Extraterrestrial formation of oldhamite and portlandite through thermal metamorphism of calcite in the Sutter’s Mill carbonaceous chondrite

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ABSTRACT

The CM and CI carbonaceous chondrites are typically dominated by phyllosilicates with variable proportions of tochilinite, anhydrous silicates, carbonates, sulfides, sulfates, oxides, and organic compounds. During thermal metamorphism the phyllosilicates dehydrate and decompose yielding water and olivine/enstatite. The thermal transformation of carbonate is less well understood, especially in the presence of volatile decomposition products, such as CO, CO2, SO2, H2S, and H2O. Here is described the mineralogical transformation of calcite (CaCO3) to oldhamite (CaS) and portlandite [Ca(OH)2] during extraterrestrial thermal metamorphism on the Sutter’s Mill parent body. Sutter’s Mill is a regolith breccia consisting of at least two lithologic components: phyllosilicate-calcite-bearing and anhydrous olivine-rich. Evidence suggests that the anhydrous stones were derived from extraterrestrial heating of the phyllosilicate-calcite-bearing material. One of only three Sutter’s Mill stones (SM3) collected prior to heavy rainfall over the recovery site is the focus of this study. Its powder X-ray diffraction patterns are dominated by olivine, with lesser enstatite, Fe-sulfides, magnetite, and oldhamite. Oldhamite is absent in the rained-on stones reflecting its water sensitivity and the pristine nature of SM3. Optical micrographs show whitish to bluish grains of oldhamite and portlandite embedded in dark, fine-grained matrix. The presence of abundant olivine and absence of phyllosilicates, tochilinite, and carbonate indicates that SM3 underwent heating to ~750 °C. At this temperature, calcite would have decomposed to lime (CaO). Volatilization experiments show that CO, CO2, SO2, and H2S evolve from CM and CI chondrites heated above 600 °C. Lime that formed through calcite decomposition would have reacted with these gases forming oldhamite under reducing conditions. Residual lime not converted to oldhamite, would have readily hydrated to portlandite, possibly through retrograde reactions during cooling on the parent body. These reactions have parallels to those in coal-fired electricity generating plants and provide an analogous system to draw comparison. Furthermore, the identification of these minerals, which are sensitive to terrestrial alteration, and determination of their formation is enabled only by the rapid collection of samples from an observed fall and their subsequent curation.

Keywords: Sutter’s Mill, portlandite, oldhamite, dehydration, dehydroxylation, sulfidation, thermal metamorphism, carbonaceous chondrite

INTRODUCTION

Carbonaceous chondrites represent primitive solar system materials with chemical similarities to that of the solar photosphere (Anders and Grevesse 1989). Many of the CM and CI carbonaceous chondrites are water-rich and contain a suite of organic compounds making them central to the study of the origins of life. Investigations of the aqueous and thermal evolution of these primitive objects is important to understanding their role in planetary formation and the distribution and composition of volatile species and organic material in the solar system.

Aqueous alteration of early solar system materials modifies their mineralogy and petrology through hydration of anhydrous silicates forming phyllosilicates, alteration of Fe-Ni metal, and precipitation of carbonates and sulfates (McSween 1979; Tomeoka and Buseck 1985; Browning et al. 1996; Rubin et al. 2007). Additionally, aequosely altered carbonaceous chondrites can experience thermal metamorphism, acting to dehydrate, decompose, and reduce minerals and organic compounds (Gibson and Johnson 1972; Gibson 1974; Gibson et al. 1974; Tomeoka et al. 1989a; Nozaki et al. 2006; Court and Sephton 2014; Tonui et al. 2014; Pizzarello and Garvie 2014; Court and Tan 2016). The energy driving this metamorphism can be generated by a range of processes including decay of short-lived radioisotopes, transient impact-generated thermal pulses, or orbital conditions that draw the parent body close to the Sun.

Thermal metamorphism of the CM and CI carbonaceous chondrites leads to dehydration of phyllosilicates, pyrolysis of organic compounds, and decomposition of tochilinite, carbonates, and sulfates. This heating releases various gases, such as SO2, H2S, H2O, CO, COS, CS2, CO2, CH4, which can react with the residual phases (Gibson and Johnson 1972; Gibson 1974; Gibson et al. 1974; Burgess et al. 1991; Court and Sephton 2014; Court and Tan 2016). Knowledge of these decomposition products and