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UV to far-IR reflectance spectra of carbonaceous chondrites- II. The Cg asteroid spectral class and the plausible link among CV and CK chondrites.

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Abstract

Primitive carbonaceous asteroids are among the darkest objects in our solar system, being the target of future sample-return missions like e.g. Hayabusa 2 and OSIRIS-REx. So far the carbonaceous chondrites arrived to our planet are the only available samples representing these asteroids. The identification of the parent body of each chondrite group is a complex puzzle that requires gain insight into the mineralogy, and physico-chemical processes occurred in space to these undifferentiated bodies. Among the carbonaceous chondrites we concentrate here in the reflective properties of two groups that are chemically related and form the so-called CV-CK clan. We present CK reflectance data that is consistent with a separated evolutionary pathway from CV chondrites. Current data supports a scenario in which the CV and CK chondrites formed in a common parent asteroid that was disrupted by collisions at an early stage of its evolution. Then, at least two asteroid fragments evolved separately and ended with dinstinctive grades of metamorphism.

1 Introduction

Most meteorites arrived to Earth are samples of asteroids that can be studied in our laboratories at zero delivery cost. Despite the different size scales between an asteroid and a meteorite, the latter share compositional and reflectance properties with their parent bodies because they were part of them. In consequence, the undifferentiated chondritic meteorites have proven to be good proxies to understand the properties of chondritic asteroids. While we can study meteorites on the ground with laboratory experiments, the properties of an asteroid are often inferred from remote sensing. Significant differences arise, not only because of the different scale, but also due to the space weathering processes that alter asteroids in the interplanetary medium. After 4.5 Ga of asteroidal evolution, a meteoroid released from a parent body can attain a favorable orbit to produce surviving meteorites.

Recovered specimens show the diversity and heterogeneity of chondritic asteroids, and provide key information about the physical processes they experienced during the history of the solar system. Laboratory reflectance spectra of differentiated meteorites can be used to identify the rock-forming materials of asteroids ([4] and [12]).

The CK group defined by [8] has close compositional and textural relationship with the CV chondrites, but they are distinguishable from one another by their refractory lithophile abundances and other compositional features [14], e.g. the refractory inclusions abundances and the presence of igneous rims around chondrules. CKs are the most oxidized extra-terrestrial rocks found so far, owing to their low abundance in Ni and Fe and their high content of fayalite and magnetite [5]. There is a hypothesis that the CKs were formed from CVs after impacts and high temperatures, and these processes made them aqueously altered and annealed [14]. Such a working scenario implies an evolutionary processing of CKs and suggests that each specimen available in meteorite collections should exhibit gradational differences with significant consequences for their reflectance spectra. In order to test that collisional scenario, a significant number of CKs and CVs samples are needed. Fortunately, the last decades have seen the recovery of a significant number of CKs discovered in Antarctica, and with scarce terrestrial weathering that make them good to test spectroscopically probable links with their parent asteroids.

Consequently, as the goal of this paper, we use CK meteorite reflectance spectra to describe specified spectral features that can be used to identify the parent bodies of this chondrite groups in remote observations. On the other hand, as CK chondrites have experienced different degrees of metamorphism, we think that their reflective behavior might help to establish asteroidal evolutionary patterns.

2 Instrumental Procedure

We have obtained the reflectance spectra of several CK carbonaceous chondrites from the NASA Antarctic collection (Table 1) by using the experimental setup described by [13]. A Shimadzu UV3600 UV–Vis–NIR spectrometer is used to obtain reflectance spectra of thick and thin meteorite sections as in our previous work. The standard setting for the spectrometer is an integrating sphere (ISR) with a working range 0.18–2.6 μm, but working in laboratory conditions the signal is too noisy beyond about 2 μm.

The spectrometer light originates from one of two lamps and passes through a variable slit, then is filtered with a diffraction grating to select the desired wavelength and afterwards is split into two alternating but identical beams with a chopper. Next the beam interacts with the sample and is routed to the detector. The reference beam interacts with the material and then goes to the same detector. Inside of the ISR is coated with a duraflect reflecting polymer [13].

Table 1: Meteorite specimens from which reflectance spectra were obtained here.

CK samples
CK4 ALH 85002
CK4 LAR 04318
CK4/5 PCA 82500
CK5 LAR 12265 thin
CK5 LAR 12265 thick

3 Results and Discussion

The reflectance spectra obtained in this work for CK4 and CK5 were averaged in Fig. 1. We have compared our mean reflectance spectra for Cg asteroidal reflectance class by using the Bus-DeMeo Taxonomy Classification. We used the average data of CK spectral reflectance and normalized them at 0.65 μm. The spectra obtained with this spectrometer always show two instrumental peaks (one from 1.4 to 1.6 μm and the other from 1.9 to 2.2 μm) and noises between $\sim$0.8 and 0.9 μm. We used thin ($\sim$30 μm) and thick (mm) meteorite sections to obtain the spectra. The spectra presented here cover a wide range (0.4 to 1.9 μm) to be compared with asteroids spectra taken from ground or space-based telescopes. In the following discussion we compare our CK data with those published by [3].

The most common mineral in CK chondrites is olivine. It exhibits an absorption feature centered near 1.06 μm that can be seen in Fig.1 [3]. With increasing Fe^{2+} content, the center of this absorption band moves to longer wavelengths, becomes deeper and darker by increasing the overall reflectance (see e.g. [9]). In our data the olivine band extends between 0.95 and 1.15 μm (see Fig. 1). Plagioclase feldspar is a minority phase in CK silicates that may exhibit a weak Fe absorption band near 1.20 μm ([1]), which appears weakly in our spectra.

Table 2: Comparison between the CK spectral properties of the data in [3], NASA Relab Spectrum and our data. Wavelenghts (μm)

Wavelengths	Wavelengths ([3])	Wavelengths Relab	Minerals
0.6,0.90 - 1.10, 1.95-2.15	0.65,0.95,2.0 – 2.10	-	FeO and Fe_2O_3 contents
0.6,0.9 - 1.1,1.27-1.3	0.6 - 0.7,1.06,1.25	0.7,1.05	Olivine
0.6 - 0.7,0.8 - 0.9,1.25	0.65, 0.9, 1.25	1.35	Plagioclase Feldspar
0.98 - 1.05	1.0	1.03	Magnetite
2.05 - 2.15	2.1	-	Fassaite

The presence of pyroxene may be located at 2 μm band, varies from 1.80 to 2.08 μm for low -Ca pyroxenes, and 1.90–2.38 μm for high–Ca Pyroxenes [3]. Our CK spectral data shows an unusual increase, but still shows this band around 1.85 μm. Basically, the pyroxene has a minimal effect on the olivine band positions in CKs than other CCs [2].

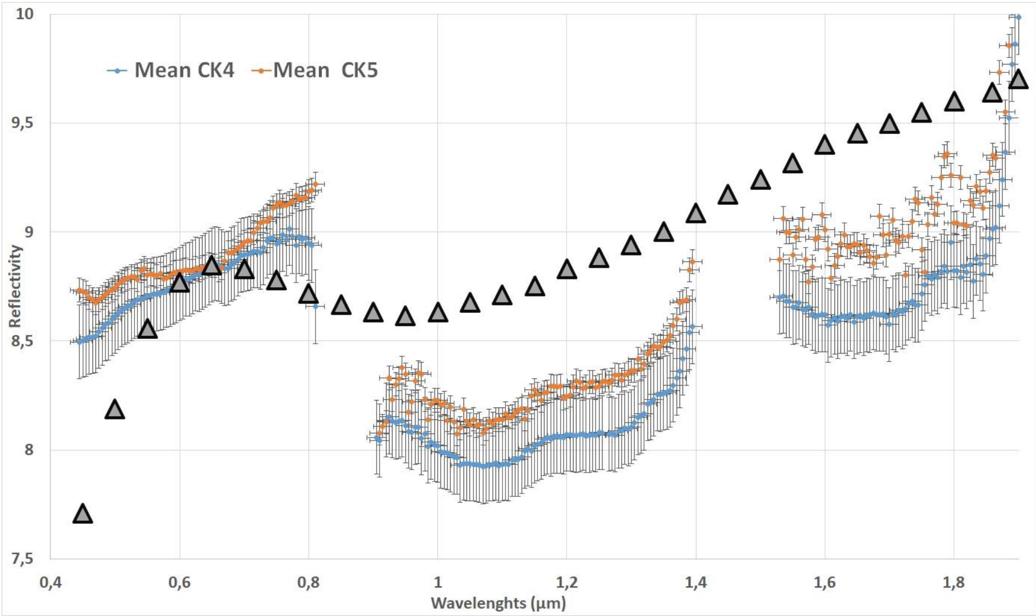

Figure 1: Reflectance averaged spectra of CK carbonaceous chondrites. The gaps are regions in which the spectrometer data show noises artifacts or were removed.

The spectral shape of the magnetite is a function of grain size and location [10] which can be seen near 1 μm. In our CK spectra, the location of this band vary from 0.98 to 1.05 μm depending on the specimen analyzed. We also noticed that other minor phases associated with refractory inclusions can be weakly featured as well, being fassaite, the most common mineral forming Ca- and Al- rich Inclusions (CAIs), the best example.

To discuss the main features observed in these spectra we focus on the main minerals forming CK chondrites. These are olivine, magnetite, Fe-sulfide, pyroxene (both low and high Ca), plagioclase feldspar, refractory oxides forming CAIs and minor amounts of carbonaceous phases [3]. As previously noted, the CKs and CVs are the only CC groups that have undergone thermal metamorphis to a significant extent [7]. Their petrologic type is suggestive of them experiencing impacts that promoted recrystallization, crushing, and aqueous alteration. Most of the CK chondrites experienced metamorphism and aqueous alteration, so these processes altered the rock-forming minerals and their reflectance properties.

Some authors have measured isotopic compositions in specimens of CV and CK chondrites precisely and found that many petrographic properties of these meteorites are nearly similar [6]. They suggested that CV and CKs come from the same reservoir but can be distinguishable by the level of experienced thermal metamorphism [14]. Fig. 1 compares the average reflectance spectra of two petrological types of CKs with increasing metamorphism. It shows that high-metamorphosed specimens have higher reflectances.

We have noticed in the CK spectra that the center of the absorption bands does not change with the metamorphic grades, but correlate with the olivine composition. The depth of bands also increases as the thermal metamorphism does and the deepest band depth is

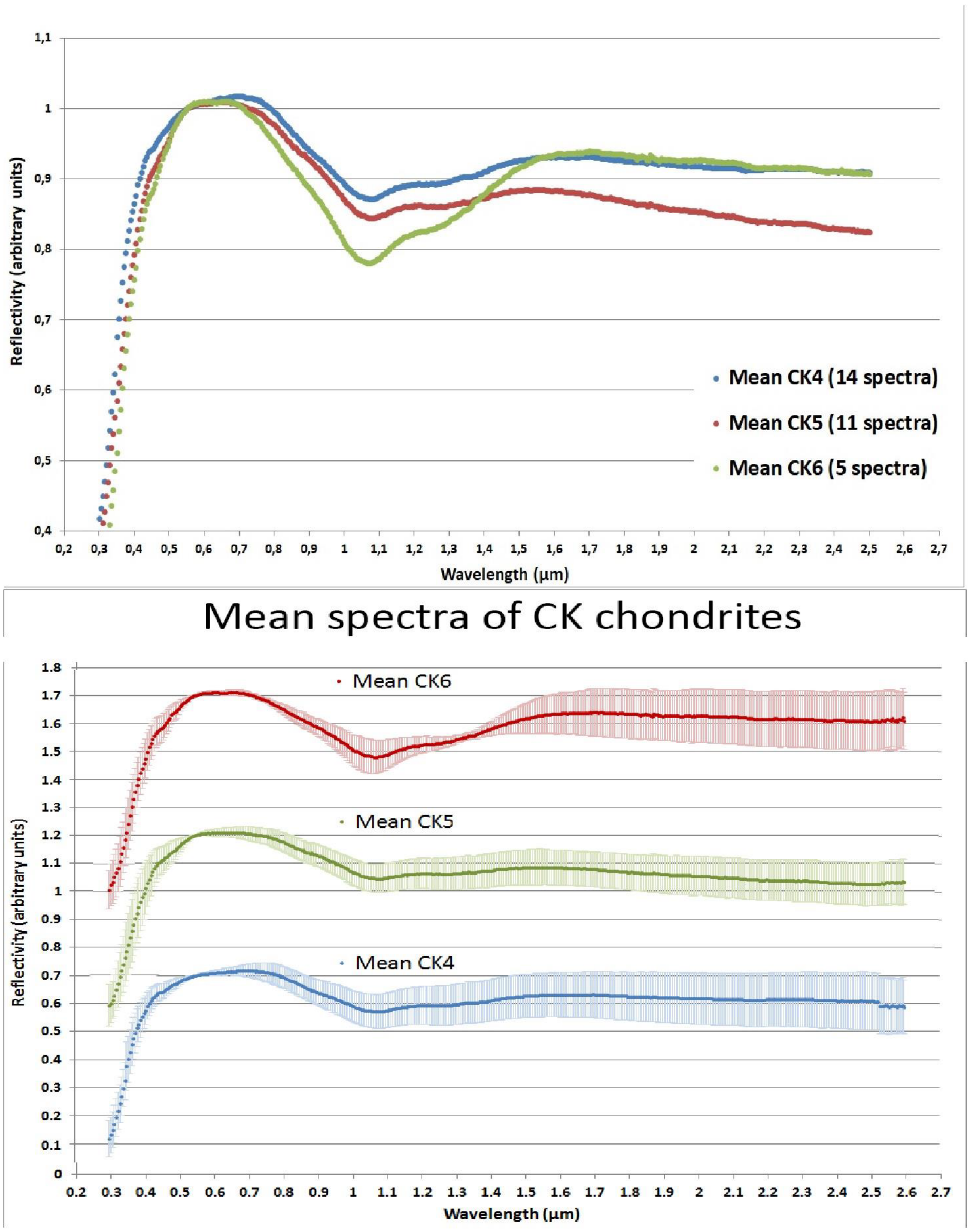

Figure 2: The mean spectral reflectance for CK4, CK5 and CK6 petrological types including the dispertion band. A total of 14, 11 and 5 spectra were plotted respectively [11].

shown in CK6 spectra Fig. 2.

We have compared our mean reflectance spectra in the range of 0.4–1.9 μm with Cg asteroidal reflectance class by using the Bus-DeMeo Taxonomy Classification. We noticed that a higher degree of metamorphism in CV-CK chondrites decreases the reflectance in the NIR that differs from Cg asteroid class. As metamorphism and aqueous alteration were followed by the formation of secondary minerals, their effect on the impact darkening in CV-CK chondrites in one of the main interest of Hayabusa 2 mission, which will return samples from the rare Cg-type asteroid (162173) Ryugu. Indeed, Cg-type asteroids, could be considered a good match for CK meteorites but differs in the NIR.

4 Conclusions

The plausible correlation between CV and CK reflectance spectra and their similar chemical compositions indicate that they could have a common parent body that was broke apart long time ago. Different parts and fragments were taken apart by non-gravitational forces and led to asteroids with different degree of space weathering, aqueous alteration and thermal metamorphism. Then, our study of the reflectance spectra of CK chondrites brought us to reach the following conclusions:

- We have found a common behavior in CK chondrite reflectance spectra. With increasing metamorphic grade, the reflectance decreases in a deeper 1 μm region absorption feature. In fact, higher petrographic degree is consistent with higher reflectivity.

- The band depth of olivine in CKs increases while the thermal metamorphism increases: the CK4–5.5 petrographic grades of meteorites display shallower band depths, while the CK6 spectra exhibit the deepest band depths.

- The best strategy to explain the mentioned differences between CV and CK chondrites is invoking a common parent body, that experienced fragmentation in an early stage of its evolution. Then at least two asteroid fragments evolved separately so they ended with distinctive grades of metamorphism.

- The parent body of CK chondrites has experienced significant collisional processing that ended in distinctive mineralogy and buck chemistry because of thermal annealing.

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