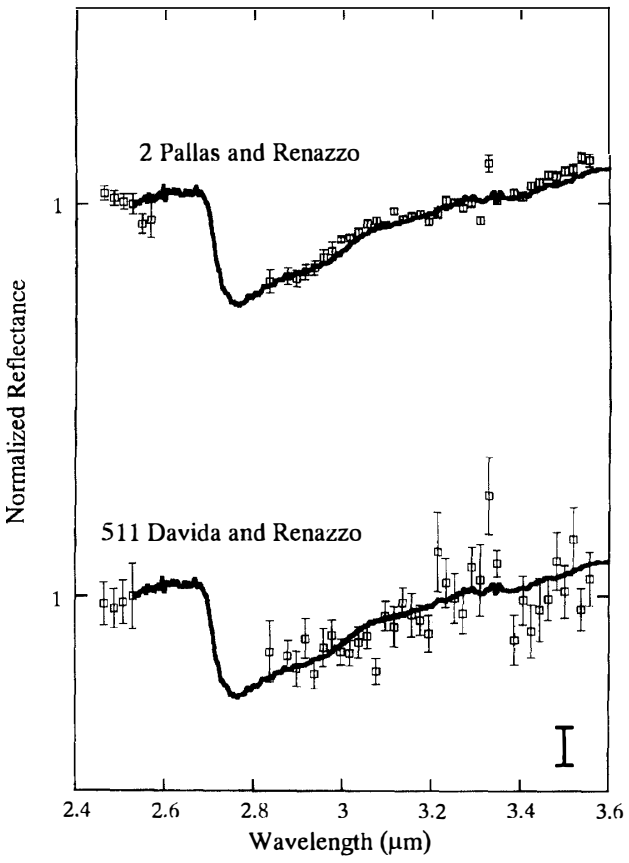

Fig. 4. Asteroid-meteorite counterparts that have similar reflectance profiles. Open squares: Telescopic reflectance spectra of asteroids. Solid curves: Diffuse reflectance spectrum of Renazzo. All spectra are scaled to 1 at 2.53 μm and offset for clarity. The scale bar for 10% is displayed on the lower right side of the figure.

In this study, no asteroid has been found that has an Antarctic CR2 meteorite counterpart. CR2 chondrites from Antarctica show the 3 μm hydration bands which have been deepened and rounded probably by terrestrial weathering. Therefore, it is difficult to compare reflectance spectra near 3 μm of weathered meteorites with those of asteroids directly.

In the wavelength region from 2.4 to 3.6 μm, Pallas and Davida show spectral similarity. But their visible-near infrared reflectance spectra are different each other. As to the proper elements of their orbits, semimajor axis, eccentricity and inclination, these asteroids are separated by two secular resonances. Therefore, Pallas and Davida cannot be considered to be genetically related each other.

4. Conclusions

We examined the spectral profiles of the absorption bands near 3 μm of the Antarctic CR2 chondrites, Renazzo and the asteroids which belong to C, G, B and F taxonomic classes. The result is as follows: (1) The spectral absorption near 3 μm of the Antarctic CR2 chondrites are more intensive and round compared to that of Renazzo. The difference in spectral profiles between Antarctic CR2 chondrites and Renazzo implies the presence of corrosion products probably due to terrestrial weathering of the Antarctic CR2 chondrites. (2)In addition to an excellent agreement between asteroid 2 Pallas and Renazzo, the overall spectral profile of asteroid 511 Davida also exhibits similarity to the Renazzo spectrum.

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