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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, CO_2, SO_2, H_2S, and H_2O. Here is described the mineralogical transformation of calcite ($CaCO_3$) 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, CO_2, SO_2, and H_2S 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