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The Significance of Detecting CO_2 in the NonIce Materials on Airless Bodies

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Abstract

We have investigated the adsorption of CO_2 onto the matrix material from eleven chondritic meteorites at temperatures relevant to the surfaces of airless bodies from the outer main asteroid belt to the icy satellites of Jupiter and Saturn. Measurements were conducted under high to ultra-high vacuum (10^{-7} to 10^{-9} torr) at cryogenic temperatures, ~ 150K. There is a relationship between amount of CO_2 adsorbed and composition of the meteorite matrix material. There is also a variation in the spectral characteristics of the CO_2. The amount of CO_2 does not appear correlated with degree of hydration, but is correlated with the abundance of complex clay minerals in the matrix.

1. Introduction

Carbon dioxide has been discovered in the non ice materials on the icy satellites of Jupiter and Saturn and is a major component of comets, even in the inner solar system. CO_2 is not thermally stable on the surfaces of any of these bodies, except in local cold traps that are not exposed to direct sun, thus the mechanism behind its presence on the illuminated portions of the icy satellites is something of a mystery. Since being first discovered by the Galileo mission, theories for the sequestering process of this CO_2 on icy satellites has ranged from vesicles in minerals [1], radiolytic production within grains [2], to the adsorption of CO_2 outgassing from the interiors of these bodies [3]. We have measured the spectral nature and residence time of CO_2 adsorbed onto various carbonaceous chondrite matrix materials, which we use as analogs to the surfaces of these bodies, as a means to probe this mystery [4]. We have found that different carbonaceous meteorites behave very differently (Figure 1).

2. Results

The carbonaceous meteorite mineralogies indicate a widely ranging thermal history. CI and CM chondrites are more primitive (only low temperature alteration appears present), while CV chondrites show compositions more indicative of greater heating. However, there is not a clear relationship between degree of alteration and propensity for CO_2 adsorption [4]. Instead, there appears two significant trends. CO_2 band depth (taken as a proxy for amount of CO_2 adsorbed given that the samples are all ground to similar grain sizes) trends counter to the Fe^{2+} in tochilinite and serpentine, but trends with Fe^{3+} and possible silicon in those minerals (Figures 2 and 3). These relationships are, however, inconsistent, and we believe are indicators of the actual mechanism behind CO_2 adsorption in these meteorites. Of the meteorites we could find mineralogical information for, those with greater

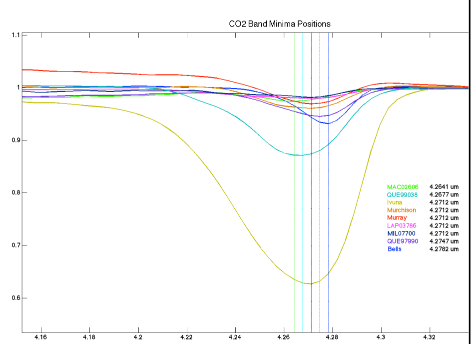

Figure 1. CO_2 band depth and position under vacuum at 150K are dependent on meteorite. The deepest bands are, in order, CI Ivuna, CV QUE99038, CM Bells

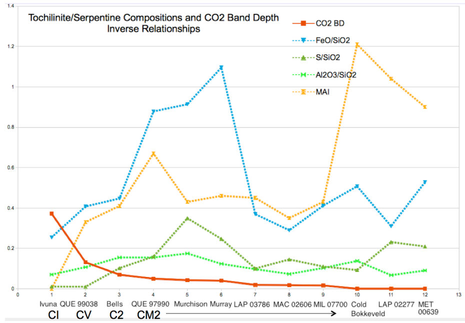

Figure 2. CO_2 abundance is partially inversely correlated with Fe^{2+} abundance. Thick red line is CO_2 band depth. Normalized elemental abundance on y-axis. Meteorite are ordered with descending CO_2 abundance, with class information below the axis.

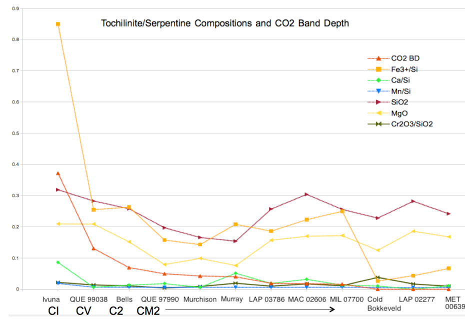

Figure 3. CO_2 abundance is possibly correlated with Fe^{3+} abundance and silicon. Thick red line is CO_2 band depth. Normalized elemental abundance on y-axis. Meteorite are ordered with descending CO_2 abundance, with class information below the axis.

abundance of complex clays – specifically montmorillonite and saponite, as well as ferrihydrite, adsorb greater CO_2. In saponite, substitutions between interlayer cations occur primarily in tetrahedral sites. This is seen as a trend between greater saponite abundances and correlates with greater Al and Si abundances. These cations can provide local charge centers for dipole attraction of CO_2 potentially explaining the raised thermal stability of CO_2 compared to ice, while the large microporosity of complex clays can potentially explain the significant number of molecules that adsorb. Montmorillonite's dioctahedral nature likely provides additional CO_2 adsorption sites despite its lesser abundance than saponite in the CI Ivuna and CV QUE 99038. Adsorption by complex clays would be consistent with previous experiments documenting significant CO_2 adsorption onto clays under vacuum at cryogenic temperatures [5]. However, the CO_2 adsorption may instead be mediated by ferrihydrite, which is a highly porous Fe^{3+} oxyhydroxide. Adsorption onto ferrihydrite could also explain the positive correlation of CO_2 with Fe^{3+} abundance. Experiments will be conducted with ferrihydrite in an attempt to distinguish which of these two mineral classes is most likely responsible for the retention of CO_2 by some carbonaceous meteorites under vacuum at cryogenic temperatures.

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