Thermal metamorphic history of Antarctic CV3 and CO3 chondrites inferred from the first- and second-order Raman peaks of polyaromatic organic carbon

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ABSTRACT

Parent body thermal metamorphism is an important process that alters the structure of organic matter in the parent asteroid of meteorites. Increasing and progressing thermal metamorphism results in carbonization and graphitization of carbonaceous matter in the parent body. Such modifications in the carbon structures can be studied by Raman microspectroscopy, thanks to its high sensitivity to structure and bonding within carbonaceous molecules. We have characterized polyaromatic carbonaceous matter in a total of 24 Antarctic CV3 and CO3 chondrites using micro-Raman imaging spectroscopy in an effort to better understand parent body thermal metamorphism and assess its effects on the carbon structures. Raman spectral parameters of the first-order carbon peaks (D and G) were extracted from at least 200 spectra for each meteorite and were compared to deduce relationships that yield information regarding the thermal metamorphism conditions. We also show, for the first time, spectral trends and relations of the second-order carbon peaks (2D and D+G) within the 2500–3200 cm⁻¹ with thermal metamorphic history. The second-order peaks appear to contain information that is lacking in the first-order peaks. Based on the second-order carbon peak parameters, we tentatively classify four CV3 chondrites into subtypes, and reclassify another. Peak metamorphic temperatures of the investigated meteorites have been estimated based on the width of the D band as well as the calculated Raman spectral curvature. Estimated temperatures appear to correlate well with the assigned petrologic types. We have calculated higher peak metamorphic temperatures for the CV3 chondrites than for the considered CO3 chondrites and further showed that the peak metamorphic temperatures of CV3 subtypes are higher than those of CO3 subtypes, indicating possibly different metamorphic conditions for the two oxidized subtypes. We observe that there is a relatively larger temperature increase going from CO3.2 to CO3.4 (150 °C increase) compared to CO3.4–CO3.6 (20 °C), which may indicate that the graphitization and structural ordering of carbon reach a critical temperature regime around petrologic type CO3.3.

Keywords: Carbonaceous chondrites, organic matter, Raman spectroscopy, thermal metamorphism; Origins of Our Solar System and Its Organic Compounds

INTRODUCTION

Secondary processes such as aqueous alteration and thermal metamorphism take place on the parent asteroids of chondrites, and, as a result, the asteroidal compositions and components are subsequently modified at varying scales and intensities (Brearley and Jones 1998; Krot et al. 2003; Huss et al. 2006). Thermal metamorphism is a relatively minor effect in carbonaceous chondrites with petrologic type 1 and 2, although these meteorites experienced sufficient heating to mobilize water, which in return initiated the aqueous alteration. Type 3 carbonaceous chondrites escaped elevated temperatures in the parent body that would potentially equilibrate the chemical compositions, however, they still reached relatively higher temperatures than type 1 and 2 chondrites, which caused a wide range of compositional modifications, including thermal processing of the organic matter (Brearley 2006; Huss et al. 2006) On the other hand, type 4, 5, 6, and 7 carbonaceous chondrites experienced even higher temperatures such that their composition has been equilibrated (Ashworth 1980; Kessel et al. 2007).

Some chondrites, especially carbonaceous chondrites, contain up to 4 wt% organic carbon in the form of soluble and insoluble organic matter, the latter comprising about ~80% of the total organic carbon (Remusat 2014). Secondary processes such as thermal metamorphism, aqueous alteration, brecciation, and impact shock can modify the organic content of chondrites (Botta and Bada 2002; Pizzarello et al. 2006). For instance, organic carbon in carbonaceous chondrites include polyaromatic macromolecular organic carbon, whose structures are sensitive to heating (i.e., thermal metamorphism) and elevated temperatures make them more graphitic (Busemann et al. 2007; Cody et al. 2008) Because carbonaceous chondrites are not differentiated, signatures of thermal metamorphism are preserved and retained in their chemical content (Scott and Krot 2007), thus opening a path for investigating the asteroidal thermal metamorphism.

Carbonaceous chondrites exhibit a wide range of chemical diversity, and some variations exist as a result of asteroidal sec-