PRE- AND SYN-IMPACT FORMATION OF CLAY MINERALS AT THE RIES IMPACT STRUCTURE, GERMANY: IMPLICATIONS FOR CLAY MINERALS ON MARS

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Introduction: The extensive presence of clay minerals in the ancient Noachian terrain of Mars continues to be used to invoke past climates that were warmer and supported surface or near-surface stable liquid water [1]. These ancient terrains host the highest density of fluvially-carved geological features such as valley networks, and thus the formation conditions of clay minerals are commonly associated with surficial water activity. Notably, these regions are also heavily cratered with much of the ancient cratering record intact; the global spatial distribution of clay minerals is circumferential to some of the largest martian impact basins (e.g., Chryse, Hellas, and Isidis) [e.g., 2]. There is growing evidence from studies of terrestrial impact craters that impact events can also result in the generation of new secondary hydrated phases, including clay minerals [e.g., 3,4]. Given this possibility, how might the provenance of the Noachian clay minerals be determined? This is indeed a pressing question in light of climate modeling that indicates Mars did not host extended periods of favorable conditions for stable surficial water [5,6].

The aim of this study is to better understand the role of meteorite impacts in forming and exhuming clay minerals on Mars through a detailed field and laboratory investigation of the composition, texture, and setting of clay minerals at the Ries impact structure, Germany, which provides an excellent site to investigate pre- and syn-impact clay minerals. Indeed, it contains some of the best-preserved and well-studied impactite deposits on Earth [e.g., 3,7]. The syn-impact deposits—surficial impact melt-bearing breccias—have been shown to contain up to 70% clay minerals [3,4]. We compare clay minerals in these impact melt-bearing breccia deposits to clay minerals that comprise pre-impact sedimentary materials, preserved from the time of impact. The pre-impact deposits were excavated as part of the ballistic ejecta deposits, known as Bunte Breccia.

Laboratory Results: Our results provide the most robust determination of the clay mineralogy of syn-impact, impact melt-bearing breccias at Ries to date, chiefly through X-ray powder diffraction (XRD) analysis of successive cation and heating/dehydration treatments of the samples. The clay minerals in both sample types were identified as dominantly smectite in composition, with varying types and amounts of interstratification. The XRD patterns were modeled in Sybilla [8] to produce theoretical compositional percentages.

The mineralogy of the syn-impact deposits includes a predominance of pure smectite phases (75-100%) with mixed-layer I/S phases (<10%) and kaolinite (<20%). Additionally, we found that much of the melt-bearing breccia groundmass consists of very fine-grained (sub-µm) or nanocrystalline smectites, potentially related to the mixed-layer smectites. These clay minerals would have formed in thin (tens of m in depth) melt-bearing breccia ejecta deposits at the Ries, and thus cooled quickly. Alteration of the deposits and clay mineral formation is likely to have occurred without appreciable exogenous volatiles through a combination of autometamorphism, hydrothermal alteration, and devitrification. The structure and composition of syn-impact clay minerals are distinct from those in pre-impact samples. The pre-impact clay minerals were found to be highly compositionally variable with lower crystallinity, which is common for clay minerals of a detrital or weathering origin.

Implications for Mars: This study indicates that impact-related processes provide a potential mechanism for clay mineral formation on Mars under cold and very dry conditions. In the case of the Ries, the pre- and syn-impact clay minerals could be clearly distinguished, and the geological setting and provenance were known. On Mars, however, it may be very difficult (perhaps even impossible) to distinguish clay minerals generated by impact-related processes from those of other formation processes in the absence of a clear geologic context and the analytical techniques necessary to examine the interlayer properties of swelling clay minerals. NASA's Mars 2020 Perseverance rover mission may investigate impact-generated clay minerals in situ and could cache some of these samples for later return which could then be analyzed with the necessary techniques in Earth laboratories.

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