American Mineralogist, Volume 109, pages 1005–1023, 2024

Ilmenite phase transformations in suevite from the Ries impact structure (Germany) record evolution in pressure, temperature, and oxygen fugacity conditions

Fabian Dellefant[1,*], Claudia A. Trepmann[1], Wolfang W. Schmahl[1,2], Stuart A. Gilder[1], Iuliia V. Sleptsova[1], and Melanie Kaliwoda[1,2]

[1]Department of Earth and Environmental Sciences, Ludwig-Maximilians-University, Theresienstr. 41, 80333 Munich, Germany
[2]Mineralogical State Collection Munich (MSM), SNSB (Bavarian Natural History Collections), Theresienstr. 41, 80333 Munich, Germany

Abstract

Aggregates of ilmenite with varying amounts of rutile, ferropseudobrookite, and pseudorutile in suevites from the Ries impact structure have been analyzed by light microscopy, analytical scanning electron microscopy, electron microprobe analysis, and Raman spectroscopy to constrain their formation conditions. The tens to hundreds of micrometer aggregates comprise isometric ilmenite grains up to 15 μm in diameter that form a foam structure (i.e., smoothly curved grain boundaries and 120° angles at triple junctions). Grains with foam structure show no internal misorientations, indicating a post-impact formation. In contrast, ilmenite grains with internal misorientation occurring in the core of the aggregates are interpreted as shocked remnant ilmenite originating from the target gneisses. They can contain twin lamellae that share a common $\{11\bar{2}0\}$ plane with the host, and the *c*-axis is oriented at an angle of 109° to that of the host. Similarly, the new grains with foam structure display up to three orientation domains, sharing one common $\{11\bar{2}0\}$ plane for each pair of domains and *c*-axes at angles of 109° and 99°, respectively. This systematic orientation relationship likely reflects a cubic supersymmetry resulting from the transformation of the initial ilmenite upon shock (>16 GPa) to a transient perovskite-type high-pressure phase (liuite), subsequent retrograde transformation to the polymorph wangdaodeite, and then back-transformation to ilmenite. Whereas, the new grains with foam structure formed from complete transformation, the twin domains in the shocked ilmenite are interpreted to represent only partial transformation. Ferropseudobrookite occurs mostly near the rim of the aggregates. An intergrowth of ferropseudobrookite, ilmenite, and rutile, as well as magnetite or rarely armalcolite occurs at contact with the (devitrified) matrix. The presence of ferropseudobrookite indicates high temperature (>1140 °C) and reducing conditions. The surrounding matrix provided Mg^{2+} to form the ferropseudobrookite-armalcolite solid solution. Rutile can occur within the aggregates and/or along the ilmenite boundaries; it is interpreted to have formed together with iron during the decomposition of ilmenite at lower temperatures (850–1050 °C). We suggest magnetite in the rims formed by electrochemical gradients driven by the presence of a reducing agent, where Fe^{2+} within ilmenite diffused toward the rim. Subsequent cooling under oxidizing conditions led to the formation of magnetite from the iron-enriched rim as well as pseudorutile around ilmenite grains.

Our study demonstrates that the specific crystallographic relationships of ilmenite grains with foam structure indicate a back-transformation from high (shock) pressures >16 GPa; moreover, the presence of associated Fe-Ti-oxides helps indicate local temperature and oxygen fugacity conditions.

Keywords: Ilmenite shock effects, transformation twinning, liuite, wangdaoedeite, ferropseudobrookite, armalcolite