

Formation and transformation of clay minerals in Mars-analog rock varnish

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ABSTRACT

Rock varnish is widely distributed across Earth's various climatic zones, especially prevalent in arid environments similar to Mars. Its potential presence on Mars has made it a significant Mars analog for planetary research. The primary components of rock varnish are clay minerals and iron-manganese oxyhydroxides, with clay minerals possibly playing a crucial role in the enrichment of iron and manganese. However, there has been scarce in-depth and detailed research on these clay minerals within rock varnish. To better understand the formation and transformation mechanisms, as well as the influencing factors of clay minerals in rock varnish, we conducted X-ray diffraction (XRD) analyses on clay minerals isolated from rock varnish samples collected across different climatic regions in China. Additionally, in situ visible to near-infrared spectroscopy (Vis-NIR), scanning electron microscopy (SEM), and focused ion beam high-resolution transmission electron microscopy (FIB-HRTEM) were performed on the rock varnish samples. The results revealed the presence of illite in all rock varnish samples, while the selective occurrence of other clay minerals was closely correlated with climatic backgrounds. Furthermore, the crystallinity of illite was significantly influenced by climatic conditions. Illite found in rock varnish existed as both detrital and authigenic forms. Generally, the detrital illite in rock varnish was thicker than the nanometer-scale authigenic illite and exhibited distinct differences in chemical composition (e.g., Si/Al, K/Al ratios) and nanoscale morphology. In many cases, the possible transformation of illite to chlorite was observed, either internally within illite particles or through the formation of regular or irregular interstratified structures between illite and chlorite. Both interlayer brucitization and talc brucitization mechanisms may be involved in the chloritization (brucitization) of illite in rock varnish. Such transformations are generally uncommon in surface environments and are more frequently associated with low-grade metamorphism, suggesting that the environment at the illuminated rock surfaces, akin to metamorphic conditions, might provide the energy needed for these reactions. Considering the strong solar irradiance characteristic of Mars and its abundance of Mg- and Fe-rich rocks, it is plausible to expect the continued occurrence of chloritization on the martian surface and even within martian rock varnish. Our findings are significant for better understanding the formation and transformation of clay minerals on the martian surface and martian rock varnish, and climate-controlled water-rock interactions on Mars.

Keywords: Clay mineral, rock varnish, rock coating, Mars analog, illite