Goldschmidt 2024 Abstract
https://doi.org/10.46427/gold2024.23901

Identifying trace tetrataenite in moderately shocked ordinary chondrites using magnetometry and transmission electron microscopy

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Tetrataenite (γ̋ ordered face-centered cubic (fcc), equiatomic FeNi) forms in equilibrated (type 4-6) ordinary chondrites as a result of thermal processing on their parent asteroids to 700–950 °C and subsequent slow cooling [1]. Due to its remarkable magnetic hardness, the mineral is easily detectable using magnetic methods. However, while non-shocked or weakly-shocked (S1-S3) ordinary chondrites typically contain ubiquitous tetrataenite, conventional magnetometry approaches indicate that the mineral is not present in higher shock grade (S4- S6) meteorites (e.g., [2]). It is usually assumed that in strongly shocked meteorites, the impact-related surges in pressure and temperature result in the irreversible disordering of the mineral into magnetically soft taenite. However, a recent study [3] of the Daule chondrite (L5, S4, W0) suggested differential post-shock survival of tetrataenite at the millimeter scale indicating heterogeneity of the impact-related temperature and pressure fields within the meteorite. Furthermore, the authors suggested that methods based on remanent magnetization are more efficient for identifying minor amounts of tetrataenite than methods based on induced magnetization [3]. These observations are consistent with the hypothesis that during S4 stage metamorphism, some regions within the asteroid may not achieve conditions sufficient for the complete disordering of tetrataenite [4]. To further test this hypothesis, we investigated the magnetic properties of twelve chondrites (ranging from S3 to S6) using a comprehensive suite of magnetometry methods including thermomagnetic analyses at high and cryogenic temperatures, analyses of magnetic hysteresis, backfield demagnetization, first-order reversal curves, and thermal and alternating field demagnetization of natural remanence. Samples exhibiting high coercivity signals were further examined for tetrataenite presence using scanning transmission electron microscopy (STEM). For these analyses, the samples were crushed and magnetically separated from the matrix, then dispersed in fluid. Utilizing the high-angle annular dark-field signal, we indexed individual grains and imaged clusters of magnetic alloys with precision electron diffraction methods.

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