# AN ATTEMPT TO REDUCE THE EFFECTS OF BLACK MATERIAL FROM THE SPECTRAL REFLECTANCE OF METEORITES OR ASTEROIDS

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***Abstract*:** An attempt to reduce the effects of black materials from the spectral reflectances of meteorites or asteroids was made by using the Kubelka-Munk function with minor modifications. Our reduction method has for its object to make clear the spectral contrast which is suppressed by the effects of the black materials. For this purpose, spectral reflectances (0.25–2.5 $\mu$m) were measured on samples of the Yamato-75258 meteorite (LL6 chondrite) which contain various amounts of black materials (carbon black or magnetite), and their changes with the effects of black materials were examined. Only a few weight percents of the black materials lower the reflectivity and weaken the absorption band strength. On the basis of these reflectance measurements, we tried to construct the spectral reflectance curve by reducing the effects of the black material from that of the Murchison meteorite and to compare the constructed curve with the spectral reflectance of Ceres. The results imply that the material which contains less carbon than the Murchison meteorite, is a better candidate for the surface material of Ceres.

Our method will be a useful one for making the spectral contrast clear, although some problems remain to be solved.

## 1. Introduction

The comparison between the spectral reflectances of asteroids and those of meteorites or various mineral mixtures enable us to interpret the mineral assemblages of asteroidal surface materials and to regard the asteroids as possible meteorite sources (*e.g.* CHAPMANN, 1976; GAFFEY, 1976; GAFFEY and MCCORD, 1977). Their works also revealed that most of the asteroids ($> \sim 80\%$) show very low reflectivity and relatively flat spectra (C, F or T type). These spectral features make it difficult to estimate the mineral assemblages of the surface materials because the absorption bands can not be clearly recognized. It is considered that the spectral reflectances of these asteroids correspond to those of carbonaceous chondrites or carbonaceous chondritic mineral assemblages. For example, although 1 Ceres (or 2 Pallas) resembles spectrally carbonaceous chondrites of various petrologic types, salient differences are noticed between the spectral reflectance of Ceres and those of carbonaceous chondrites, especially in the wavelength region of 0.3–0.6 $\mu$m (*e.g.* GAFFEY and MCCORD, 1978; LARSON *et al.*, 1979).

Low reflectivity and flatness of these spectra seem to be caused by the low reflectance materials contained in the asteroidal surface materials. In order to examine the effects of low reflectance materials on the spectral reflectance of meteorites or asteroids, we carried out spectral reflectance measurements of meteorite samples in which various amounts of low reflectance material (carbon black or magnetite) were mixed. On the basis of these spectral reflectance data, we developed a method to enhance the spectral contrast, which is suppressed by the effects of the low reflectance materials in the spectral reflectance of black meteorites such as carbonaceous chondrites or asteroids (GAFFEY and MCCORD, 1977).

## 2. Method

We use the Kubelka-Munk function with a minor modification. This function gives the relation among absorption and scattering coefficients and reflectance (WENDLANDT and HECHT, 1966).

$$\frac{K(\lambda)}{S(\lambda)}=\frac{(1-R_\infty(\lambda))^2}{2\cdot R_\infty(\lambda)}\equiv f(\lambda), \tag{1}$$

where $\lambda$, $K$, $S$ and $R_\infty$ are wavelength, absorption coefficient, scattering coefficient, and the reflectance of infinitely thick diffusing layer, respectively. We regard $K$, $S$ and $R_\infty$ as being the function of wavelength $\lambda$. This function enabled us to transform the measured reflectance into $K/S$.

We assume that the sample consists of a black material and the matrix (host material). Assuming the additivity of $K$ and $S$ of the individual components (*i.e.* black material and host material) of a mixture, we obtain

$$\begin{aligned} K(\lambda)&=(1-p\cdot C_b(\lambda))\cdot K_h(\lambda)+p\cdot C_b(\lambda)\cdot K_b(\lambda),\\ S(\lambda)&=(1-p\cdot C_b(\lambda))\cdot S_h(\lambda)+p\cdot C_b(\lambda)\cdot S_b(\lambda), \end{aligned} \tag{2}$$

where $C_b$ is the 'effective' concentration of the black material per unit weight, $p$ is a parameter which corresponds to the amount of the black material, $b$ and $h$ denote black material and host material, respectively. Generally, the Kubelka-Munk function does not hold in the region of low reflectance. In order to try to correct this deviation, we regard $C_b$ as being the function of wavelength $\lambda$. Namely, $C_b$ is the 'effective' concentration of black material at every wavelength $\lambda$. We try to determine the value of $C_b$ at every wavelength $\lambda$.

Because the scattering coefficient $S_b$ of black material is considered to be very small, substituting eq. (2) for eq. (1) under assumption $S_b=0$, we obtain (KORTÜM, 1969)

$$\begin{aligned} f(p,\lambda)&=\frac{K_h(\lambda)}{S_h(\lambda)}+\frac{p\cdot C_b(\lambda)}{1-p\cdot C_b(\lambda)}\cdot\frac{K_b(\lambda)}{S_h(\lambda)}\\ &\equiv f(0,\lambda)+A(p,\lambda). \end{aligned} \tag{3}$$

The reflectance of the host material can be transformed into $K_h/S_h$ by using eq. (1). Namely, $f(0, \lambda)$ and $f(p, \lambda)$ correspond to the reflectance of the sample without black material and that of the sample containing black material, respectively. We regard $A(p, \lambda)$ as the effects of black material. Because eq. (3) contains three unknown parameters, $p\cdot C_b$, $K_h/S_h$, and $K_b/S_h$ at every wavelength $\lambda$, we can calculate $A(p, \lambda)$ from the spectral reflectance data (transformed by using eq. (1)) observed for at least three different values of $p$. Therefore, we can construct the spectral reflectance curve from that of the sample which contains the black material by choosing a suitable value of $p$ (*i.e.* by reducing the effects of the black material), and make the spectral contrast clear. These calculations were carried out at every wavelength.

## 3. Experimental

The spectral reflectance measurements were made with a Beckman UV 5240 spectrophotometer with an integrating sphere and Halon was used as a standard. The details of the instrumentation are described in MIYAMOTO *et al.* (1981). The spectra were scanned at a constant rate of 0.125 nm/s in the 0.25–0.8 $\mu$m region and a rate of 0.5 nm/s in the 0.8–2.5 $\mu$m region. The spectral data were recorded on a floppy-disc every 1 second in digital form (that is, data were recorded every 0.125 nm in the 0.25–0.8 $\mu$m region and every 0.5 nm in the 0.8–2.5 $\mu$m region), and also on a chart. The program system (PSRAM coded by A. MITO in 1982) for a HITAC-M280H computer was used to process and arrange these spectral data with a graphic display terminal. The slight mismatches in the spectral curves caused by changing detectors, lamps, or filters were digitally corrected.

Samples were placed in a hollow space cut into the blackened holder by a acrylic plastic paint and covered with the same calibrated cover glass as a standard. The cover glass is necessary to allow the samples to be held vertically. The effects of the reflection of the cover glass were corrected digitally by using the spectral reflectance data measured for the cover glass. The incident beam is perpendicular to the surface of the sample.

The Yamato-75258 (LL6 ordinary chondrite) meteorite was supplied by the National Institute of Polar Research (YANAI, 1979). The Murchison (C2 chondrite) meteorite was offered by courtesy of Prof. C. B. MOORE. Meteorite samples were crushed and ground in a clean agate mortar and sieved to obtain three size fractions, that is, $<1190$ $\mu$m, $<149$ $\mu$m and $<46$ $\mu$m. Olivine crystals (San Carlos, Arizona) was also crushed and sieved to obtain the $<149$ $\mu$m sample. The $<1190$ $\mu$m, $<149$ $\mu$m or $<46$ $\mu$m sample was the sample passed through the 1190 $\mu$m-, 149 $\mu$m- or 46 $\mu$m-sieve, respectively. We abbreviate $<1190$ $\mu$m sample, $<149$ $\mu$m sample or $<46$ $\mu$m sample as CG sample (Coarse-Grained), MG sample (Medium-Grained) or FG sample (Fine-Grained), respectively.

In order to examine the effects of low reflectance materials (black materials) on the spectral reflectance of the meteorite, we mixed the Y-75258 samples with various amounts of carbon black (Koso Chemical Co., SOJ2481) or magnetite (Wako Pure Chemical Industries, Ltd., 093–01035). The mixtures were made by tumble mixing and stirring. The particle size of carbon black and magnetite seems to be smaller than the FG sample of the meteorite. These spectral reflectance data of the Y-75258 samples mixed with black material were used for the reduction of the effects of the black material from the spectral reflectance of the meteorite (Murchison) or asteroid (Ceres).

## 4. Results and Interpretations

### 4.1. *Effects of black material on spectral reflectance*

Figure 1a shows the spectral reflectance curves of the CG samples of Y-75258 mixed with 0, 0.5, 1.5, 2.0 or 2.5 wt% carbon black. In order to examine the spectral reflectance changes, the representative curves normalized to 1.0 at wavelength 0.56 $\mu$m are shown in Fig. 1b. Figure 2a shows the spectral reflectance curves of the FG samples of Y-75258 mixed with 0, 1.0, 2.0 or 5.0 wt% carbon black. Figure 3a shows the spectral reflectance curves of the CG samples of Y-75258 mixed with 0, 1.0, 2.0, 3.0 or 4.0 wt% magnetite. Figure 4a shows the spectral reflectance curves of the FG samples of Y-75258 mixed with 0, 1.0, 2.0 or 5.0 wt% magnetite. On the basis of these spectral reflectance data, the following effects of the black materials (low reflectance materials) on the spectral reflectance of the meteorite (Y-75258) can be observed (Miyamoto *et al.*, 1981; Mito *et al.*, 1981).

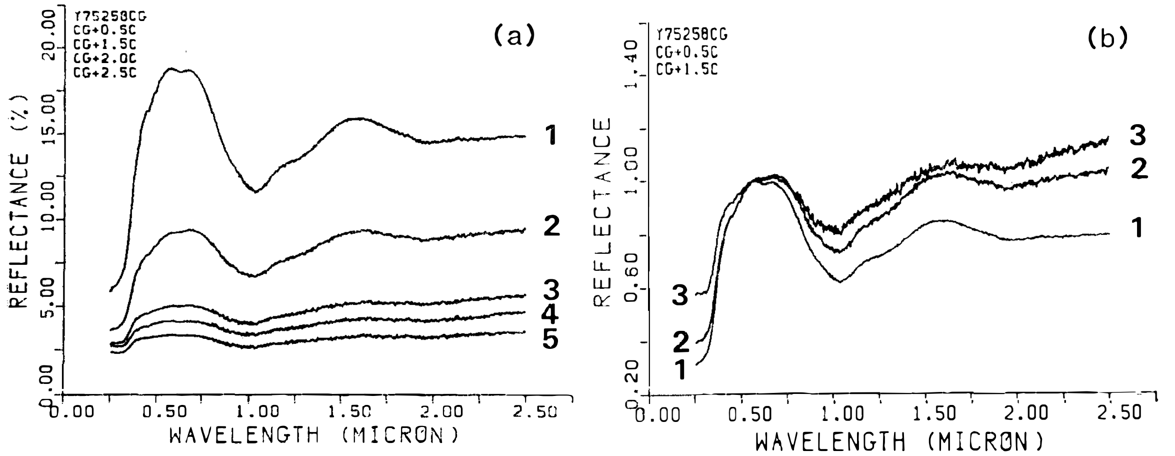


*Fig. 1. Spectral reflectance curves for the <1190 μm samples of Yamato-75258 mixed with different amounts of carbon black (a) and those normalized to 1.0 at wavelength 0.56 μm (b). 1: <1190 μm Y-75258 sample, 2: <1190 μm Y-75258 mixed with 0.5 wt% carbon black, 3: <1190 μm Y-75258 mixed with 1.5 wt% carbon, 4: <1190 μm Y-75258 mixed with 2.0 wt% carbon, 5: <1190 μm Y-75258 mixed with 2.5 wt% carbon.*

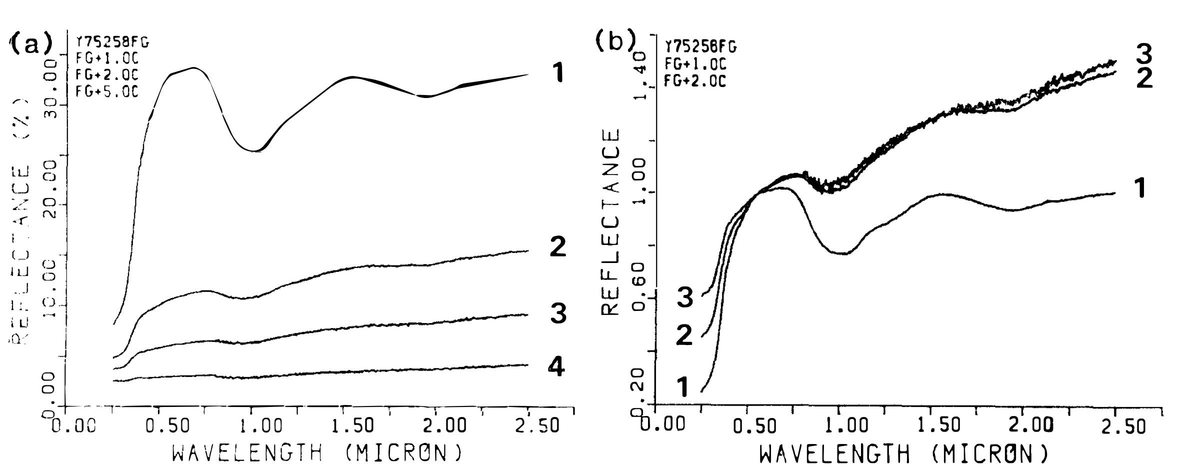


*Fig. 2. Spectral reflectance curves for the <46 μm samples of Yamato-75258 mixed with different amounts of carbon black (a) and those normalized at 0.56 μm (b). 1: <46 μm Y-75258 sample, 2: <46 μm Y-75258 mixed with 1.0 wt% carbon, 3: <46 μm Y-75258 mixed with 2.0 wt% carbon, 4: <46 μm Y-75258 mixed with 5.0 wt% carbon.*

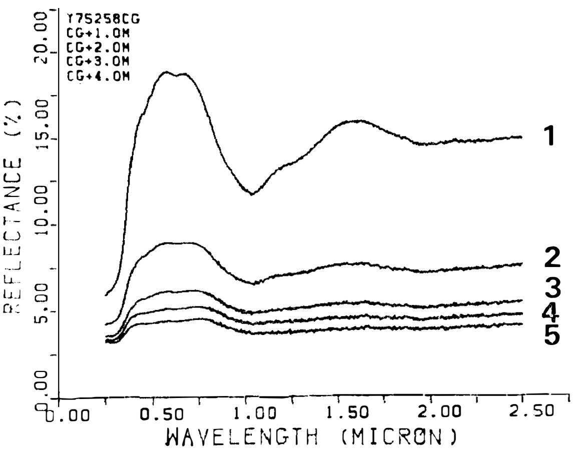


*Fig. 3a.* *Spectral reflectance curves for the <1190 μm samples of Yamato-75258 mixed with different amounts of magnetite. 1: <1190 μm Y-75258 sample, 2: <1190 μm Y-75258 mixed with 1.0 wt% magnetite, 3: <1190 μm Y-75258 mixed with 2.0 wt% magnetite, 4: <1190 μm Y-75258 mixed with 3.0 wt% magnetite, 5: <1190 μm Y-75258 mixed with 4.0 wt% magnetite.*

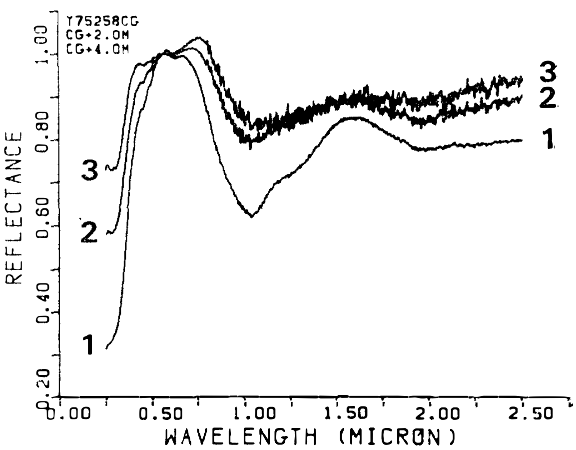


*Fig. 3b.* *Spectral reflectance curves normalized at 0.56 μm. 1: <1190 μm Y-75258 sample, 2: <1190 μm Y-75258 mixed with 2.0 wt% magnetite, 3: <1190 μm Y-75258 mixed with 4.0 wt% magnetite.*

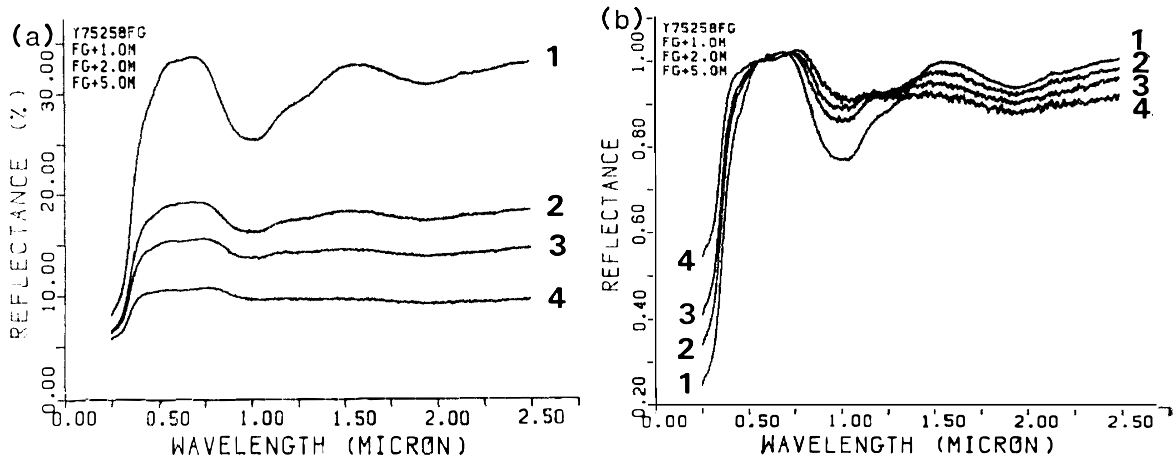


*Fig. 4.* *Spectral reflectance curves for the <46 μm samples of Yamato-75258 mixed with different amounts of magnetite (a) and those normalized at 0.56 μm (b). 1: <46 μm Y-75258 sample, 2: <46 μm Y-75258 mixed with 1.0 wt% magnetite, 3: <46 μm Y-75258 mixed with 2.0 wt% magnetite, 4: <46 μm Y-75258 mixed with 5.0 wt% magnetite.*

(1) Only a few weight percent of the black materials lowers the reflectance and significantly reduces the spectral contrast.

(2) Because the absorption band strength found in wavelength about 1 μm or UV region is weakened by the black materials, the peak at about 0.5 μm is suppressed and the UV drop-off position apparently shifts toward shorter wavelength. Therefore, the reflectance around 0.7 and 0.4 μm is relatively enhanced. As shown in Fig. 5, by pulverizing the sample of Y-75258, the absorption band strength around 1 μm is also

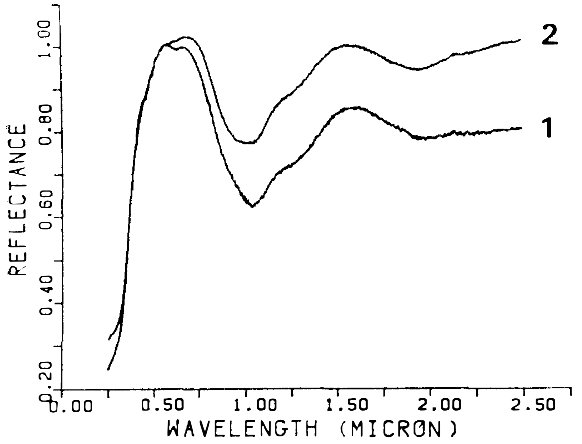


*Fig. 5. Normalized spectral reflectance curves for the <1190 μm (1) and the <46 μm (2) samples of Yamato-75258.*

weakened and the reflectance around 0.7 μm is relatively enhanced. The curvature of the UV drop-off is, however, not influenced very much.

(3) By mixing carbon black, the reflectance in the NIR region increases with increasing the wavelength ('reddening') (Fig. 1b, 2b). Carbon is more effective for 'reddening' than magnetite. It is an interesting result that by mixing magnetite with the FG sample of Y-75258, the reflectance in the NIR region lowers contrary to the 'reddening'.

### 4.2. *Calculation of $A(p, \lambda)$ from spectral reflectance data*

$A(p, \lambda)$ in eq. (3) can be calculated on the basis of the spectral reflectance data measured for the samples mixed with the three different concentrations of a black material. $A(p, \lambda)$ is considered to be dependent on the kind of the black material contained in a sample or the grain-size distribution of a sample. Therefore, we tried to calculate the $A(p, \lambda)$'s for the following cases:

(1) $A^{C}_{CG}$ calculated on the basis of the spectral reflectance data for the CG samples of Y-75258 mixed with 0, 0.5 or 2.5 wt% carbon black.

(2) $A^{C}_{FG}$ from the spectral reflectance data for the FG samples of Y-75258 mixed with 0, 1.0 or 5.0 wt% carbon black.

(3) $A^{M}_{CG}$ from the spectral reflectance data for the CG samples of Y-75258 mixed with 0, 1.0 or 4.0 wt% magnetite.

(4) $A^{M}_{FG}$ from the spectral reflectance data for the FG samples of Y-75258 mixed with 0, 1.0 or 5.0 wt% magnetite. Suffix C and M denote carbon black and magnetite, respectively.

### 4.3. *Check on the reduction of black material*

Before we try to construct the spectral reflectance curve by reducing the effects of a black material from the spectral reflectance curve of meteorites or asteroids, we carried out some checks in order to verify our method of the reduction of the black material. Because $A^{C}_{CG}$ is calculated on the basis of the spectral reflectance data for the CG samples of Y-75258 mixed with 0, 0.5 or 2.5 wt% carbon black (curves 1, 2 and 5 in Fig. 1a), the spectral reflectance data for the CG sample of Y-75258 mixed with 1.5 wt% carbon (curve 3 in Fig. 1a) are not dependent on the $A^{C}_{CG}$. By reducing the effects of carbon by using $A^{C}_{CG}$ from the spectral reflectance curve for the CG sample of Y-75258 mixed with 1.5 wt% carbon (curve 3 in Fig. 1a), we tried to reconstruct the spectral reflectance curve of the CG sample of Y-75258 mixed with 0 wt% carbon (*i.e.* free from carbon) (curve 1 in Fig. 1a). The result is shown in Fig. 6a. The agreement between the two curves seems to be satisfactory. The noisy curve in Fig. 6a is the reconstructed curve because the noises observed in the primary curve (curve 3 in Fig. 1a) are amplified. Because the spectral reflectance data for the FG sample of Y-75258 mixed with 2.0 wt% carbon are independent of the $A^{C}_{FG}$ in the same manner as the $A^{C}_{CG}$, we reconstructed the spectral reflectance curve of the FG sample of Y-75258 mixed with 0 wt% carbon

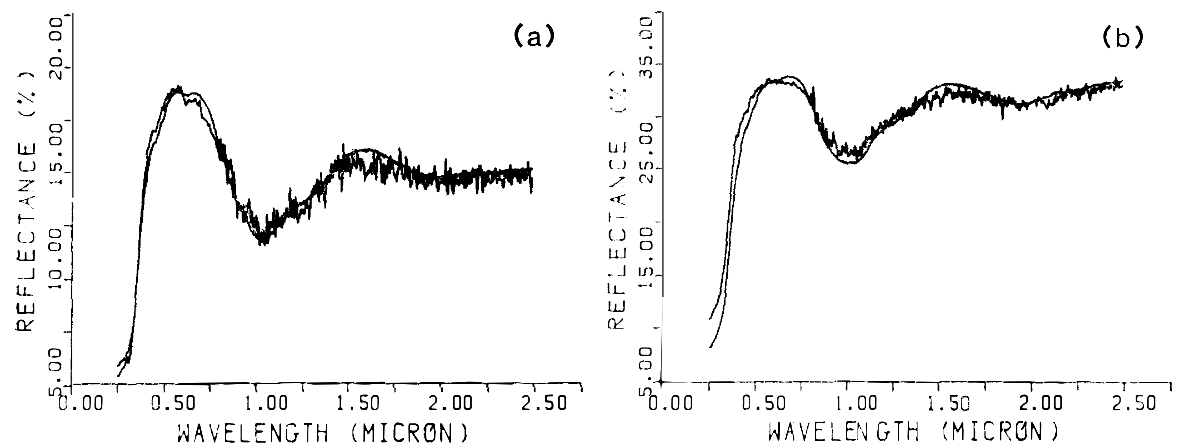


*Fig. 6. The reconstructed curves (noisy curves) by reducing the effects of carbon (a) from the spectral reflectance curve for the <1190 μm sample of Y-75258 mixed with 1.5 wt% carbon (curve 3 in Fig. 1a) by using the $A^{C}_{CG}$, and (b) from the spectral reflectance curve for the <46 μm sample of Y-75258 mixed with 2.0 wt% carbon (curve 3 in Fig. 2a) by using the $A^{C}_{FG}$. The smooth curves are (a) for the <1190 μm sample of Y-75258 mixed with 0 wt% carbon and (b) for the <46 μm sample of Y-75258 mixed with 0 wt% carbon.*

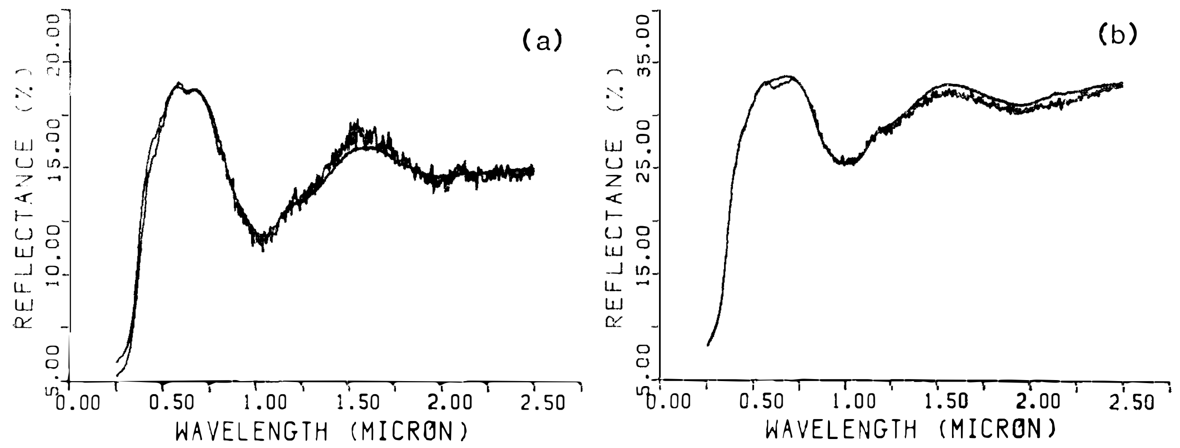


*Fig. 7. The reconstructed curves (noisy curves) by reducing the effects of magnetite (a) from the spectral reflectance curve for the <1190 μm sample of Y-75258 mixed with 2.0 wt% magnetite (curve 3 in Fig. 3a) by using the $A^{M}_{CG}$, and (b) from the spectral reflectance curve for the <46 μm sample of Y-75258 mixed with 2.0 wt% magnetite (curve 3 in Fig. 4a) by using the $A^{M}_{FG}$. The smooth curves are (a) for the <1190 μm sample of Y-75258, and (b) for the <46 μm sample of Y-75258.*

by reducing the effects of carbon on the basis of $A^{C}_{FG}$ from the spectral reflectance curve for the FG sample of Y-75258 mixed with 2.0 wt% carbon (curve 3 in Fig. 2a). The result is shown in Fig. 6b. Similar reconstructions were made of both the CG and FG samples of Y-75258 mixed with magnetite (Figs. 7a, b). In either case the agreement between the reconstructed curve and the sample free from black material seems to be satisfactory.

To examine the variations of $A(p, \lambda)$ caused by the difference of the grain-size distribution of the host material (Y-75258), we tried to reconstruct the spectral reflectance curve of the CG sample of Y-75258 mixed with 0 wt% carbon by reducing the effects of carbon from the spectral reflectance curve of the CG sample of Y-75258 mixed with 1.5 wt% carbon (curve 3 in Fig. 1a) by using $A^{C}_{FG}$. The slight differences between two curves (Fig. 8a) are found around 0.4 and 0.7 $\mu$m, and in the region of 2.0–2.5 $\mu$m. Figure 8b shows the result of the reconstruction of the CG sample of Y-75258 mixed with 0 wt% magnetite by reducing the effects of magnetite from the CG sample of Y-75258 mixed with 2.0 wt% magnetite (curve 3 in Fig. 3a) by using the $A^{M}_{FG}$. The differences in the degree of the 'reddening' are found in the NIR region.

In these checks, the host material (that is, the Y-75258 meteorite) of the samples from which we try to reduce the effects of a black material is the same as that of the samples free from the black material. In order to carry out further checks on a different host material, we measured the spectral reflectances for the MG samples of olivine mixed with about 2 wt% carbon black (Fig. 9a) or about 4 wt% magnetite (Fig. 9b). We mixed carbon or magnetite with the olivine samples so that the reflectance at wavelength 0.56 $\mu$m of these mixtures shows about 5.4% (*i.e.* that of Ceres). We tried to reconstruct the spectral reflectance curve of the MG sample of olivine mixed with 0 wt% carbon from that of the MG sample of olivine mixed with carbon by reducing the effects of carbon on the basis of the $A^{C}_{FG}$. A similar check was made for the case of

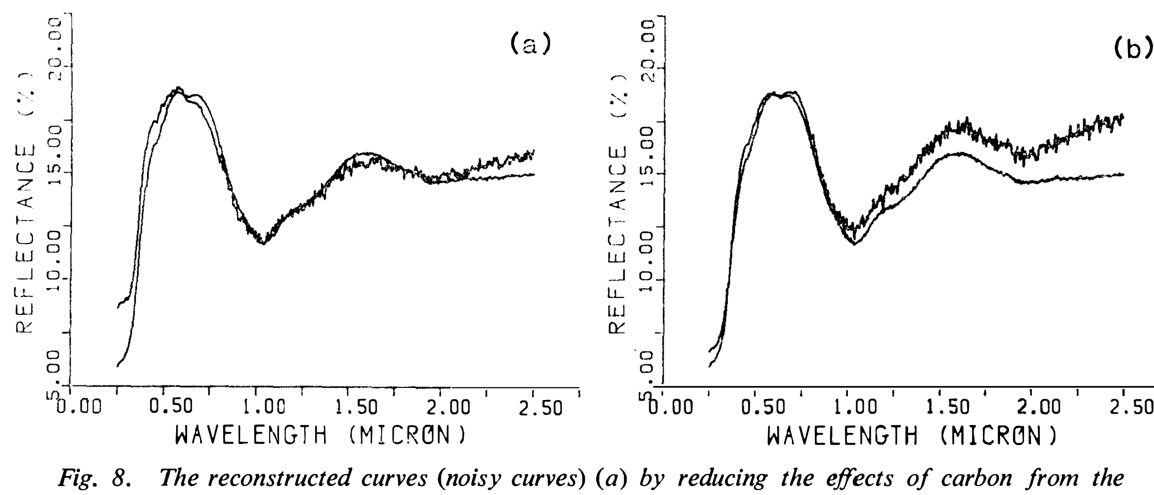


*Fig. 8. The reconstructed curves (noisy curves) (a) by reducing the effects of carbon from the spectral reflectance curve for the <1190 $\mu$m sample of Y-75258 mixed with 1.5 wt% carbon (curve 3 in Fig. 1a) by using the $A^{C}_{FG}$, and (b) by reducing the effects of magnetite from the spectral reflectance curve for the <1190 $\mu$m sample of Y-75258 mixed with 2.0 wt% magnetite (curve 3 in Fig. 3a) by using the $A^{M}_{FG}$. The smooth curves are for the <1190 $\mu$m sample of Y-75258.*

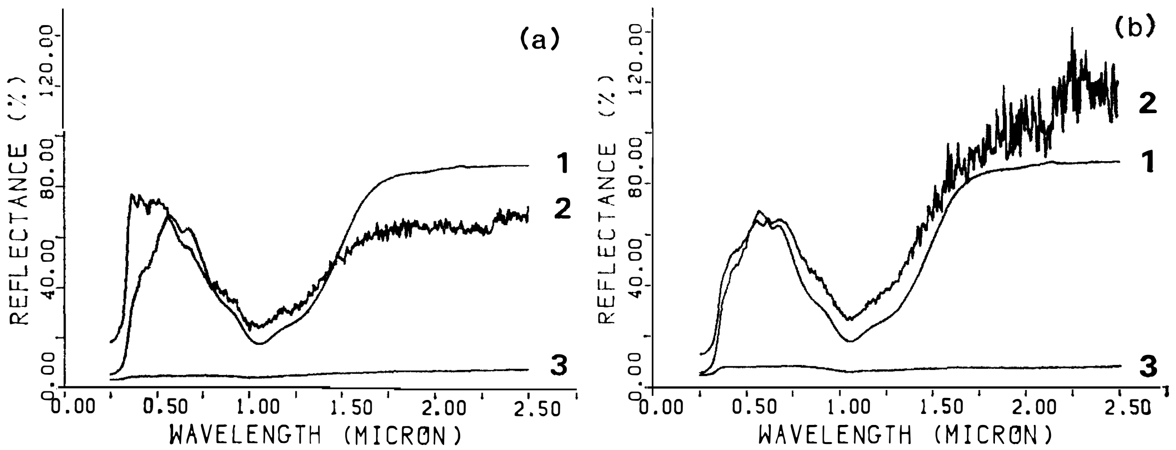


*Fig. 9. The reconstructed curves (noisy curves, 2) (a) by reducing the effects of carbon from the spectral reflectance curve for the <149 μm sample of olivine mixed with about 2 wt% carbon (curve 3) by using the $A^{C}_{FG}$, and (b) by reducing the effects of magnetite from the spectral reflectance curve for the <149 μm sample of olivine mixed with about 4 wt% magnetite (curve 3) by using the $A^{M}_{FG}$. Curves 1 are for the <149 μm sample of olivine.*

magnetite. The results in the case of $A^{C}_{FG}$ and $A^{M}_{FG}$ are shown in Fig. 9. These two reconstruction are extreme cases. The reflectivity of about 5% (curve 3 in Fig. 9) is enhanced up to that of about 70%. The result shown in Fig. 9b seems to be satisfactory. The spectral contrast is recovered to a large extent, although there is disagreement between two curves (curves 1 and 2) in the results of Fig. 9a.

### *4.4. Reduction of black material from the spectral reflectance of the Murchison meteorite*

We tried to apply our method of the reduction of black materials to the spectral reflectance of the Murchison meteorite (C2 chondrite) in order to study the surface material of asteroid Ceres (or Pallas). Figure 10 shows the spectral reflectance curves of the CG and FG samples of Murchison. The spectral reflectance of the FG sample of Murchison shows the 'reddening' compared with that of the CG sample of Murchison. The comparisons between the normalized spectral reflectance of Ceres and those of the CG and FG samples of Murchison are shown in Fig. 11. The normalized spectral

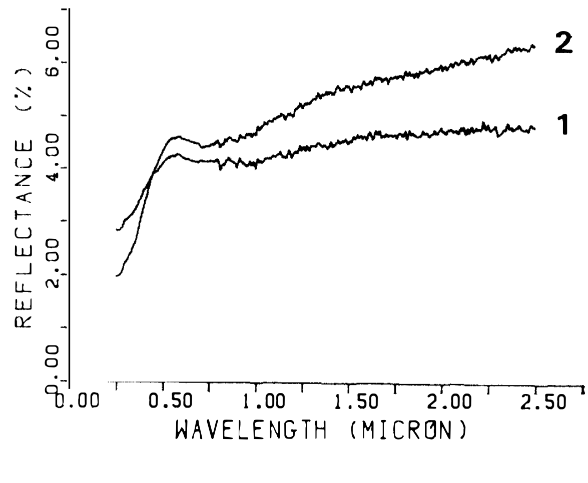


*Fig. 10. Spectral reflectance curves for the <1190 μm sample (1) and the <46 μm sample (2) of the Murchison meteorite.*

reflectance of Ceres are adopted from CHAPMAN *et al.* (1973) in the region of 0.3–1.1 $\mu$m. The 1.25, 1.65 and 2.2 $\mu$m data are from JOHNSON *et al.* (1975). The 0.9–2.5 $\mu$m data are from FEIERBERG *et al.* (1980) for comparison. The following differences in the reflectances between Ceres and Murchison are observed:

(1) The absorption band strength around 0.6 $\mu$m found in Murchison is weaker than that of Ceres. (2) The curvature of the UV drop-off differs from each other. (3) The reflectance of Murchison in the NIR region seems to be too high to compare it with that of Ceres.

The reflectance at wavelength 0.56 $\mu$m of the Murchison meteorite is about 4.2% (Fig. 10), whereas the albedo of Ceres is reported to be about 5.4% (MORRISON, 1977). Therefore, we reduced the effects of carbon black or magnetite from the spectral reflectance of Murchison so that the reflectance of Murchison at wavelength 0.56 $\mu$m shows about 5.4%. By using the $A^{C}_{CG}$ calculated on the basis of the spectral reflectance

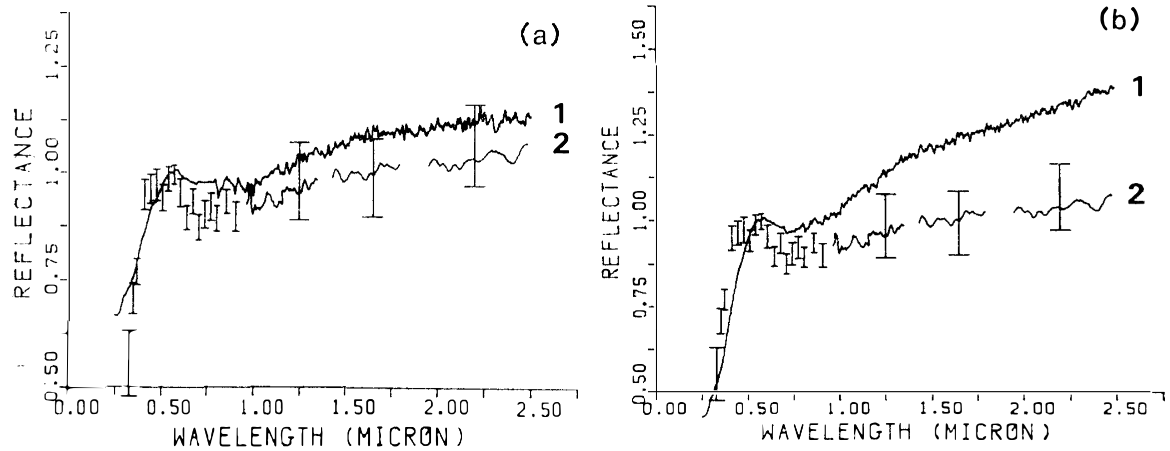


*Fig. 11. Comparisons of the spectral reflectance curves of the <1190 μm sample (a, curve 1) and the <46 μm sample (b, curve 1) of Murchison with that of asteroid Ceres (curve 2). The normalized spectral reflectance data of Ceres (curve 2) are from* CHAPMAN *et al. (1973) in the region of 0.3–1.1 μm. The 1.25, 1.65 and 2.2 μm data are from* JOHNSON *et al. (1975). The 0.9–2.5 μm data are from* FEIERBERG *et al. (1980) for comparison.*

data of the Y-75258 meteorite, the reduction of the effects of carbon was made of the spectral reflectance of the CG sample of Murchison. The constructed (reduced) curve normalized at wavelength 0.56 $\mu$m is shown in Fig. 12a, together with the spectral reflectance of Ceres for comparison. Although the constructed curve shows an improvement in the 1.0–2.5 $\mu$m region in comparison with the reflectance of the CG sample of Murchison (Fig. 11a), the absorption band strength around 1 $\mu$m of the constructed curve remains unimproved. Figure 12b shows the result of the reduction of carbon from the spectral reflectance of the CG sample of Murchison by using the $A^{C}_{FG}$. The constructed curve in the 0.8–2.5 $\mu$m region agrees well with that of Ceres. Although the curvature around 0.6 $\mu$m of the constructed curve is improved compared with that of the CG sample of Murchison, the absorption band strength around 0.7 $\mu$m is still weak. The curvature of UV drop-off of the constructed curve is different from that of Ceres.

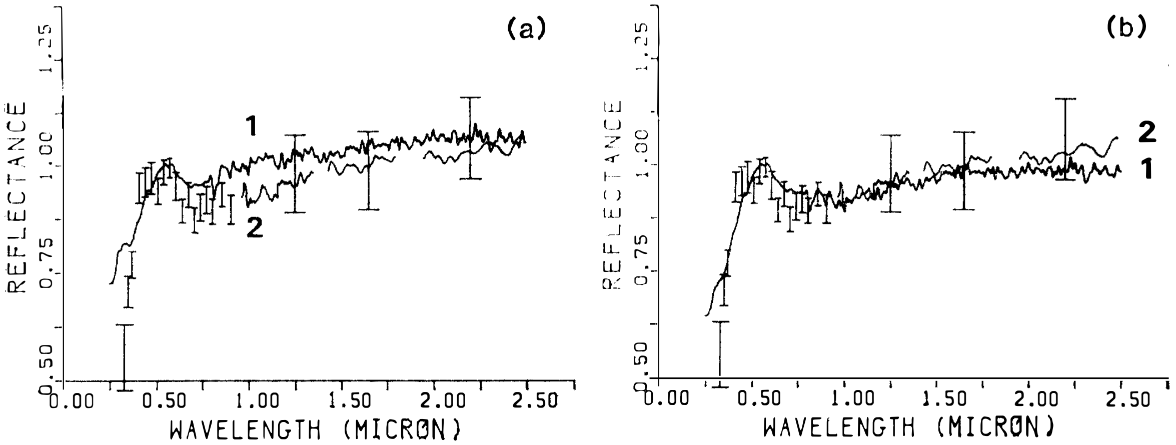


*Fig. 12. Comparisons of the constructed curves by reducing the effects of carbon from the spectral reflectance curve of the <1190 μm sample of Murchison by using the $A^{C}_{CG}$ (a, curve 1) and the $A^{C}_{FG}$ (b, curve 1) with that of Ceres (curve 2).*

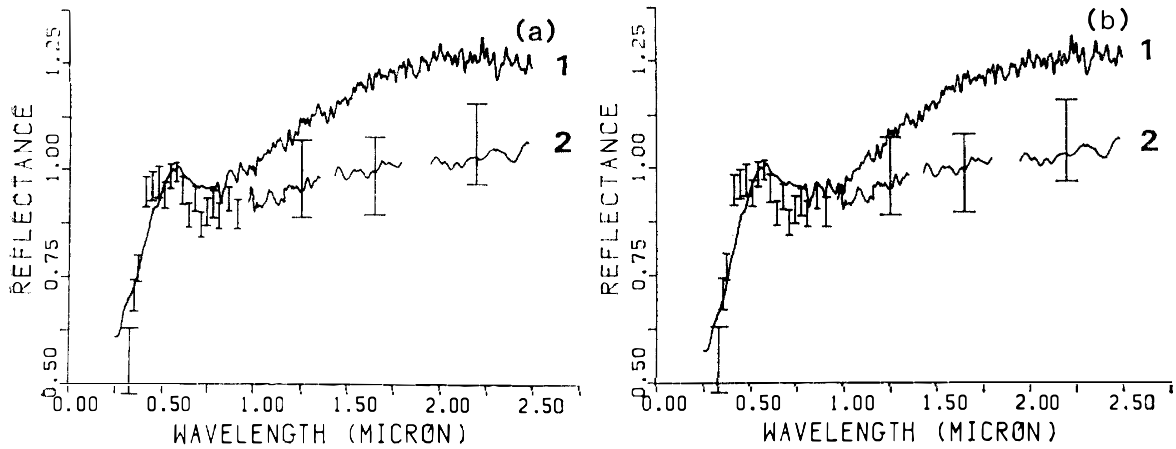


*Fig. 13. Comparisons of the constructed curves by reducing the effects of magnetite from the spectral reflectance curve of the <1190 μm sample of Murchison by using the $A^{M}_{CG}$ (a, curve 1) and the $A^{M}_{FG}$ (b, curve 1) with that of Ceres (curve 2).*

The effects of magnetite was reduced from the spectral reflectance of the CG sample of Murchison by using the $A^{M}_{CG}$ (Fig. 13a) and the $A^{M}_{FG}$ (Fig. 13b). The 'reddening' of the constructed curves in both cases is different from that of Ceres, because the reflectance in the 1.0–2.5 μm region of the constructed curves is enhanced by reducing magnetite.

Similar reductions of the effects of carbon or magnetite from the FG sample of Murchison were also made. The reduction of carbon from the FG sample of Murchison was made by using the $A^{C}_{CG}$ (Fig. 14a) and the $A^{C}_{FG}$ (Fig. 14b). Figure 15 shows the results of the reduction of magnetite from the FG sample of Murchison by using the $A^{M}_{CG}$ (Fig. 15a) and the $A^{M}_{FG}$ (Fig. 15b). In the case of the FG sample of Murchison, the constructed curves by reducing the effects of magnetite show strong 'reddening' compared with that of Ceres.

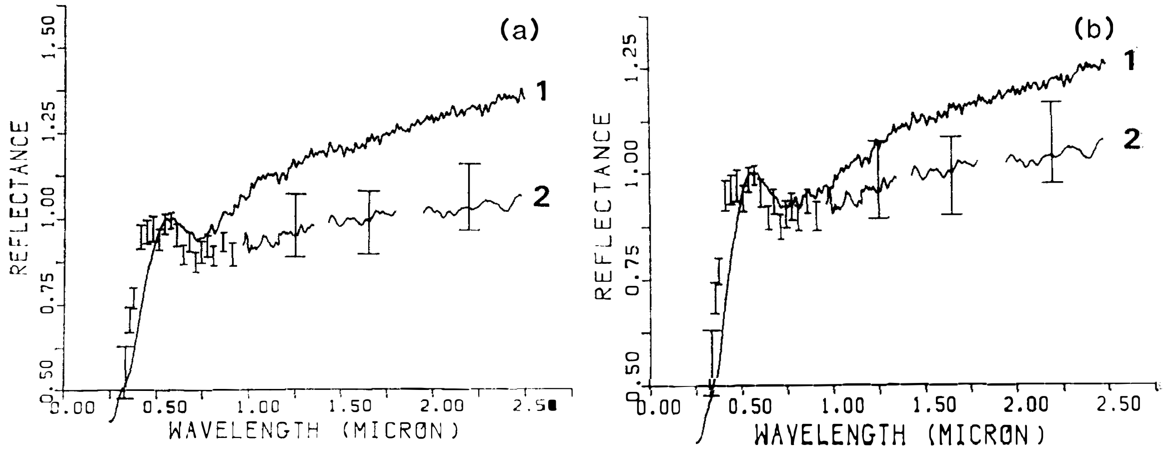


*Fig. 14.* *Comparisons of the constructed curves by reducing the effects of carbon from the spectral reflectance curve of the <46 μm sample of Murchison by using the* $A^{C}_{CG}$ *(a, curve 1) and the* $A^{C}_{FG}$ *(b, curve 1) with that of Ceres (curve 2).*

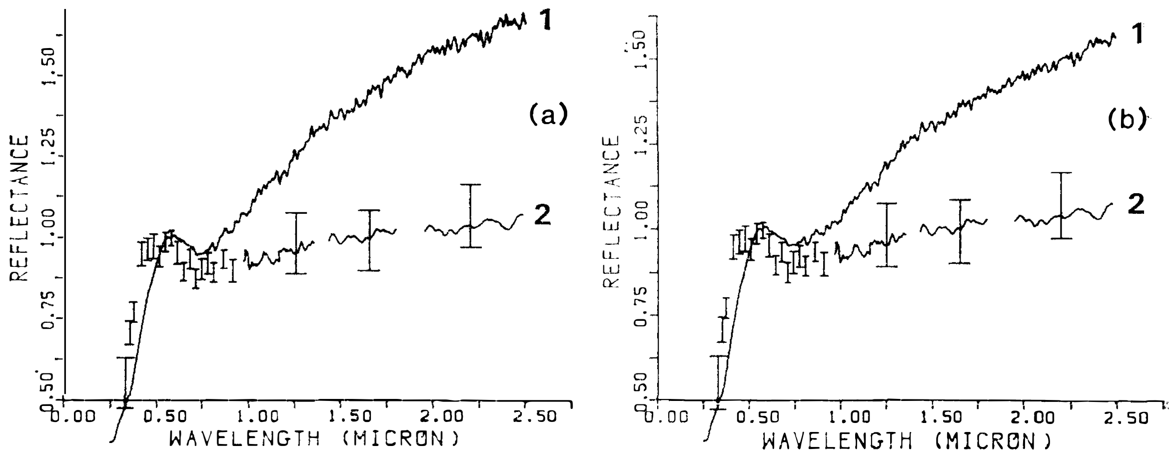


*Fig. 15.* *Comparisons of the constructed curves by reducing the effects of magnetite from the spectral reflectance curve of the <46 μm sample of Murchison by using the* $A^{M}_{CG}$ *(a, curve 1) and the* $A^{M}_{FG}$ *(b, curve 1) with that of Ceres (curve 2).*

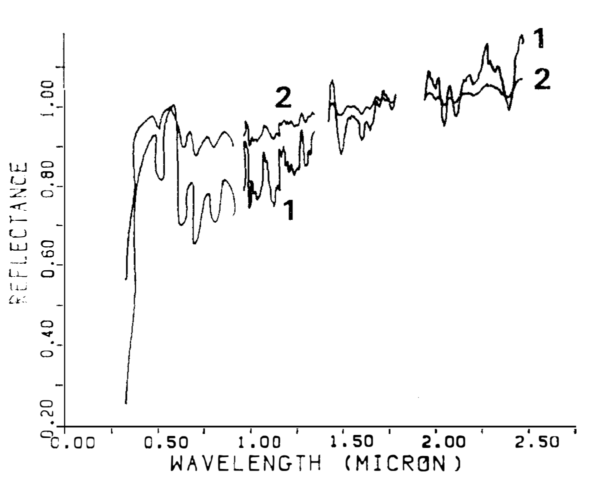


*Fig. 16.* *Comparison of the constructed curve (curve 1) by reducing the effects of carbon from the spectral reflectance of Ceres (curve 2) by using the* $A^{C}_{FG}$*. Each curve is joined by a smooth curve.*

In order to make the spectral contrast clear, we tried to reduce the effects of carbon from the spectral reflectance of Ceres by using the $A^{C}_{FG}$ (Fig. 16). The constructed curve is normalized to 1.0 at wavelength 0.56 $\mu$m for comparison, whereas the reflectivity of the constructed one is about 15–20%, which corresponds to that of ordinary chondrites. In Fig. 16 the measured points in the spectral reflectance of Ceres are joined by a smooth curve to enable comparison with the constructed one.

## 5. Discussions

The deviations from the Kubelka-Munk theory are examined under various conditions (*e.g.* KORTÜM, 1969). When we use the Kubelka-Munk function, it is necessary to take into consideration the applicability of the Kubelka-Munk theory or the assumptions involved in this theory. In our method of the reduction of a black material, the condition that the scattering coefficient of the black material can be assumed to be zero (*i.e.* $S_b=0$) is in favor of the Kubelka-Munk theory (KORTÜM, 1969). In order to try to correct the deviations from the Kubelka-Munk function, we regard not only $K/S$ but also $C_b$ as being the function of wavelength $\lambda$. The $p \cdot C_b$ in eq. (2) is a constant independent of the wavelength determined by a given mixture because it is the concentration of the black material. We, however, consider that $C_b$ is the 'effective' concentration of the black material at a wavelength, and that $p$ is a parameter which is independent of the wavelength and concerned with the concentration of the black material. In other words, $C_b$ is considered to be a correction term for the deviations of the Kubelka-Munk function. In our method three unknown parameters involved in eq. (3) are determined on the basis of the spectral reflectance data measured for three mixtures which contain different amounts of the black material.

The Y-75258 meterorite (LL6 ordinary chondrite) was selected for the sample to examine the effects of carbon black or magnetite on the spectral reflectance because of the following reasons:

(1) The spectral reflectance of this meteorite is little influenced by the oxidized iron produced by the weathering on the earth (MCFADDEN *et al.*, 1980).

(2) This meteorite shows relatively high reflectance among Antarctic ordinary chondrites.

Differences between the effects of carbon black and those of magnetite on the spectral reflectance of Y-75258 were observed (Figs. 1–4). One of the differences is found in the curvature of the reflectance around 0.7 $\mu$m. The 'reddening' caused by carbon found in NIR region is more remarkable than that by magnetite. Conversely, in the case of the $<46$ $\mu$m sample of Y-75258 mixed with magnetite (Fig. 4), the reflectance normalized at wavelength 0.56 $\mu$m decreases gradually with increase of the wavelength. This tendency becomes more pronounced as the amount of magnetite increases. Although these differences between carbon and magnetite seem to be caused by the difference of the nature of these materials, we cannot exclude the possibility that these differences are dependent on the grain-size distribution of these black materials. The grain-size of the black materials used in this study is considerably smaller than that of host material, because it is considered that the grain-size of the 'black material' contained in carbonaceous chondrites is very small. We could not measure the grain-size of the black materials used in this study because of its minuteness. Future study is needed to examine the differences due to the grain-size distribution of a black material in the effects of the black material on reflectances.

MIYAMOTO *et al.* (1981) reported that the curve feature of the UV drop-off around 0.45 $\mu$m is influenced when the particle grain-size of the sample (olivine) is 'very fine-grained' ($\ll$46 $\mu$m). As is shown in Fig. 5, we can see no difference in the curve feature of the UV drop-off in the region of 0.3–0.5 $\mu$m between the CG and FG samples of Y-75258. The curve feature in this wavelength region may be influenced by the amount of 'very fine-grained' particles.

When we calculate the $A(p, \lambda)$ in eq. (3) on the basis of the spectral reflectance data measured for the samples which contain various amounts of a black material, we chose three reflectance curves whose reflectances are different from one another as much as possible. Therefore, one is the reflectance curve for the sample mixed with 0 wt% black material, and another is that for the sample which shows the lowest reflectivity among the all curves measured. In the case of the FG sample of Y-75258 mixed with carbon, the reflectance of the FG sample of Y-75258 mixed with 5.0 wt% carbon (curve 4 in Fig. 2a) seems to be too low to calculate effects of carbon $A^{C}_{FG}$, because of its flatness and experimental error. It is necessary to measure very low reflectance with a high accuracy in order to calculate $A(p, \lambda)$. If one can obtain enough spectral reflectance curves containing various amounts of a black material, it may be advisable to calculate effects $A(p, \lambda)$ of the black material by the least-squares method. As is shown in Fig. 9a, even in such an extreme case as the reflectivity of the original curve increases by a factor 10 and the different host material shows the strong absorption band strength, the absorption band strength of major peaks is reconstructed. There are, however, differences between the spectral reflectance curve of the olivine sample free from carbon and that of the constructed curve by using the $A^{C}_{FG}$. In fact, improvements were made on these differences by using effects of carbon $A(p, \lambda)$ calculated on the basis of the spectral reflectance data for the FG samples of Y-75258 mixed with 0, 1.0 or 2.0 wt% carbon (curves 1, 2 and 3 in Fig. 2a).

As is shown in Figs. 6, 7 and 8, the absorption band strength of the major peaks is well reconstructed except for the minor peaks found in the 0.3–0.9 $\mu$m region. There is a larger difference between the two curves in the 0.3–0.9 $\mu$m in Fig. 6 than that in Fig. 7. This result may be dependent on the difference of the grain-size distribution of the black materials. There is a slight difference in the 'reddening' between the two curves, probably due to the particle-size effects of the host material (Fig. 8b).

The spectral reflectance of asteroid 1 Ceres has been a subject of intensive research (JOHNSON and FANALE, 1973; CHAPMAN and SALISBURY, 1973; MCCORD and GAFFEY, 1974; CHAPMAN *et al.*, 1975; CHAPMAN, 1976; GAFFEY and MCCORD, 1978; LARSON and VEEDER, 1979; LARSON *et al.*, 1979; GAFFEY, 1981). Although it has been considered that the reflectance of Ceres resembles those of carbonaceous chondrites of various petrologic types or carbonaceous chondritic mineral assemblages, its low reflectivity and the flatness of the reflectance curve make the determination of the surface materials difficult. The following reasons are why we tried to reduce the effects of black materials from the spectral reflectances of the Murchison meteorite in order to compare the constructed curve with that of Ceres:

(1) The reflectance at wavelength 0.56 $\mu$m of Murchison (about 4.2%, Fig. 10) is lower than that of Ceres (about 5.4%).

(2) The salient differences are observed between the reflectance of Murchison and that of Ceres in the NIR region, in the absorption feature around 0.6 $\mu$m and in the curvature of UV drop-off.

Among the constructed curves shown in Figs. 12, 13, 14 and 15, the closest agreement between the spectral reflectance of Ceres and the constructed one can be obtained in the case of the reduction of the effects of carbon from the curve of the CG sample of Murchison by using the $A^{C}_{FG}$ (Fig. 12b). There are, however, slight but significant differences between the constructed curve (Fig. 12b) and that of Ceres in the absorption feature around 0.6 $\mu$m and in the curvature of UV drop-off. The absorption band strength around 0.6 $\mu$m seems to be still weak in the constructed curve. The small peak around 0.35 $\mu$m observed in the reflectance of Ceres can not be explained by the reduction of the effects of carbon (Fig. 12b). There is closer agreement between the reflectance of Ceres and the curve constructed by using the $A^{C}_{FG}$ than the $A^{C}_{CG}$. It is considered that the differences between the $A^{C}_{FG}$ and the $A^{C}_{CG}$ are mainly dependent on the grain-size of the host material (Y-75258). Because the absorption band strength seen in the spectral reflectance of the FG sample of Y-75258 (Fig. 2a) is weaker than that seen in the CG sample of Y-75258 (Fig. 1a), the flatness of the reflectance of the host material may be favorable for examination of the effects of a black material and for calculation of $A(p, \lambda)$. The reduction of the effects of magnetite (Figs. 13, 15) makes the reflectance in the NIR region high. Because the reflectance in the NIR region of the FG sample of Murchison (Fig. 11b) is higher than that of Ceres, the differences between the two curves can not be improved by the reduction of the effects of carbon or magnetite (Figs. 14, 15).

In short, the results of our reduction method imply that the material which contains lesser amounts of carbon than the Murchison meteorite is a better candidate for the surface material of Ceres.

Although an attempt (Fig. 16) to reduce the effects of carbon from the spectral reflectance of Ceres was made, the number of the measured points in the visible region seems to be too small to discuss in detail. Our result (Fig. 16) suggests that a strong absorption band exists around 0.7 $\mu$m. It is interesting that the small peak around 0.35 $\mu$m observed in the spectral reflectance of Ceres disappears in the constructed curve by reducing the effects of carbon (curve 1 in Fig. 16) and that the constructed one shows the gentle slope of the UV drop-off.

Such a reduction method of the effects of black material as developed by us will be very useful for making the spectral contrast clear, as development in the accuracy and the number of measured points of the spectral reflectance of asteroids can be expected in the future, whereas our method involves some problems to be solved. For example, $S_b$ may not be approximated as zero (eqs. (2), (3)), when the relation $S_b \ll S_h$ does not hold true (*e.g.* the host material is a hydrated silicate assemblage). It is necessary to study the changes of the '$A$' parameter in eq. (3) with the kinds of host materials and black materials.

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